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The Development and Evaluation of a Sensor-Enabled Abdominal Palpation Simulator

by

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TABLE OF CONTENTS

Table of Contents ii

Table of Figures ix

Table of Tables xvi

Abbreviations xix

Thesis Abstract xxii

Declaration xxiii

Acknowledgement xxiv

CHAPTER 1. Introduction 1

1.1 Objectives of Research 1

1.2 Contribution to new knowledge 2

1.3 Thesis Outline 3

CHAPTER 2. Abdominal Palpation 5

2.1 Introduction 5

2.2 Why is Abdominal Palpation Important? 6

2.3 Abdominal palpation and techniques 8

2.3.1 The Abdominal Examination 8

2.3.2 Abdominal Palpation technique 9

2.4 Why is abdominal palpation difficult to teach and assess? 16

2.4.1 Abdominal Palpation in the Medical Curriculum 16

2.5 Summary 18

CHAPTER 3. Simulation Training in Medical Education 19

3.1 Introduction 19

3.2 Medical Simulation Training 20

3.2.1 Medical Simulation Training History 20

3.2.2 Types of Simulators 22
3.3 Benefits and Limitations of Clinical Simulators 23
3.3.1 Standardising medical curriculum 23
3.3.2 Evaluation and assessment of students 24
3.3.3 No risk to patients and a safe environment for student learning 25
3.3.4 Feedback, Reflection and Repetition 25
3.3.5 Enhanced learning and preparation for patients 26
3.4 Importance of Simulation Training in Healthcare 26
3.4.1 Learning by Doing and Skills Training versus Patient Safety 26
3.4.2 Meeting Demand for Skills Training 27
3.4.3 Skills Performance Improvements 28
3.5 Simulation models 29
3.5.1 Quantitative feedback palpation models 29
3.5.2 Quantifying Forces in Palpation 32
3.5.3 Abdominal Palpation simulators 36
3.6 Summary 39
CHAPTER 4. Research Problem Definition 40
4.1 The Problem 40
4.2 Project Scope 40
4.3 Proposed Solution 41
4.4 Design Requirements 41
4.4.1 Design Approach 42
4.5 Summary 42
CHAPTER 5. Preliminary investigation: How Hard Do Clinicians Press (HHDCP)? 43
5.1 Introduction 43
5.2 Methods 44

5.2.1 Location, Materials and Equipment Setup 44
5.2.2 Procedure of data collection 46
5.2.3 Data Analysis Methods 48
5.3 Results and Discussion 52
5.3.1 Data Sample 52
5.3.2 Part 1: Palpation examination as per clinician’s usual technique 53
5.3.3 Part 2: Palpation examination according to specified sequence 54
5.3.4 Part 3: Light and deep palpation repeats in specified region 59
5.3.5 Clinician Feedback 68
5.4 Conclusion 69
CHAPTER 6. Prototype Design and Development 70
6.1 Introduction 70
6.2 Prototype Construction 72
6.2.1 Torso Development 72
6.2.2 Force sensing platform 78
6.2.3 Definition of abdominal regions for model 82
6.2.4 Software and Interface 85
6.3 Summary 90
CHAPTER 7. Evaluation and Testing of the Abdominal Palpation Simulator: Methods 91
7.1 Introduction 91
7.1.1 Research Questions 91
7.2 Approvals – Human Ethics Committee and Flinders University School of Medicine 92
7.3 Methods – Simulator Testing 92
7.3.1 Location and Materials 92
7.3.2 Inclusion Criteria of Study Participants 93
7.3.3 Recruitment and Data Collection 94

7.3.4 Design Limitations 95

7.4 Data Analysis Methods 96

7.4.1 Data processing with MATLAB 96

7.4.2 Statistical Analyses 101

CHAPTER 8. Evaluation and Testing of the Abdominal Palpation Simulator: Results and Discussion 105

8.1 Introduction 105

8.2 Exclusions of Data 106

8.3 Data Sample – Participant Information 106

8.4 Results # 1: Questionnaire Results 109

8.4.1 Is the simulator sufficiently realistic? - Multiple Choice Question Response........... 109

8.4.2 Questionnaire Responses by Gender 111

8.4.3 Questionnaire Responses by Participant Type 112

8.4.4 Questionnaire Responses by Medical Graduate Years since Graduation................. 114

8.4.5 Questionnaire Responses by Student Year Level 116

8.4.6 Questionnaire Responses by Skill level 117

8.4.7 Results Section #1: Multiple Choice Question - Summary 118

8.5 Results # 2: Other Comments Feedback, and Observations.. 120

8.5.1 Participant Comments and Patient Observations 120

8.5.2 Results Section #2: Other Comments Feedback and Observations - Discussion...... 123

8.6 Results Section #3: Coverage of the Abdomen.. 125

8.6.1 Total Regions Palpated 125

8.6.2 Total Regions Palpated Overall.. 125

8.6.3 Total Regions Palpated – by Participant Type 126

8.6.4 Total Regions Palpated – By Gender 128

8.6.5 Total Regions Palpated by Participant Type Subcategory: Medical Graduate - Years Since Graduation 130

8.6.6 Total Regions Palpated by Participant Type sub category: Students - Year Level 132
8.6.7 Results Section #3: Coverage of the Abdomen - Summary 134
8.7 Results Section #4: Systematism 135
8.7.1 Systematism of Approach.. 135
8.7.2 Initial Sequence Order by Participant Type 136
8.7.3 Initial Sequence Order by Gender 138
8.7.4 Initial Sequence: Student Year Level (1-4) versus region number and order........... 140
8.7.5 Patterns in first three palpated regions 141
8.7.6 Region Numbers Palpated and Missed.. 144
8.7.7 Results Section #4: Systematism - Summary... 147
8.8 Results #5: Technique for diagnoses 149
8.8.1 Average Force of Peaks in Regions 150
8.8.2 Count of Peaks in Each Region 155
8.8.3 Time in Regions – GLMM model.. 159
8.8.4 Results Section #5: Technique - Summary 164
8.9 Results # 6: Peak Force and Force Bands.. 166
8.9.1 Overall palpation peak forces... 166
8.9.2 Palpation Force Bands - Individual Patterns... 167
8.9.3 Palpation Force Bands - by Participant Type 176
8.9.4 Results Section #6: Peak Force and Force Bands - Summary 180
8.10 Evaluation and Testing of the Abdominal Palpation Simulator - Summary 181
CHAPTER 9. Thesis Summary and Recommendations.. 182
9.1 Summary of Contributions.. 182
9.2 Recommendations for future development.. 188
9.3 Conclusion 192
CHAPTER 10. Appendices 193

Appendix A. Chapter 5 HHDCP Supplementary Information 193
10.1 Ethics Documents 193
10.2 Study Checklist 198
10.3 Analysis Methods 199
10.3.1 Maxima and minima 199
10.3.2 Duration of Palpation 201
10.4 Part 2 Data 202
10.5 Part 2 Graphs 204
10.6 Part 3: Graphs 214
10.7 Questions Feedback 224
Appendix B. Chapter 6 Prototype Design Supplementary Information 225
10.8 Moulding 225
10.8.1 Moulding Materials List 225
10.8.2 Moulding Instructions 225
10.9 Force sensing design Options 227
10.10 Custom force sensing platform 229
10.11 WBB Calibration 230
10.12 Labview code 234
Appendix C. Chapter 7 Discussion Supplementary Information 242
10.13 Trial Ethics Approval Documents 242
10.13.1 Application Form Text 242
10.13.2 Trial Promotional Flyer 246
10.13.3 Trial Letter of Introduction 247
10.13.4 Trial Participant Information Sheet 248
10.13.5 Trial Consent Form 250
10.13.6 Investigator Protocol 251

10.13.7 Participant Response Forms 253
Appendix D. Chapter 8 Results Supplementary Information 256
10.14 Results Appendices 256
10.14.1 Full Sequences of Patterns 256
10.14.2 Participant Comments 261
Appendix E. List of Publications and Presentations 274
References 275

TABLE OF FIGURES

Figure 1. Palpation of a male abdomen [6] 5

Figure 2. Abdominal quadrants 10

Figure 3. Nine regions of the abdomen 10

Figure 4. Liver examination 13

Figure 5. Abdominal organs 14

Figure 6. Topographic anatomy of the abdomen [30] 15

Figure 7. The anterior abdominal muscles include the medially located rectus abdominis, which is covered by a sheet of connective tissue called the rectus sheath. On the flanks of the body, medial to the rectus abdominis, the abdominal wall is composed of three layers. The external oblique muscles form the superficial layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the deepest layer. Muscles of the Abdomen © OpenStax / CC-BY-4.0 15

Figure 8. METI Pelvic ExamSIM [51] 29

Figure 9. A Haptic Cow training session using a PHANToM 1.5 haptic device [120] 30

Figure 10. Shafer Blood Pressure Cuff Method [125] 33

Figure 11. Patkin’s measurement of Tenderness with upside down scale “tenderness meter” 34

Figure 12. Pharmabotics Lumps and Bumps box [132] 36

Figure 13. Honglian KAF-980 Digital Abdomen Palpation Manikin [133] 36

Figure 14. Limbs and Things Abdominal Examination Trainer [134] 37

Figure 15. Abe the Tummy Dummy [136] 37

Figure 16. SmarTummy [138] 38

Figure 17. Simulator by ACDET [139] 38

Figure 18. Examination table legs positioned on floor force plates (grey). Reflective markers (yellow in image) on table in line with each table leg. 45

Figure 19. Marker placement on bony landmarks of subject's abdomen to identify lines for the nine abdominal regions. Markers on third and fifth fingers of clinician's hand and either side of wrist to define the plane of the hand. 45

Figure 20. The reflective markers were attached to the subject's abdomen with medical tape. 46

Figure 21. Still frame from video of clinician palpating subject's abdomen for Part 1 46

Figure 22. Nine regions identified by arbitrary numbers 1-9, Blue arrows indicate the direction of the specified palpation sequence as indicated in the textbox "Set Order", Yellow circles indicate location of reflective markers. 47

Figure 23. Total Force (N), Clin1-Part2 Light Palpation Sequence repeated 3 times, W = window, UT = upper threshold, LT = lower threshold 50

Figure 24. Total Force Clin1-Part3, Top: Light and Deep Palpation Repeats, Middle: Light Palpation Section of examination Bottom: Deep Palpation section of examination 51

Figure 25. Specified sequence of palpation, set order = 7-6-5-4-3-2-1-8-9 54

Figure 26. Mean Light and Deep Forces during specified sequence 55

Figure 27. Intra-examiner and inter-examiner forces for specified sequence of forces 56

Figure 28. Total duration of Light and Deep Sequences 57

Figure 29. Durations of Individual palpation presses within the specified sequence 58

Figure 30. Clin2 Light and Deep Palpation repeats 59

Figure 31. Clin1, Clin2, Clin3, Clin4 Light Palpation Repeats 60

Figure 32. Clin1, Clin2, Clin3, Clin4 Light Palpations with the same timebase highlights the different patterns/techniques... 61

Figure 33. Clin1, Clin2, Clin3, Clin4 Deep Palpation Repeats.. 63

Figure 34. Mean Palpation forces for repeated palpation in a single region 65

Figure 35. Comparison of Light and Deep Forces both in sequence and repeated in one region ... 66

Figure 36. Mean duration of Light and Deep Palpation repeats 67

Figure 37. AbSIM system including physical abdomen model and custom software 70

Figure 38. AbSIM Prototype and LabVIEW GUI 71

Figure 39. The moulding process: A) Applying the Body Double to the volunteer. B) Removing the supporting shell. C) Demoulding. D) The finished Body Double mould inside the support shell..... 73

Figure 40. Dragon Skin layer produced from the Body Double mould.. 75

Figure 41. AbSIM layers of skin and foam to produce a realistic feel during palpation 76

Figure 42. Flex-iT! X Foam, Soama Foama, Ribs & Pelvis bony landmarks, Thin Foam layers.......... 77

Figure 43. Exploded view of the various moulded layers in AbSIM 78

Figure 44. Force platform sensors and coordinates 79

Figure 45. Nintendo Wii Balance Board, left: top view, right: bottom view 81

Figure 46. Abdominal regions x-plane coordinates.. 83

Figure 47. WBB sensor coordinates (top view) 84

Figure 48. WBB, 9-regions coordinates reference 84

Figure 49. AbSIM Graphical User Interface developed in LabVIEW 87

Figure 50. AbSIM Labview Software Program Loops.. 88

Figure 51. MG1-T5-fig1.png "Plot 1" 98

Figure 52. MG1-T5-fig2.png "Plot 2" 99

Figure 53. MG1-T5-fig3.png "Plot 3" 101

Figure 54. Example distributions of data a) Average force of peaks in region 5. b) Average force of peaks in region 9. 103

Figure 55. Overall Participant responses to MCQ 110

Figure 56. MCQ Responses by Gender 112

Figure 57. Participant Type MCQ Responses........ 113

Figure 58. MCQ responses from Medical Graduates by years of experience 115

Figure 59. MCQ Responses from Students by Year Level........ 116

Figure 60. MCQ Responses by skill level 117

Figure 61. Total Number of Regions Palpated by Participant Type........ 127

Figure 62. Total number of Regions Palpated by Male and Female Participants........ 129

Figure 63. Total Number of Regions Palpated by Medical Graduate Years of Experience........ 131

Figure 64. Total number of Regions Palpated by Student Year Level 133

Figure 65. First and Second Region Palpated by Participant Type 137

Figure 66. First and Second Regions Palpated by Gender........ 139

Figure 67. Regions more likely palpated second by males (blue), females (pink)........ 139

Figure 68. First and Second Region Palpated versus Year Level........ 141

Figure 69. Regions palpated in first 4 moves of sequence 144

Figure 70. Regions commonly missed by participants 145

Figure 71. Specific Regions Palpated by Participant Type 145

Figure 72. Shaded regions palpated at least 94% of the time by a) Medical Graduates, b) Medical Students. Darker shaded regions indicate regions palpated 99% or more of the time. 146

Figure 74. Histograms of F_{av_peaks} in Regions 1-9 as per 1-9 labelling of Regions in abdominal palpation simulator model 150

Figure 75. a) Effects of Participant Type on GLMM b) Effects of Gender on GLMM 151

Figure 76. Effects of Lesion Location on GLMM 152

Figure 77. Estimates of Average force of peaks in Region with GLMM, full dataset........ 153

Figure 78. Pearson Residual for Average Force of Peaks per Region GLMM model 154

Figure 79. Frequency histograms for Count of Peaks in Regions 155

Figure 80. GLMM within factor, Count of peaks in regions, Lesion Region Location 156

Figure 81. Pearson Residual of GLMM Count of peaks in regions........ 157

Figure 82. Frequency histograms for time spent in regions........ 159

Figure 83. GLMM Estimates within factor, Time in Regions, Gender........ 160

Figure 84. GLMM Estimates within factor, Time in Regions, Lesion Region Location........ 161

Figure 85. GLMM Estimates Time in Regions 162

Figure 86. Time in Regions GLMM Pearson Residual Histogram........ 163

Figure 87. St29 Palpation Peak Forces, and peaks per force band........ 167

Figure 88. St54 force of palpation peaks and count of peaks in bands........ 168

Figure 89. St12 Force at palpation peaks and force band data 168

Figure 90. St43 Force at palpation peaks and force band data 169

Figure 91. Medical Graduate 22, Palpation Peak forces, peaks per force band........ 169

Figure 92. Student 12 Force at palpation peaks and force band data 171

Figure 93. Medical Graduate 17 Force and palpation peaks and force band data 171

Figure 94. Student 43 Force at palpation peaks and force band data 172

Figure 95. Medical Graduate 1, Force at palpation peaks and force bands................................. 173

Figure 96. Student 5 force of palpation peaks and count of peaks in bands 174

Figure 97. Medical Graduate 19. Force of palpation peaks and count of peaks in force bands. ... 175

Figure 98 Mean count of palpation peaks within force bands... 177

Figure 99. Average time spent in each force band... 178

Figure 100. Ratio of Duration within force band to Count of Peaks within force band 179

Figure 101. AbSIM Abdominal Palpation Simulator 192

Figure 102. Specified sequence of palpation, set order = 7-6-5-4-3-2-1-8-9 202

Figure 103. Clin1 Light Palpation Sequences.. 204

Figure 104. Clin1 Deep Palpation Sequences 205

Figure 105. Clin2 Light Palpation Sequences.. 206

Figure 106. Clin2 Deep Palpation Sequences 207

Figure 107. Clin3 Light Palpation Sequences.. 208

Figure 108. Clin3 Deep Palpation Sequences 209

Figure 109. Clin4 Light Palpation Sequences.. 210

Figure 110. Clin4 Deep Palpation Sequences 211

Figure 111. Clin5 Light Palpation Sequences.. 212

Figure 112. Clin5 Deep Palpation Sequences 213

Figure 113. Clin1, Top: Light and Deep Palpation Repeats, Middle: Light Palpation Section of examination Bottom: Deep Palpation section of examination 214

Figure 114. Clin1 Light Palpation Repeats 215

Figure 115. Clin1 Deep Palpation Repeats 216

Figure 116. Clin2, Light Deep Summaries 217

Figure 117. Clin2, Deep Palpation Repeats 217

Figure 118. Clin2 Light Palpation Repeats 218

Figure 119. Clin2 Deep Palpation Repeats 219

Figure 120. Clin3, Light Palpation Repeats 220

Figure 121. Clin3, Deep Palpation Repeats 220

Figure 122. Clin3 Light Palpation Repeats 221

Figure 123. Clin3 Deep Palpation Repeats 221

Figure 124. Clin4, Light Palpation Repeats 222

Figure 125. Clin4, Deep Palpation Repeats 222

Figure 126. Clin4 Light Palpation Repeats 223

Figure 127. Clin4 Deep Palpation Repeats 223

Figure 128. AbSIM layers within torso 226

Figure 129. Custom Aluminium Force Platform 229

Figure 130. Force Platform and Foam interfaced with Labview, with masses for testing 229

Figure 131. Left Top (LT) sensor calibration graph 230

Figure 132. Left Bottom (LB) sensor calibration graph 231

Figure 133. Right Bottom (RB) sensor calibration graph 232

Figure 134. Right Top (RT) sensor calibration graph 233

TABLE OF TABLES

Table 1. Abdominal palpation clinical skills inclusions in FUSOM GEMP curriculum 18

Table 2. HHDCP preliminary investigation Clinician participant demographics 52

Table 3. Part 1 observations of Clinicians natural sequence on video recording 53

Table 4. Comparison of light and deep forces in specified sequence 54

Table 5. Comparison of durations for light and deep full sequences 56

Table 6. Comparison of Individual Palpation durations in Light and Deep Sequence 57

Table 7. Mean Palpation Force for repeated palpation in a single region 64

Table 8. Mean duration of light and deep palpation repeats 66

Table 9. Problems encountered in casting the body double mould 74

Table 10. Wii Balance Board Specifications [153] 82

Table 11. Region lookup table, coordinate definitions 85

Table 12. AbSIM flowchart stages explained 89

Table 13. Frequencies of Clinical Study Participant Sample: Participant Types and Gender (n=144) 106

Table 14. Medical Graduates years since Graduation frequencies 107

Table 15. Medical Graduate Disciplines 107

Table 16. Medical Student Year Level Frequencies 108

Table 17. Number of abdomens palpated versus year level. Fisher's Exact Test Value is 70.069 with an exact significance of 0.000 which means p<0.05 and the null hypothesis of independence can be rejected, therefore year level does influence the number of human abdomens palpated as would be expected. 108

Table 18. Responses to MCQ by Participant Type 109

Table 19. MCQ Responses by Gender 111

Table 20. MCQ Responses by Participant Type 112

Table 21. MCQ responses of Medical Graduates by Years since Graduation 114

Table 22. MCQ Responses by Student Year Level 116

Table 23. MCQ Response by Skill Level 117

Table 24. Is the abdominal simulator sufficiently realistic? Medical Student and Graduates combined responses 119

Table 25. Count of comment themes from participant responses 122

Table 26. Total number of Regions Palpated, N=143 125

Table 27. Total Regions Palpated by Participant Type 126

Table 28. Total number of Regions Palpated by Gender 128

Table 29. Total Number of Regions Palpated by Medical Graduates Years Since Graduation 130

Table 30. Total number of Regions Palpated by Student Year Level 132

Table 31. Summary of Total Regions Palpated significance and effect values for categorical variables 134

Table 32. First and Second Region Palpated by Participant Type 136

Table 33. First and Second Region palpated by Gender 138

Table 34. First and Second Region Palpated by Student Year Level 140

Table 35. Prevalence of Patterns in first three palpated regions 142

Table 36. Regions Palpated in first three of sequence 143

Table 37. Regions Palpated in first 4 moves of sequence 143

Table 38. Specific Regions Palpated by Participant Type 144

Table 39. GLMM Average force peaks per region: Fixed Effects.. 151

Table 40. Estimates of Average Force (N) of Peaks in Regions, full dataset................................. 153

Table 41. GLMM Count of peaks per region: Fixed Effects 156

Table 42. GLMM Count of peaks in regions, Estimates... 157

Table 43. GLMM Time in Regions: Fixed Effects 160

Table 44. GLMM Estimates Time in Regions 162

Table 45. Summary of GLMM means per region for force, count of peaks, time......................... 164

Table 46. Summary of Force data for all Participants 166

Table 47. Average number of palpation peaks in each force band, and t-test comparison of Student and MG mean values.. 176

Table 48. Time (in seconds) spent in each force band 178

Table 49. Part 2 - Light Palpation Specified Sequence Participant Summary Data 202

Table 50. Deep Palpation Specified Sequence Participant Summary Data 203

Table 51. HHDCP Clinician Feedback to Questions 224

Table 52. Commercially available force sensing options in a tactile setting in 2007 227

ABBREVIATIONS

3DMA	three-dimensional motion analysis
AbSIM	abdominal palpation simulator (developed by Lynne Langman)
ACLS	Advanced Cardiovascular Life Support
ALS	Advanced Life Support (generally associated with training)
AR	Augmented Reality
AW	abdominal wall
BLS	Basic Life Support (generally associated with training)
BMI	Body Mass Index
CBE	clinical breast examination
CPR	cardiopulmonary resuscitation
CSLU	Clinical Skills Learning Unit
CSSU	Clinical Skills Simulation Unit
CSU	Clinical Skills Unit
ED	Emergency Department (Australian term)
EEO	examining each other
ER	Emergency Room (American term)
FCREC	Flinders Clinical Research Ethics Committee
FMC	Flinders Medical Centre (hospital where main research conducted)
FUSOM	Flinders University School of Medicine
GEMP	Graduate Entry Medical Program (Medical school program at Flinders University)

GIT	gastrointestinal system
GUI	graphical user interface
HHDCP	How Hard Do Clinicians Press? (Pilot Study conducted in 2008)
HHDSP	How Hard Do Surgeons Press? (Preliminary study, attempted in 2007)
HIRO	Haptic Interface Robot
HPS	Human Patient Simulator (or high fidelity simulator)
IAP	intra-abdominal pressure
ICU	Intensive Care Unit
ICT	Information Communications Technology
IT	Information Technology
LLQ	left lower quadrant
LUQ	left upper quadrant
MCQ	multiple choice question
NaN	not a number (value is used to represent missing data)
OR	Operating Room (American term)
OT	Operating Theatre (Australian term)
PACU	Post Anaesthetic Care Unit
RCT	Randomised Controlled Trial
RGH	Repatriation General Hospital (Hospital where HHDCP conducted)
RLQ	right lower quadrant
RUQ	right upper quadrant

SAMAC	South Australian Movement Analysis Centre
SBREC	Flinders University Social and Behavioural Research Ethics Committee
Sims	simulators
SOM	School of Medicine
SPs	Standardised Patients or Simulated Patients
US	United States (of America)
USMLE	United States Medical Licensing Examination
VR	Virtual Reality
WBB	Wii Balance Board

THESIS ABSTRACT

Abdominal palpation is a routine but critical diagnostic procedure performed in different clinical settings. It provides an initial diagnosis of a patient's condition and determines the relative urgency and next steps for treatment. A clinician systematically palpates the regions of the abdomen to feel for tenderness, guarding, and underlying abnormalities such as masses or enlargement of organs. This involves both observing the patient's response and feeling the response of their abdomen to different levels of applied forces in the different regions. Typically, an examiner performs a survey of the area with a "light palpation", then followed up by pressing more firmly with an action called "deep palpation" to help find deeper masses and feel for some abdominal structures. This procedure requires a tactile sensitivity to gather information by applying pressure to the abdomen. It is a difficult technique to teach and assess and there can be significant variation between examiners. Simulation provides opportunities to overcome many of the limitations of previous training methods, to give students the ability to practice and develop adequate clinical skills to succeed.

The aim of this research was to develop an abdominal palpation simulator and test it across a range of participants to determine if it was sufficiently realistic for use as a training tool.

A simulator was developed using baseline abdominal palpation force data from a preliminary investigation. The abdominal palpation training simulator (AbSIM) consists of: a force platform able to measure the magnitude and location of applied force, a physical mould of a male torso comprising silicone rubber skin and foam layers, and an interface to a computer with custom software which records and displays the applied forces of the simulation session on a screen. AbSIM provides a physical abdominal manikin for students to palpate and provides feedback of the forces applied.

The proposed AbSIM was evaluated by conducting a trial with 144 participants with varying levels of experience (both medical graduates and medical students). Participants palpated the abdomen according to the clinical scenario while the system recorded the simulation data, then participants gave feedback on the simulator. 62.5% (CI: 54.4-70.0) of participants said that the simulator was sufficiently realistic to learn the technique. Data recorded showed variation in technique of participants in coverage, sequence, technique, and forces applied. This bespoke simulator provides a potential way to teach the sense of touch for abdominal palpation in medical students and graduates.

AbSIM, the abdominal palpation simulator, was constructed and developed as part of Lynne Langman's (nee Burrow) Research Higher Degree PhD studies at Flinders University.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed____________________________________ Date_________________

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CHAPTER 1. Introduction

Abdominal palpation is a routine but critical diagnostic technique performed in many clinical situations. It provides an initial diagnosis of a patient's abdominal condition and determines the relative urgency and next steps for treatment. The technique requires a tactile sensitivity to gather information by applying pressure to the abdomen. It is a difficult skill to teach and assess and there can be great variation between practitioners palpation skills.

The aim of this research was to develop a proof-of-concept abdominal simulator for standardising training and assessment of medical students' abdominal palpation examination skills. The proposed concept was for the simulator functionality to display the location and magnitude of the force applied by an examiner's hand on the simulated patient's abdomen, and provide feedback regarding the palpation forces applied to assist students to learn palpation sensitivity.

This chapter presents the objectives of the research and contribution to improving training and testing of abdominal palpation skills in medical education and training. This is followed by an overview of the thesis and an outline of the main sections that include: background and review of the literature, a preliminary study to determine how hard clinicians press, development of the prototype abdominal palpation simulator, the report of the trial of the prototype simulator with medical students and graduates, discussion of the results and a summary of contributions to research.

1.1 Objectives of Research

The objectives of the research were to:

- develop a prototype abdominal palpation simulator,
- test the custom-made abdominal palpation simulator on medical students and medical graduates to determine if it was sufficiently realistic for use as a training tool,
- better understand the techniques of examiners and the forces applied for light and deep palpation and if there are discernible differences due to gender or experience.

1.2 Contribution to new knowledge

This research contributes to the knowledge of clinical skills training, education of abdominal palpation, and understanding of the applied forces during abdominal palpation by recording data from medical graduates and students. It demonstrates the use of a prototype abdominal palpation simulator and highlights the inconsistency of abdominal palpation skills within a trial group and the need for better education and training in this space.

The research also contributes to the knowledge of training and assessment of clinical skills for abdominal palpation by the development of a custom designed low-cost abdominal palpation simulator.

Acknowledgement and awareness of the forces and technique required to palpate the abdomen was lacking in the published literature and in clinical practice. Since palpation is such a subjective technique it is hard to quantify. This thesis provides some quantification of these forces through both a preliminary study of clinicians, and a trial of the prototype abdominal palpation simulator where the forces applied were recorded. This simulator also provides a method for investigation of technique in the future and the ability to teach quantitatively with opportunity for students to practise and receive feedback.

The use of a custom made abdominal palpation simulation prototype has provided a cost effective method to both qualitatively and quantitatively review the skills of medical students and medical graduates in the technique of abdominal palpation without causing patient discomfort. Analysis of data recorded from a trial of the prototype showed that further education is required for abdominal palpation consistency in practitioners.

1.3 Thesis Outline

The thesis consists of four parts: 1) a background on abdominal palpation and current methods for teaching the technique, a review of the literature to look at simulation training in medical education, identifying the gap in the literature regarding quantifying abdominal palpation; 2) the initial assessments of a small dataset of experienced clinicians to obtain baseline data for the development of a prototype; 3) the development of a custom made abdominal palpation simulator prototype; and 4) a trial to test the validity of the prototype and provide proof of concept for such a simulator.

Chapter two explores abdominal palpation and techniques, reasons for the practice, the variability and reliability of palpation as a diagnostic procedure, and why it is such a difficult skill to teach and assess. This chapter helps to identify the importance of abdominal palpation as a skill, deficiencies in current teaching practices and methods of skill uptake, the importance of particular aspects of the technique, and why it is a problem that needs to be addressed.

Chapter three provides a brief history of simulation in medical training and looks at the benefits and limitations of simulators for hands on practise and clinical skills development. The value of manikin clinical simulators as a learning tool are then considered, with an overview of the types of simulators available commercially, a review of quantitative palpation models, and an analysis of current uses of simulation and force detection.

Chapter four defines the research problem, and outlines the scope and methodology used to approach the problem.

Chapter five details the preliminary study that investigated “How Hard Do Clinicians Press”, to determine the typical range of forces that “expert” clinicians use when palpating the abdomen. The results of this investigation helped establish an estimated range of forces that the prototype simulator would need to measure and display.

Chapter six covers the development of the AbSIM prototype, giving an in-depth description of each of the components and elements of the design.

Chapters seven and eight detail the evaluation and testing of the abdominal palpation simulator undertaken at Flinders University and Flinders Medical Centre, where both medical students and medical graduates participated in trialling the AbSIM abdominal palpation prototype by using the simulator and giving user feedback. This provided user performance data which was then analysed. Chapter seven describes the methods of the study, covering the ethics and approval requirements, study procedural methods, data analysis techniques used, and statistical methods used to analyse the data.

Chapter eight presents the results and discussion in six sections: multiple choice question feedback, comments and feedback from the participants, coverage of the abdomen, systematism of palpation, and aspects of technique and force data.

Chapter nine concludes the thesis, providing a summary of the research, contributions to new knowledge, and outlining recommendations for future developments.

This research was conducted part-time over a twelve-year period. Because of this, there were changes in both information communication technology and simulation technology over this period that impact the methodology of approach, the technology used and available at stages during the research, and the path taken at various points in the research study that makes up this thesis.

CHAPTER 2. Abdominal Palpation

2.1 Introduction

Abdominal pain is the most commonly presenting complaint in emergency departments [1, 2]. Conditions classified as urgent require treatments within 24 hours [3]. Clinical evaluation is the first step in the diagnostic pathway, using medical history and a physical abdominal examination to determine if further investigations are required [3, 4].

"Both a science and an art, this examination (abdominal palpation) requires technical skill, anatomic and pathophysiologic knowledge, and sensitivity to the whole patient." [5]

Figure 1. Palpation of a male abdomen [6]

The abdominal examination is a routine, but critical, diagnostic examination. It may be performed in many clinical situations, such as: part of a full physical examination; in emergency, surgical and trauma patients; when a patient presents with abdominal pain; or when there is suspected internal injury [7]. It is the first clinical step to determine if further examinations are required and diagnosis must be sufficiently accurate to justify laboratory tests or imaging [3]. A wide range of pathologies can cause abdominal pain, ranging from benign to life-threatening [3, 7-11]. In particular, the identification of clinical signs that indicate the classification of urgency and need for emergency surgery (i.e. ruptured appendix, perforated peptic ulcer) are more timely using this diagnostic method than other methods (i.e. imaging) [3, 5].

This chapter looks at the importance and reliability of palpation as a diagnostic procedure, the technique of abdominal palpation, why it is practised, and the reasons it is a difficult skill to teach and assess. It considers the deficiencies in current training and why these need to be addressed.

2.2 Why is Abdominal Palpation Important?

Data reported from a 2005 survey on visits to hospital emergency departments (EDs) in the United States (US) [12] showed that the most frequent reason for visiting the ED was for stomach and abdominal pain (6.8%). The survey also listed abdominal pain as the leading ED diagnosis category (by age group) for adults 22-49 years of age, the second leading diagnosis for adults 50-64 years (second only to chest pain), and the second most frequent primary diagnosis category (4.0%) overall [12].

Data from the same US National Survey repeated in 2013 [1] showed that the most common reason for a visit to the ED was again for “stomach and abdominal pain, cramps and spasms” (7.7%) with 10 million visits in 2013, and abdominal pain the leading primary “diagnosis group” at 4.1% overall, equal to 6.7 million people.

The most common diagnosis group in the Australian Institute of Health and Welfare “Emergency Department Care 2015-16: Australian Hospital Statistics” report was “Abdominal and pelvic pain” (4.2%) (ranked higher than “Pain in the throat and chest” (3.4%)), with 312,374 people presenting with abdominal and pelvic pain and 118,182 reported with it as their principal diagnosis in the year [2].

The physical examination of the abdominal examination is integral in determining the diagnosis, management and treatment of patients [4]. As the first line diagnostic procedure, it is essential that there is confidence in the accuracy of the physician’s assessment and recommendations for treatment.

Some studies have indicated that the physical examination for patients with abdominal pain is highly variable depending on the physician [4, 10, 13]. A study by Pines and colleagues [10] found that in a real-time ED setting, the abdominal examination can be a highly subjective diagnostic experience depending on the examiner. They raised concern about the variability of diagnosis for different examiners, since the interpretation of a physical exam determines the clinical decisions made about diagnosis, treatment and disposition of ED patients with acute abdominal pain.

Diagnostic tests (including the physical examination) need to be reliable and reproducible when repeated by the same or different examiners, as they determine patient treatment [14]. Yen and colleagues [14] studied the inter-examiner reliability in physical examination of paediatric patients with abdominal pain. Overall agreement between the physician groups ranged from 65.2% for abdominal tenderness with palpation, to 95.5% for clinical diagnosis of peritonitis. They found poor inter-examiner reliability in the components of the clinical examination of abdominal pain, and attributed the disparities to a combination of differences in training, levels of experience and the different meanings of positive clinical findings[1] to different physician types.

A "Guideline for the Diagnostic Pathway in Patients with Acute Abdominal Pain" [3] released in 2014, initiated by the Association of Surgeons of the Netherlands[2], reviewed international literature on abdominal pain. The authors reported that diagnosis based on medical history and physical examination is correct 43-59% of the time and that the accuracy is greater when the determination is between urgent and non-urgent conditions.

[1] "Positive" classifications due to the different focus of examiners was dependent on participant speciality – i.e. less experienced participants more likely to give a "positive" to send to a referral.

[2] In Collaboration with: Netherlands Association of Internal Medicine, Dutch Society of Obstetrics and Gynaecology, Radiological Society of the Netherlands, Netherlands Society of Emergency Physicians, Dutch College of General Practitioners.

2.3 Abdominal palpation and techniques

2.3.1 The Abdominal Examination

Clinician and patient positioning

To prepare the patient and ensure the patient's abdominal musculature is relaxed, the clinician will get the patient to ensure their bladder is empty, lie flat with their hips and knees slightly flexed, elevate the head slightly (with a small pillow), and expose the abdomen from the xiphoid process to the symphysis pubis [5, 15-17]. Generally, the clinician stands on the supine patient's right side so they can observe and monitor the patient's facial expressions during the examination while they palpate with their right-hand [5, 15, 17, 18].

Inspection, Observation, Auscultation and Percussion

It is generally accepted that there are four components to an abdominal examination; inspection and observation, auscultation, percussion, and palpation [4, 5, 7, 15-20]. Information is first obtained by inspecting the abdomen and observing skin characteristics and elements which help to reveal patient history and provide a basis for further investigation. The examiner inspects for signs of unusual colouring, scars, stomas or fistulae, distension, prominent veins, pulsations, visible peristalsis, skin lesions, dermatitis, petechiae, bruising, spider angiomas, suspicious moles, stretch marks and hernias [4, 5, 15-17, 19].

Observation of the shape and symmetry of the contour of the abdomen can reveal clinical information for diagnosis: the "normal" abdomen is usually symmetric from ribcage to pubis (xiphoid process to pubic symphysis) along the midline, either flat, scaphoid or symmetrically protuberant, depending on the size of the patient [5, 15, 17]; asymmetry can indicate the presence of a mass or hernia, which can be confirmed by palpation later on [5].

Auscultation involves the use of a stethoscope to listen for bowel sounds, bruits (abdominal or renal) and rubs which may indicate different functions, obstructions, or other abnormalities in the abdomen [20]. It is usually performed before percussion and palpation as they may affect the sounds [5, 21].

Percussion is a tapping technique used to determine the size and characteristics of organs or masses, discover the presence of fluid, and identify tenderness [4, 17, 19].

While these are all important aspects of the abdominal examination, the focus of this research is on the palpation component of an abdominal examination.

2.3.2 Abdominal Palpation technique

Abdominal palpation is a practised tactile examination skill, which involves developing a sensitivity of “touch” and “feel”. A clinician palpates with their hands and fingers, utilising the sense of touch to gather information, applying pressure to survey areas and detect any abnormalities. The pads or flats (as opposed to the fingertips) of the fingers are the most sensitive part of the fingers and so are used when palpating [17-19].

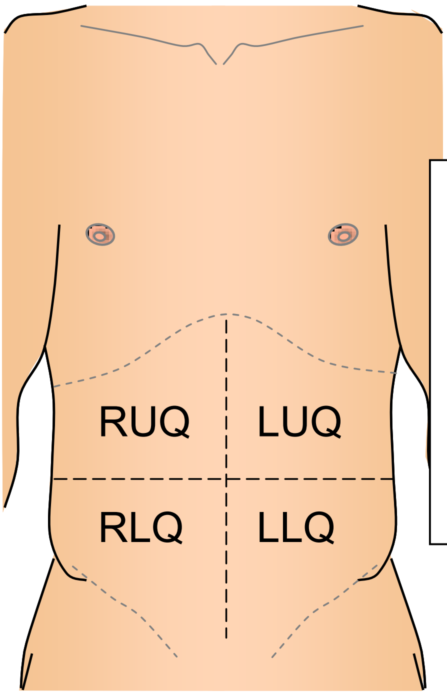
For general abdominal palpation, the palmar surface of the right hand is used (see Figure 1), flat and with the fingers acting together (movements of the hand only occur at the metacarpophalangeal joints). The hand moulds to the shape of the abdominal wall [15, 16, 18, 22] and the movement comes from the wrist, so that the fingertips do not “poke the patient” and cause the patient’s abdominal muscles to tense [17, 18].

The purpose of palpation is to assess the tissue and organs of the abdominal cavity, detect and determine the size and presence of any masses, fluid and areas of tenderness, locate any hidden structures, organ abnormalities or lumps in soft tissue, and note muscular tone, organomegaly, presence of hernias and any warmth and pulsations [23].

Abdominal Quadrants and Regions

To assist in describing the areas of the abdomen, the abdomen is generally divided with imaginary lines into grids of either four quadrants (see Figure 2) or nine regions (see Figure 3) [17, 19, 20] to help identify the location of any abnormalities. The four-quadrant approach (see Figure 2) uses imaginary lines from the sternum to symphysis pubis, and across the umbilicus [5, 15, 17, 19].

The nine regions approach divides the abdomen into regions using the mid clavicular lines on the left and right (see Figure 3) and along planes from the right to left hypochondrals and right to left iliac fossas [20].



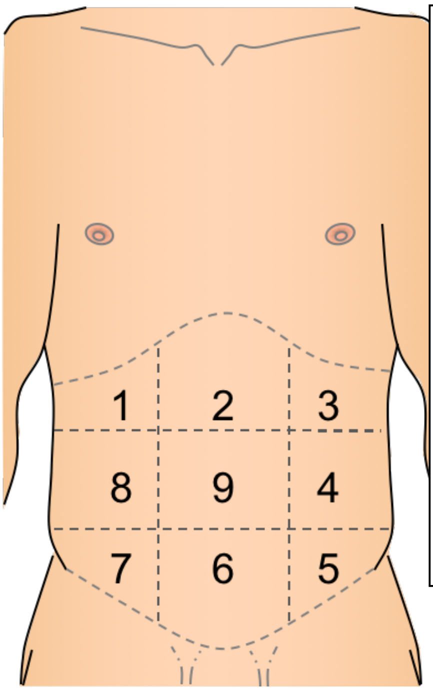
Right Upper Quadrant (RUQ)

Left Upper Quadrant (LUQ)

Right Lower Quadrant (RLQ)

Left Lower Quadrant (LLQ)

Figure 2. Abdominal quadrants



1. Right hypochondrium
2. Epigastrium
3. Left Hypochondrium
4. Left flank/loin/lumbar region
5. Left iliac fossa
6. Suprapubic/Hypogastrium/Pelvic Region
7. Right iliac fossa
8. Right flank/loin/lumbar region
9. Central/Umbilical region

Figure 3. Nine regions of the abdomen

Light Palpation

Clinicians begin palpating with “light pressure” [17] or “light palpation” in each region. Palpation starts in areas that are expected to be “normal” and progresses to areas of suspected tenderness, noting abnormalities such as muscle guarding, rigidity, and superficial masses. Both an anticlockwise [24] and a clockwise palpation sequence [15] are taught. The common premise is on using a logical sequence [25] with use of a light, gentle dipping motion [15] pressing no deeper than 1cm [25, 26] to apply soft pressure in each region [5, 16]. The hand is kept in contact with the abdominal wall as it is moved from one region to the next, to avoid causing the patient to contract their abdominal muscles [18, 25].

Light palpation facilitates the detection of abnormalities, areas of increased resistance and muscle guarding, tenderness, or superficial masses in each region [5, 15, 16]. These are then explored in more detail at the end of the examination [5, 17].

Deep palpation

Deep palpation is performed after light palpation with a greater pressure, avoiding any areas where tenderness was found until the end of the examination [17, 25]. Deep palpation helps to refine observations noted during light palpation, to define discovered masses and detect deeper masses, to outline abdominal organs and estimate their size and consistency, and to carefully characterise and describe each of these [5, 16-18, 26].

Deep palpation involves pressing down to a depth of about 4cm [18] to feel the underlying structures. The pads of the fingers move smoothly back and forth over and around deep structures [5] and detect the borders of the rectus abdominis muscles, the aorta, parts of the colon (especially the sigmoid colon) [18, 23, 26], and the main organs of the liver and spleen [5]. Generally a single-handed method is used (see Figure 1) but with a greater pressure applied (than light palpation), however some clinicians prefer a two-handed handed method for deep palpation on obese patients [25]. Mehta [15] describes the two-handed approach where the non-dominant hand is placed over the dominant hand to assist in performing deeper palpation (3.8-5cm). The non-dominant hand produces the pressure while the dominant hand senses tactile input [5].

There are various types of pain and muscle tensing to consider in an abdominal examination. Most people complain of some level of tenderness with deep palpation [5]. Tenderness on direct touch however, indicates an inflammation of either the abdominal wall limited to a small area (especially the parietal peritoneum) or an internal organ (viscus), or distension of an organ capsule [5]. There are three specific responses to tenderness:

- Guarding is the term used to describe the spasm of a muscle when it is palpated. This results in increased tone and resistance to palpation due to the contraction of the abdominal muscles, preventing the examiner from feeling the underlying abdominal structures [5, 7, 16, 18]. Guarding can result from tenderness or anxiety and can be voluntary or involuntary [5, 7, 16, 18].
- Rigidity is the constant involuntary reflex or contraction of the abdominal muscles [7, 16, 18]. It is associated with tenderness and indicates peritoneal irritation [16, 19] and/or inflammation [5, 7, 16, 18, 19, 27, 28].
- Rebound tenderness is the sudden sharp pain a patient experiences elicited after a rapid release of pressure due to the removal of the examiner’s hand after pressure has been applied to an area [5, 7, 16, 19].

Light and deep palpation are followed by palpation of the liver, spleen, gallbladder and kidneys. The lateral surface of the forefinger is the most sensitive part of the hand, so is used to palpate edges of these organs (see Figure 4) and any identified masses [17].

Figure 4. Liver examination

To palpate the liver (see Figure 4), an examiner aligns their hand parallel to the right costal margin [5, 15, 16, 23], and begins in the right iliac fossa [16]. The right hand is pressed gently but deeply in and up under the ribs. The patient is asked to breathe in and out deeply [5, 15, 16, 19], and with the expiration the examiner feels for the liver edge [17, 23]. The normal liver is not usually palpable, although may be felt slightly below the right costal margin during deep inspiration, particularly in thin people [5, 15, 16, 20, 23]. The normal edge should be felt to be firm, smooth, and regular with a sharply defined border and a smooth liver surface [16]. A liver is considered "enlarged" (hepatomegaly) if the edge of the liver is extended more than 2cm below the right costal margin [15], and in some instances a predominantly enlarged left lobe is felt in the epigastrium [5] (see Region 2 in Figure 3). In patients with a large liver, further assessment should be made of the surface characteristics [5]. The edge of the liver and surface may be: hard or soft; tender or non-tender; regular or irregular; pulsatile or non-pulsatile [16].

The technique for palpating the spleen is similar to that for the liver. The left hand is placed over the left lower ribs, and the right hand is placed parallel to the left costal margin on the abdomen below the umbilicus. The right hand is moved towards the left costal margin, and while this happens the left hand applies pressure to the rib cage so as to produce a loose fold of skin and remove tension from the abdominal wall. If the spleen is palpable, then it is likely abnormal [5, 20, 23] and it is not until the spleen is 1.5-2 times enlarged that splenomegaly is just detectable [16].

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Figure 5. Abdominal organs

Other abdominal structures are sometimes felt during palpation (see Figure 5, Figure 6). Kidneys are generally not palpable. A palpable kidney “feels like a swelling with a rounded lower pole and a medial dent (the helium)” [16]. The caecum can often be palpated as a soft, gas-filled mass in the right lower quadrant (RLQ) (see Figure 6). Masses can grow to a large size here without causing obstruction [16].

The sigmoid colon, in the left lower quadrant (see Figure 5, Figure 6), can often be identified and sometimes contains palpable faeces, particularly in severely constipated patients. Faeces, unlike masses, can be indented by the examiner [5, 29]. The gallbladder can sometimes be palpated below the right costal margin [16], particularly in very thin individuals [5] where it crosses the lateral border of the rectus muscles. Bladders are generally impalpable when empty [16].

Once an intra-abdominal mass is detected, it is described using size and shape, location (region), consistency, contour of surface and edge, mobility with movement and inspiration, tenderness, and pulsatility [5, 16, 19].

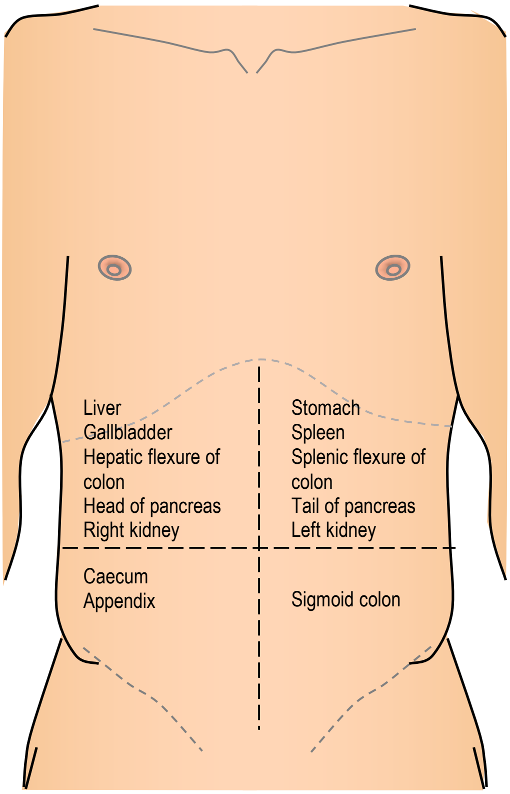

Figure 6. Topographic anatomy of the abdomen [30]

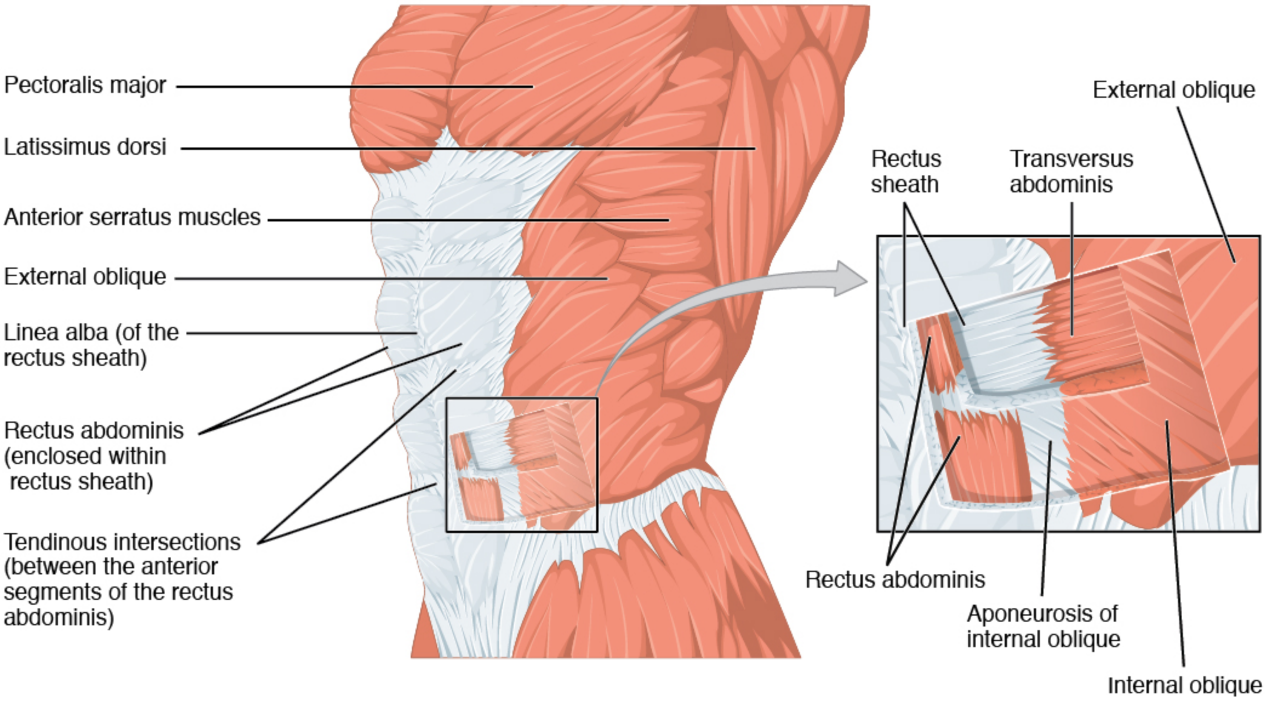

Figure 7. The anterior abdominal muscles include the medially located rectus abdominis, which is covered by a sheet of connective tissue called the rectus sheath. On the flanks of the body, medial to the rectus abdominis, the abdominal wall is composed of three layers. The external oblique muscles form the superficial layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the deepest layer. Muscles of the Abdomen **©** OpenStax **/** CC-BY-4.0

2.4 Why is abdominal palpation difficult to teach and assess?

The physical examination of the abdomen is a highly subjective assessment with potential for discrepancy between physicians. Reuben [4] calls it an "abstract art based on empiricism and tradition… laced with science". Martin and Rossi [7] say examination of the abdomen is "an art" and palpation is an acquired skill. Sensitivity to "touch" and "feel" is a very subjective technique, and the transfer of knowledge from the teacher to the student is difficult because of this subjectiveness. Studies by Annett [31-33] (cited in [34]) have shown that a skill[3] in a motor task, has no relation to the ability of the individual to describe what he or she is doing [34]. So a student may have intellectual knowledge of a skill but not be practically proficient at all. Abdominal palpation is predominantly a closed skill[4] [35], a motor pattern that needs to be reproduced consistently, however it has open skill[5] components in that the environment is changeable and the differences in patients introduce dynamic and unpredictable aspects.

Finding abdominal abnormalities "demands finely honed physical examination skills" [19]. It is hard for an instructor to know whether a student is "feeling" what they are meant to be "feeling" as they have no way of observing internal landmarks or organs that the student should have assessed. The technique required for detection of an abnormally sized spleen or liver requires gentle skilfulness and perceptiveness [19].

2.4.1 Abdominal Palpation in the Medical Curriculum

Taking Flinders University School of Medicine (FUSOM) Graduate Entry Medical Program (GEMP) as an example of a typical curriculum, the training in abdominal palpation skills is predominately taught in the Clinical Skills Learning Unit (CLSU) in Year 1 and Year 2 of the medical degree (see Table 1), after which students transition to clinical practice. In the CLSU tutorial sessions, students receive demonstrations of skills and practise by examining each other (EEO), then in subsequent sessions they are assessed using Standardised Patients (SP) [36-38].

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[3] Skills such as: doing the breast stroke or tying shoes

[4] Allard and Starkes (1991) in analysis of highly skilled movement categorise motor skills in two ways: "closed" skills and "open" skills. They define closed skills as those "skills that are displayed by performance in a consistent, typically stationery environment" where motor patterns are the skills and it is essential that the performer reproduce it consistently and in a set pattern. It is a skill performed in a consistent environment with the goal of a particular motor pattern as the skill.

[5] Open skills are defined as those displayed by performance in a moving, dynamic environment, often including an opponent, where the effectiveness of a motor pattern in producing a particular environmental outcome is what constitutes the skill.

As in Table 1, in the first year of the FUSOM GEMP Clinical Skills program there is an introduction to abdominal examination skills and five tutorials during the year in which to practise the technique and receive feedback throughout different topics. Students are assessed on their physical examination skills at the end of each semester using an SP.

During the second year of medicine, topics relating to abdominal skills occur during the coverage of the Gastrointestinal (GIT) system. There are four tutorials in which students have the opportunity to practise an examination, and they are encouraged to practise on each other between tutorials. However the majority of medical students are young and healthy, so there is limited diversity to their practice.

In all, there are limited time and opportunities for students to hone palpation skills that require a practised technique to learn the “touch” and “feel” that is only developed through repetition over time.

Table 1. Abdominal palpation clinical skills inclusions in FUSOM GEMP curriculum

Course Section	Relevant Clinical Skills modules	Sessions	Topic Requirements relating to Abdominal Palpation
Year 1 Semester 1	Generic physical examination skills of observation, palpation, percussion and auscultation	1 Tutorial: CLSU Session EEO	In-training assessment by tutor. Practical Clinical Exam (history taking)
Year 1 Semester 2	Generic abdominal examination Integrated heart, lungs and abdominal examination	Renal Section Tutorial Sessions: 2 Demos/Practise EEO Assessment of abdomen examination with SP. Human Life Cycle Section Tutorial Sessions: 2 Demo/Practise EEO Assessment of Integrated Examination with SP 1 Feedback with students	In-training assessment by tutor. Assessment of physical examination with SP. OSCE at end of module.
Year 2 Semester 1	Gastrointestinal (GIT) examination	2 Tutorial: Demo/Practise EEO 1 Lecture: Demo from an experienced clinician Students encouraged to practise EEO or patients between tutorials.	Perform a comprehensive physical examination for all body systems in a logical sequence. Assessment with SP.
Year 2 Semester 2	Gastro	2 Tutorials	Perform a full physical examination, including more detailed examination of relevant special areas.

2.5 Summary

Abdominal palpation is an important component of the abdominal examination. As abdominal pain is the most commonly presenting condition in EDs, competence in abdominal palpation is essential. Currently there are limitations in the training options available to medical students, with few opportunities for them to practise this subjective skill. The Flinders Medical Centre Clinical Skills and Simulation Unit approached me with a concept that an abdominal palpation simulator was required as it was not easily taught nor simulated. Simulation provides an approach to overcome many of the limitations of other training methods, giving students the means to practise a physical task and develop the adequate clinical skills required. The focus of this research was thus on developing a manikin-based physical simulator of an abdomen for teaching abdominal palpation.

CHAPTER 3. Simulation Training in Medical Education

3.1 Introduction

Ericsson [39] defined skills as “actions (and reactions) which an individual performs in a competent way in order to achieve a goal.” According to Lane (2001), skills required by physicians can be categorised as: a) patient-centred skills, b) process-centred skills, and c) environment-centred skills [40], where patient-centred skills are of particular interest and relevance to this thesis and relate to the direct care of a patient, including: history taking and physical examination, communication skills, interpersonal skills, and technical skills [40].

According to Ericsson [39], acquired skills, knowledge, and physiological adaptations in response to intense practise are the critical factors for developing high-levels of performance. The primary mechanism of elite performance is deliberate practise, of which essential elements include setting “specific goals to improve performance, successive refinement through repetition, [and] feedback and instruction” [39]. Skilfulness in sports and medical practice may have some similarities as “there is evidence that elite athletes use their perceptual-motor expertise in various situations to predict what is coming next and select appropriate actions” [41 p862]. Medical trainees need opportunities to practise clinical skills, through repetition with instruction and feedback from experienced clinical practitioners to enable them to move from the stage of novice through to expert (elite performance). Benner’s Model [42] describes the stages of competency as Novice (no experience), to Advanced Beginner (remembers rules), to Competent (analytic contemplation of problem), to Proficient (experienced-based ability), to Expert (intuitive grasp of situation).

Simulation training and flight simulators have been utilised over many decades by pilots and astronauts [43] to learn high risk tasks that need prior experience and training before having to undertake them in a real life situation. Flight students are required to clock extensive hours in simulators learning the skills and intricacies of each aircraft before flying in actual planes.

In medical education, similar situations arise where the safety of the patient must come before the learning of the student, while the need for medical students to “learn-by-doing” [44] and practise the clinical skills is still required. Simulator training provides a learner-centred approach to teach such high-risk skills in a risk-free environment.

The value of simulation as a training method is well-established for procedural skills [45] and medical schools and hospitals are increasingly using simulated patients or simulators to assist in standardising both the curriculum and the assessment of students and staff. The fields of anaesthetics, cardiology, critical care, and surgery have been the leaders in using simulation for clinical training [46].

This chapter covers a brief history of simulation training in medical education, addressing the benefits and limitations of simulation, including hands on practise and assessment of clinical skills, and the importance of simulation training in healthcare. A broad overview of the types of simulators available is presented, simulators with quantitative feedback and palpation quantification considered, and current abdominal palpation simulators reviewed.

3.2 Medical Simulation Training

3.2.1 Medical Simulation Training History

Medical education trailed the aviation industry and armed forces in using simulation combined with intentional debriefing in the early 2000s [40]. While the high-stakes decision-making that goes on in a hospital emergency department is similar to that which aeroplane pilots face in crisis situations in the cockpit, widespread application of simulation technology in medicine education only really emerged since the mid-1990s [47].

A 1999 report by the Institute of Medicine Committee on Quality in America, highlighted that “The need for safe and effective training solutions has acted as a catalyst for the development of medical simulators” (cited in [40]). The use of simulation training in medicine since then has increased steadily, with many types of physical simulator models available [48], from full-scale manikins to single task trainers, multi-modality trainers utilising tablets/computers that control physical simulations, and numerous other immersive environment simulators such as virtual reality, augmented reality, haptics and application models becoming more prevalent.

One of the most well-known early manikin simulators was Laerdal's Resusci-Anne, a basic cardiopulmonary resuscitation (CPR) training manikin, was developed in the 1960s by Dr. Peter Safar (an anaesthetist) and Asmund Laerdal (a manufacturer of toys made of soft plastic materials) in response to observation of poor resuscitation technique [47]. Since then, Laerdal claims that Resusci-Anne and variants of her, have been used to train an estimated 300 million people in CPR worldwide [49].

As technology improved and became more economically accessible in the 2000s, the simulation industry developed more advanced computerised and programmable full-body patient simulator training models for a fraction of the cost. These included critical care simulators such as 'SimMan®' by Laerdal [50], 'Stan D. Ardman the Human Patient Simulator' by METI [51] and the cardiology patient simulator 'Harvey®' [52, 53]. In the mid 2000s, new entries to the market included infant and child simulators such as Laerdal's SimBaby and PediaSim by METI (now CAE Healthcare).

Since the 2010s, simulation in medical education has exploded [54, 55]. There are countless task trainers and simulators for both specific and general procedures, with many interfaces and options for simulating patient conditions, vital signs and controlling or monitoring scenarios. There are more immersive Simulation Centres and flexible training options with tablet and mobile device control options now available. What were early training methods when this research began, are now becoming standard training practise. The three main manikin simulator companies (Laerdal, CAE Healthcare and Gaumard) all produce numerous adult and paediatric simulators at similar price points with varying features and models between them [56]. The demand for hands on training plus the benefits of simulation over traditional teaching methods is driving the growth in the medical simulation market [54]. The leading healthcare simulation companies now include Laerdal Medical, CAE, Gaumard Scientific Company, Limbs & Things, 3D Systems, Medaphor, Kyoto Kagaku, Simulab, Simulaids and more, with distributors worldwide [54].

As Chinese medical schools become bigger users of simulators [57] to improve competencies, and the annual National Clinical Skills Competition [58] in China becomes more popular and promoting simulation-based skills development, a further boom in simulation training and cost effective simulators is pending. The global medical simulation industry is expected to double from USD 1,284 million industry in 2017 to a projected USD 2,575 in 2020 [54].

3.2.2 Types of Simulators

The definition of a simulator in Levine [59] is “a device, instrument, or piece of equipment designed to reproduce the essential features of clinical practice.” There are various types of simulators, including manikin and skills-based trainers, game and screen-based simulators that are desktop and tablet based, immersive training that can include haptics, augmented reality and other components of the real environment it is simulating and hybrid simulation incorporating elements of each. Physical simulators can be “Standardised Patients” (SPs) (also known as Simulated Patients) played by actors, or manikin-based simulators, used either on their own or a combination of both in conjunction with an immersive simulation environment with relevant medical equipment for contextualisation [48]. Other modalities that utilise physical interaction include haptic devices in simulated patients [60]. Typical haptic devices use a mechanical interface for users to interact with providing force feedback [61]. Popular commercial devices, such as the Phantom® series of haptic devices (3D Systems, formerly SensAble Phantom), use a pen-type interface rather than the finger pads that are required for an abdominal palpation application [62, 63].

When considering the focus of manikin-based physical simulators, they are generally divided into two main categories:

- Immersive simulation, with full-scale manikins to simulate a full body scenario in a recreated environment like an Operating Room (OR), Intensive Care Unit (ICU) or Emergency Department (ED) [52, 56]; or
- Part-task skills trainers/simulators or procedural simulators, for training and developing proficiency in a particular task, procedure, or skill [59].

Full-scale patient simulators comprise full-body manikins such as the well known SimMan® [64], involving the use of props, personnel and interactions. An instructor directs the simulation and must be able to create a seamless transition between reality and simulation, improvising where necessary convincing the participant that the experience is real or realistic. ‘Harvey’ the lifelike cardiac simulator is another example of an early sophisticated simulation model used to assess student’s physical examination technique. Harvey allows interpretation of venous pulsations and can be programmed to represent a range of conditions [65], and simulators such as Noelle [66] and Lucina [67] are examples of full-body birthing simulators for practicing deliveries of varying complexities.

Part-Task Trainers are designed to focus the attention of the participant on a particular task or procedure rather than a situation and may or may not involve feedback [45]. These types of devices are generally skill oriented, with specific skill level goals [68], such as Resusci-Anne for CPR training or Ambu® Airway Management Trainer [69] for intubation training. Some models are static and permit examination by the student but do not respond to students' actions. Others are interactive with students in some way.

The focus of this research is on the physical manikin-based simulators, and more specifically a part-task trainer for teaching abdominal palpation.

3.3 Benefits and Limitations of Clinical Simulators

Medical education simulators (Sims) are now recognised as accepted teaching tools in addition to clinical teaching [40, 44, 45, 70, 71]. Simulators range from basic to highly complex and can teach single tasks, grouped tasks, or a series of interrelated tasks. They range from low-tech simple plastic models to realistic high-technology adult patient simulators with computer controlled interfaces, and various combinations in between. They can be integrated into the medical educational curriculum to both teach and assess different levels of skills and provide the opportunity for students to learn by doing. The benefits of the use of simulators in the clinical curriculum are numerous, including standardising the medical curriculum, evaluation and assessment of students, no risk to patients and a safe environment for student learning, time for practise, feedback and reflection, learning consequences of errors, an interactive curriculum, and better preparation of students for patient examination. Limitations of manikins are that they can be lacking in realism and have limited options for altering anatomy, which can have effect on student performance depending on the context and the simulated environment.

3.3.1 Standardising medical curriculum

The use of simulators provides a means of standardising the medical curriculum, so that every student can experience a wide range of normal and pathological cases and clinical scenarios required by medical boards within their training course.

Access to simulated patients at any stage of the curriculum enables inclusion of specific clinical cases at the appropriate point in the topic of study rather than when patients are available as has traditionally occurred [40, 44, 46, 72, 73].

Simulation training also allows consistent and unlimited exposure to a variety of clinical presentations and procedural contexts, including atypical patterns, rare diseases, critical incidents, complex or infrequent events or conditions, near misses and crises [74]. In addition it can simulate selected findings, conditions, situations and complications at any specified point in the learning process rather than relying on the once off or ad hoc clinical availabilities of real patients [40, 41, 44, 46, 68, 72, 74-76].

A more interactive curriculum engages students and teaches them to problem-solve. It improves acquisition and retention of knowledge and accelerates experiential learning, consolidating textbook knowledge [77]. It can also assist in teaching soft skill aspects of the medical curriculum such as teamwork, leadership, interpersonal communication skills, stress management, critical-thinking, decision-making, and the ability to prioritise under pressure [75].

3.3.2 Evaluation and assessment of students

An integral part of any curriculum is also the evaluation and assessment of the students to ensure they have satisfactorily achieved the objectives of the training. The use of simulation in assessment of trainee clinical skills has been steadily rising [59, 78]. High-technology simulation is an increasingly important learning aid for procedural skills [79]. Simulators such as sophisticated manikins that respond to interventions – with features such as respiration, oximeter readings, and heart sounds – are used to assess how individuals and teams manage various clinical situations.

Since 2004 all graduating US medical students have been required to take a competency-based skills examination for licensure [80, 81]. The United States Medical Licensing Examination (USMLE) evolved from using a paper-based examination to computer-based simulations for written assessments in 1999, which opened up opportunity for computer-based simulations in the examination [59]. Other assessments for which simulators play a key role include Basic Life Support (BLS) and Advanced Cardiovascular Life Support (ACLS) which are annual requirements at most medical institutions [59, 82].

A limitation of simulation-based assessment, is that students can have a Hawthorne bias [83] such that they adapt their behaviour and performance in response to an awareness of being examined and observed.

3.3.3 No risk to patients and a safe environment for student learning

The key advantage of the use of simulators in medical education is that there is no risk to patients. The simulation environment provides a risk-free, non-threatening and less stressful environment for students which is more conducive to learning. It is a place where students can practise and learn principles, and where errors are not life-critical. Students can learn from errors immediately, or to even purposely make errors and see them take their course, and understand the implications and consequences of their actions [70]. It promotes open discussion and review of errors without concern for liability [84]. The downside of accepting errors, is the risk of complacency and lack of care or intensity of a real life or death situation at the required moment.

Students have more autonomy over their learning in the simulation environment; they are able to learn at their own pace, repeat scenarios if required, practise techniques, and replay to see different outcomes with different interventions. In the simulated training environment, complexity levels and time limits can be set by educators according to the focus of the topic, or level of the students. Simulators help equip students so that their first encounters with real patients occur once they have reasonable levels of technical and clinical proficiency [77, 84, 85]. The benefit and limitation of this is that there is less unpredictability to the learning, which assists the learners to study, but removes the learnings that come from the unknown real-life factors with real patients that also need to be managed with supervision.

3.3.4 Feedback, Reflection and Repetition

Another benefit of the use of simulators is that students can have instant feedback regarding the decisions they make [45]. This feedback may come in various forms, such as a change in vital signs or that other conditions are triggered as a result of decisions made. Learning from mistakes becomes an element of the learning process and of shaping future behaviour and expertise.

Feedback in simulation can come from instructors or facilitators, devices, patients, or other learners, and constructively addresses specific aspects of a student’s performance to assist in their learning [60].

Feedback may also be delayed, for example where scenarios are video recorded, and the student can then look back on their performance, and review and learn from it. It may also be in the form of a debriefing session where instructors take the students step by step through a scenario and review it [86]. The time for reflection and feedback, debriefing of scenarios and reviewing simulations in various formats, provide learners with a safe interactive simulated experience and mentoring.

3.3.5 Enhanced learning and preparation for patients

An important note, is that simulation is not identical to real life or actual events [41, 44, 85, 87]. The human-side of interactions with real patients, the emotions, the vital sign changes, the physical changes/colours/responses are not all going to be realistic and interact like a human in a simulator. Simulation mimics reality, with situations where cognitive and behavioural responses emulate those which would occur in real settings [41, 46, 85]. The patient simulator is a learning tool and not a substitute for working with real patients, but can be a good educational learning tool for preparation of students for their patient interactions.

3.4 Importance of Simulation Training in Healthcare

3.4.1 Learning by Doing and Skills Training versus Patient Safety

The traditional training method of "learning by doing" [88], which involves medical students practicing on patients alongside a bedside teaching apprenticeship model is on the decline [89]. Much traditional training was rigidly structured and lecture-based, focussed on memorisation [44, 46]. In this model students under supervision followed the progression of a disease process for a patient through to its clinical outcomes [88]. The method has become increasingly less acceptable to patients when invasive and high-risk care is required. It also fails to provide an ordered means to acquire skills due to the variability in clinical availability and patient flow [44]. In current hospital systems and settings patient care has also changed, with length of stay times dramatically reduced over the past few decades, and workload of clinicians increased, decreasing the suitability of using patients for bedside rounds [89]. Conditions that previously required hospitalisation are now able to be treated at home, or surgeries that required week long hospital stays are now day surgery [90]. The result of this has required change in the way medicine is taught.

There are indications in the literature that there should also be more concern for patient care and safety [46, 85, 88]. The 1999 report by the (United States) Institute of Medicine informed of the fact that medical errors were the eighth leading cause of death in the US [91]. The report recommended newer and safer methods of patient care be developed and delivered. Historically, publicity of medical failings such as this, and an increased awareness of the ethical issues involved in utilising patients for teaching and examinations, reduced the willingness of patients to participate in educational exercises [77, 92]. The three “Cs” of consent, choice, and confidentiality, and patient and family engagement, now come into the conversation for patient involvement in education [93].

The traditional “learning by doing” training technique for medical students in today’s hospital environments is empowered by simulation, providing experience and opportunity to practise skills without the risk to patients. The use of simulators in training acknowledges medical errors are a high risk to patients, and reduces the risk while addressing training shortfalls from reduced accessibility to patients in the current hospital environment.

3.4.2 Meeting Demand for Skills Training

Emergency Departments (ED) and Intensive Care Units (ICU) are dynamic, high-pressure, challenging environments for students to learn essential reasoning and psychomotor skills [46]. It is crucial that students learn how to apply these skills in these environments; however, students are often excluded from the primary management of acute patients in these situations, because of both patient and clinical concerns regarding their safety [46]. This results in limited opportunities for students to practise, reflect, or receive constructive feedback.

The UK General Medical Council [94] standards relating to clinical teaching resources require that: “the medical school ensures there are sufficient clinical teaching and learning resources, including sufficient patient contact, to achieve the outcomes of the course.” In a similar vein, the Australian Medical Council [95] states “it is essential that students be exposed to common medical problems of a more transient nature that are not seen in the hospital setting.” If this is not possible in a hospital setting, then an alternative is required.

Strategies to address the availability of clinical teachers, teaching time, access to patients, and necessary infrastructure for the projected increase in trainee numbers [72] include using simulation and a wider range of clinical teaching settings to teach clinical skills [72, 73].

"In the long run it is clear that we must find alternatives to teaching hospitals as the major sites for acquiring clinical skills… Simulation is an attractive alternative, and for many technical skills a satisfactory one…" [96]. There is an ongoing tension between academic and practical approaches, and minimum time spans for training equating to being competent versus competency-based medical training [97].

3.4.3 Skills Performance Improvements

Studies in the early 2000s demonstrated the superior performance of those receiving simulator training compared with those who did not [98, 99], however some groups found that multiple encounters were required to ensure a reliable result [100, 101]. Validation studies of simulators were challenging as students not trained with simulators would prepare thoroughly for examinations and self-train, so it was difficult to have a true control group. One research group ([102] cited in [98]) indicated it would not have been ethical to have a control group for clinical evaluation as the skill level of students who received simulator training outperformed those who did not [98].

Student opinion is generally in favour of teaching using high-fidelity simulators [103, 104] or medium-fidelity simulators and working in simulated team situations [105]. They rate their competence as improved and identify a difference between knowing what they should do and actually doing it in a realistic simulated medical emergency [105]. They value simulation-based teaching very highly, as it offers them the opportunity to learn through experience, reflection and feedback, the opportunity to practise, and to learn in a non-threatening environment that is engaging, interactive, and clearly relevant to practise [105].

A critical review of simulation-based learning in medical education [106] found it is producing strong and lasting educational effects. Students from medical schools with simulation-based skills training throughout their programs score significantly higher compared to traditional lecture-based curriculums [104, 107]. Staff learning procedural techniques improved their skill level from web-based presentation when hands-on simulation training was implemented [108]. It has been demonstrated that learners perform better and learn faster as a result of training involving patient simulation [109-112].

3.5 Simulation models

3.5.1 Quantitative feedback palpation models

Quantitative feedback in the medical simulation field is still a growing area. Many haptic computer simulations provide quantitative feedback, but the haptic feedback is generally related to a surgical procedure where an instrument is used to apply the force or a small or confined area is being examined i.e. for pulse or localised cancer detection [61]. A limitation of haptics for abdominal palpation is that interfaces are usually limited to one or two fingers or a "pen" [113], while abdominal palpation uses aspects of the whole hand (see CHAPTER 2). There is still limited research available regarding objective quantitative feedback to students for physical examination techniques. This feedback is of particular significance in areas of the body where you cannot see what is happening and that involve the development of a tactile sensitivity for diagnosis. The ability to detect and diagnose abnormalities with a practised tactile sense is essential for physical examinations.

3.5.1.1 E-Pelvis / ExamSIM

Pugh and colleagues [114] were some of the first to include quantitative feedback in a simulator trainer for gynaecological pelvic examinations. They developed the E-Pelvis (later named the Pelvic ExamSIM when commercialised with METI pictured in Figure 8), a part-task trainer that used individual sensors to detect whether students had touched an area inside the pelvis or felt an abnormality.

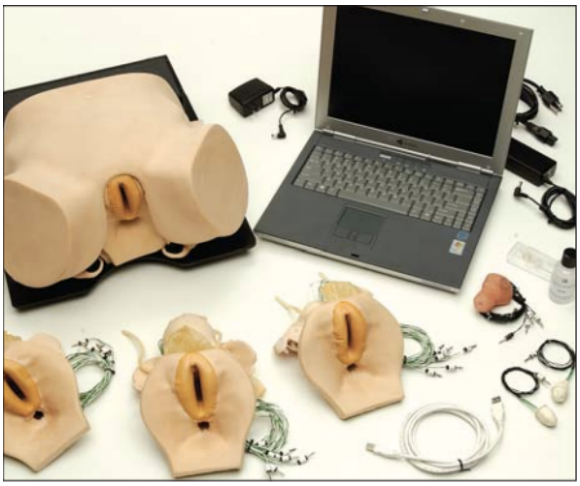


Figure 8. METI Pelvic ExamSIM [51]

The Pelvic ExamSIM is a partial manikin, umbilicus to mid-thigh, designed to assess medical students' female pelvic examination skills through direct electronic recording of their palpations. The manikin has several internal electronic sensors that communicate, indirectly, with a computer-generated interface for immediate visual feedback. This allows students and instructors to see which structures are being touched, and how much pressure is being applied during the pelvic exam. The objective and measurable feedback helps both learners and instructors to know if students are ready to perform proficient and sensitive female pelvic exams.

In a validation study of 3 groups (control, manikin and the simulator with visual feedback), it was found that students in the simulator group with visual feedback had a superior learning experience with instantaneous feedback from the simulator, combined with affirmation from an instructor and the interaction with classmates [99, 114-117].

3.5.1.2 Bovine Rectal Simulator

Another early simulator that used a similar concept is the Bovine rectal simulator [118-120] (see Figure 9). It uses haptic technology inside a fibreglass cow to train veterinary students in uterine examination. Students palpate virtual objects representing the bovine reproductive tract and the teacher follows the student's actions on the monitor and gives instructions.

<Figure has been removed due to copyright restrictions>

Haptics: Perception, Devices and Scenarios, Developing the 'Ouch-o-Meter' to teach safe and effective use of pressure for palpation. Baillie et al. pp.912-917 © Springer-Verlag Berlin Heidelberg 2008, used with permission.

Figure 9. A Haptic Cow training session using a PHANToM 1.5 haptic device [120]

During the simulator sessions, the teacher has the advantage of being able to see the student's actions. The teacher therefore is able to provide more effective guidance to a student's movements and hand position, identifying structures to be palpated, and providing immediate feedback on performance. Baillie and colleagues validated this method by comparing performance of a group of traditionally trained students versus a group whose training was supplemented with a simulator training session. Subsequent performance in the real task when examining a cow for the first time was assessed, with the results showing a significantly better performance for the simulator group [119].

3.5.1.3 *Dynamic Breast Model and Prostate Examination Simulator*

Gerling and Thomas [121] developed a novel method of modelling clinical breast examinations (CBE), using visual feedback of pressure changes in balloons embedded in silicone under palpation, to address the lack of tactile training for CBE. The Dynamic Breast Model consisted of 15 dynamically controllable lumps in a silicone breast model. Handmade balloons embedded in formed silicone were inflated with water to simulate lumps of controllable hardness, and were undetectable when deflated. Tactile feedback to the trainee, in the form of oscillating water pressure while the trainee's finger was near the balloon, also aided in lump localisation.

Visual feedback of pressure changes in the balloons embedded in silicone under palpation, provided learners with positive confirmation of their performance. Their findings from a study of 48 medical students demonstrated the advantage of using the dynamic model over conventional models for training CBE tactile skills [122] with students having enhanced confidence in lump detection and improving sensitivity and specificity.

Gerling and colleagues [123] then designed and evaluated a computerised physical simulator for training clinical prostate exams using a similar silicone-elastomer balloon method. They analysed learning issues associated with the digital rectal examination (DRE) and the teaching curriculum, identifying that clinicians needed to learn to perform two tasks sequentially. They determined that the simulator needed to have multiple and reconfigurable scenarios of graded difficulty.

Granados and colleagues [124] used position tracking and pressure sensing using a capacitive pressure sensor pad on the fingertip to capture pressure for internal examinations (DRE and bimanual Vaginal Examination (BVE)). They reported duration for aspects of the examination sub-tasks, movement distances relative to aspects of the DRE/BVE, and the standardised pressures of the sensors on the index and middle fingers of the examining and external hand.

3.5.2 Quantifying Forces in Palpation

A review of the literature found few studies have been performed to quantify the actual forces applied during a palpation examination. Rudimentary methods were published early on using techniques such as a blood pressure cuff [125] and kitchen scales [126]. Pugh's (2002) early research on the E-Pelvis published quantifiable data, but without units, while recently in 2016 Laufer et al (Pugh's colleagues) [127] have produced a Breast Examination Simulator capable of measuring force with fabric force sensors [127].

Tuttle [128] reported that the magnitude of force applied by physical therapists (physiotherapists) using manual therapy techniques can vary between practitioners by as much as 500%. He notes that providing feedback to students is complicated due to the multiple points of contact and the difficulty in recording forces without affecting technique or performance. Tuttle demonstrated the use of a force-sensing resistor to provide feedback on manually applied forces for forces up to 50N for use with the cervical spine.

3.5.2.1 *Blood Pressure Cuff*

Shafer (1967) in, 'A new method of Abdominal Examination: Preliminary Report' [125] described his early experience with a method using a regular blood pressure cuff in order to measure and standardise the degree of pressure applied to the abdomen. It was an early attempt to standardise the way improvement or intensification of pain in the same patient was measured, regardless of the examiner.

The blood pressure cuff was inflated to the point where it would lie approximately flat, then folded in half, so that when pressure was applied to the cuff, air was not merely displaced (see Figure 10). Depending on the clinician's preference, the cuff was placed either directly on the abdomen or on top of the hand touching the abdomen between hands – in either case the physician placed one hand on top of the folded cuff.

<Figure has been removed due to copyright restrictions>

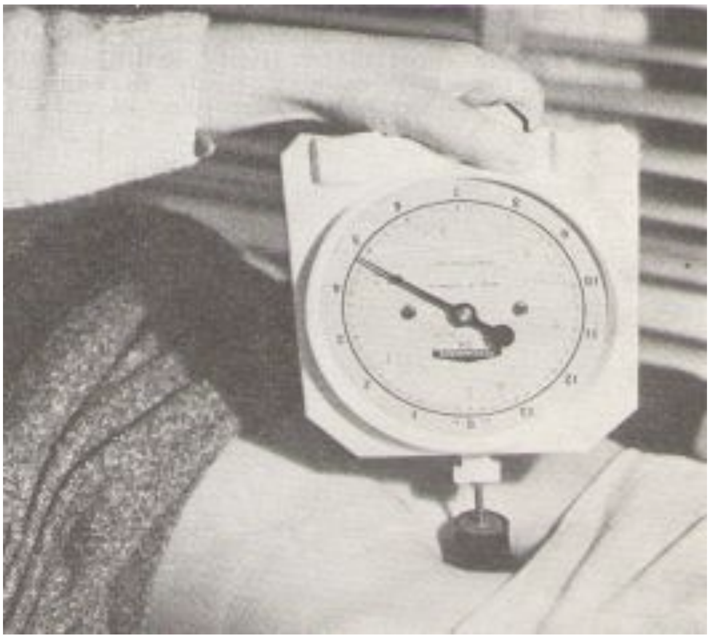
Figure 10. Shafer Blood Pressure Cuff Method [125][6]

[6] This image was published in Current Therapeutic Research, Volume 9, Issue 2, Nathaniel Shafer, "A new method of abdominal examination: preliminary report", pp82-84, Copyright Elsevier (1967), used with permission.

The cuff was applied to a series of normal patients (as well as those with pathological conditions), and up to 120mmHg of pressure was applied without producing pain. The average pressure applied on deep palpation by 20 physicians was 35mmHg. It was impractical to measure light palpation unless a special sphygmomanometer was used with range 0-20mmHg. He claimed this provided a means to standardise pain intensity, to evaluate rebound tenderness, locate the point of maximal tenderness, show progression and pain, help to evaluate psychogenic pain (i.e. consistency of response), and document these things objectively [129].

3.5.2.2 *Upside-down Kitchen Scale*

In 1970 Patkin [126] used a kitchen scale upside down as a method of quantifying abdominal tenderness with a simple instrument (see Figure 11). His method represented tenderness as a scalar quantity in such terms as slight, mild, moderate, marked, and exquisite and that in some situations the change in level of tenderness is important. His technique involved an ordinary spring operated kitchen weighing scale; where the pan was replaced by a long bolt and some rubber disks carrying a large rubber knob 4cm in diameter.



Patkin M. Measurement of tenderness with the description of a simple instrument. Med J Aust 1970; 1(13):670-672.

Figure 11. Patkin's measurement of Tenderness with upside down scale "tenderness meter"

He measured the tenderness relative to the site of the pathology and monitored the tenderness over time by the patient's response. From a small set of cases he reported quantifiable values for tenderness as:

- marked or "acute" tenderness = 1-2lb (0.5-1kg approximately)
- moderate tenderness = 4-5lb (about 2kg)
- slight tenderness to a pressure of = 6-8lb (3-4kg)
- tenderness of a skin boil – pressures of only a few grams'

The method was intended to provide a simple, cheap, easily accessible instrument to assist in making decisions and reporting the progress of a patient's condition.

3.5.2.3 *Haptic Interface Robot*

An early 2000s study used model-based force prediction in a haptic breast palpation model. The paper "Medical palpation of deformable tissue using physics-based model for Haptic Interface Robot (HIRO)" by Daniulaitis et al. [130] highlighted that medical education had a strong need for palpation training. Daniulaitis et al. created a virtual reality (VR) training for breast palpation simulation utilising a multi-fingered Haptic Interface Robot (HIRO) [130]. Their simulation allowed the user to perform breast palpation on a realistic model of the breast, and using a Finite Element Model, estimated reaction forces to be between |0-6|N.

3.5.2.4 Breast Exam Simulator

A breast exam simulation study by Pugh and colleagues in 2011 showed 15% of physicians who participated did not apply enough force to find a lesion, and more than 50% did not practise the recommended palpation technique that achieves greatest tissue coverage [131].

Laufer et al (colleagues of Pugh), in 2016 reported the development of novel fabric force sensors for their Clinical Breast Examination Simulator, to enable objective assessment of performance against the Clinical Breast Exam (CBE) published recommendations. While in early development, their pilot study provided quantifiable results showing the mean forces of accurate examinations were 13.53 +/- 6.29N [127].

3.5.3 Abdominal Palpation simulators

Abdominal palpation simulators were rare when this research began, with the only available options including simple static options such as the Pharmabotics “Lumps and Bumps Box (LBB100)” for basic clinical skills training to familiarise with the sense of touch, with two skins, 2 layers of foam, and an assortment of shapes (see Figure 12) [132].

<*Figure* has been removed due to copyright restrictions>

Figure 12. Pharmabotics Lumps and Bumps box [132]

A specific abdominal simulator from Shanghai Honglian Medical Instrument Development Co, the “KAF-980 Digital Abdomen Palpation Manikin” (see Figure 13) purchased by Flinders University in 2007 featured an adult woman torso, with a palpable liver, spleen, gallbladder and breast [133].

<*Figure* has been removed due to copyright restrictions>

Figure 13. Honglian KAF-980 Digital Abdomen Palpation Manikin [133]

Since 2010, a number of abdominal palpation simulators have appeared in the public domain, but none with palpation force feedback.

The Limbs and Things Abdominal Examination Trainer (see Figure 14) is a recent product for practicing palpation, auscultation, and percussion elements of abdominal examination. The model has interchangeable organs, MP3 for audio, and an air pump for distention [134].

<Figure has been removed due to copyright restrictions>

Figure 14. Limbs and Things Abdominal Examination Trainer [134]

Abe the Tummy Dummy (see Figure 15), was developed by students at National University of Singapore. It is a static abdominal model with a focus on palpation for repetition, made from plastic and silicone with viscera of various sizes to be palpated or balloted. The group surveyed 44 students, with 93.2% of students finding it to be a useful tool in learning the steps of abdominal palpation properly and 79.6% reported being more confident in their ability to perform the abdominal examination after completing the pilot [135].

<Figure has been removed due to copyright restrictions>

Figure 15. Abe the Tummy Dummy [136]

The SmarTummy manikin's patented [137] abdomen is divided into 100 regions by two layers of balloons (see Figure 16). The developers describe the use of reconfigurable inflatables designed to replicate the tactile feel of abdominal ailments using a computer-interface to select a series of pre-programmed patient conditions. The inflatables separately and independently supply the elements with a pressurised medium and the user can receive feedback of which inflatables were palpated [138].

<*Figure has been removed due to copyright restrictions*>

Figure 16. SmarTummy [138]

A simulator[7] by ACDET (see Figure 17) is a newly released abdominal simulator training package in 2017 and claims to be the world first abdominal medical simulator[8] with tactile, visual and audio feedback [139, 140].

<*Figure has been removed due to copyright restrictions*>

Figure 17. Simulator by ACDET [139]

[7] The ACDET simulator goes by the name AbSim, but is unrelated to the researchers or research presented in this thesis. The name AbSIM has been used and presented at conferences by Lynne Langman (nee Burrow) since 2011 (ref).

[8] They have a US Patent Application 20160314718, filed 15 Dec 2014, and published 27 Oct 2016.

In Japanese Kampo medicine, abdominal palpation for abdominal diagnosis is called "Fukushin". Yakubo and colleagues developed a Fukushin simulator using synthetic plastics and an electric motor to simulate the heart beat for the abdominal aorta [141].

There are other abdominal simulators such as the AbdoMAN [142][9], but these are designed for simulation of surgical techniques not palpation.

3.6 Summary

There were few palpation feedback simulation models available on the market when this research was begun in 2006. While there have been developments in abdominal models in the last few years, there is still need for information about the forces applied during abdominal palpation, to develop simulators incorporating force assessment and feedback.

[9] AbdoMAN 142. Kroese, L.F., et al., *The 'AbdoMAN': an artificial abdominal wall simulator for biomechanical studies on laparotomy closure techniques.* Hernia, 2017: p. 1-9. is a surgical simulator for laparotomy use and incisional hernia.

CHAPTER 4. Research Problem Definition

4.1 The Problem

Abdominal palpation is a routine but critical diagnostic procedure performed in many clinical situations. As addressed in CHAPTER 2 and CHAPTER 3, there is no standardised way to teach or assess abdominal palpation that allows the instructor to know that a student has examined all the abdominal regions and applied appropriate forces for any particular clinical scenario. It is impossible to discern through observation of performance, if a learner is "feeling" the correct things, has applied an appropriate pressure, has covered all the abdominal regions, and developed the right sensitivity of touch both for the patient's comfort and for diagnosis capability. As was identified in 2.2, abdominal related presentations are the most common presenting conditions to ED, so importance should be placed on learning skills for appropriate diagnosis. A means to record and evaluate technique, identify technique that needs improvement, and demonstrate competence is needed.

An objective method of teaching, training and testing students is therefore necessary, to provide an improved learning experience for the student and to ensure that students are practised, competent, and more confident before entering a clinical setting. More opportunities for students to develop and practise with feedback and reflection would improve skill uptake. As discussed in CHAPTER 2, physical simulators are now standard practice in clinical skills training and utilising this method would meld with current medical training practice.

Project definition: The development of an abdominal palpation skills simulator

4.2 Project Scope

The scope of the work described in this thesis was to develop a clinical educational tool for the purpose of training and assessing medical students in abdominal palpation. The tool should be sufficiently realistic to provide students the opportunity to develop and practise palpation skills and receive feedback for reflection and improvement.

Skills that were identified as important were:

- Consistency and appropriateness of applied forces
- Development of touch sensitivity and familiarity to detect abnormalities
- Systematic coverage of the abdomen
- Critical and analytical thinking

4.3 Proposed Solution

The proposed solution to this problem was to develop an abdominal palpation simulator that could be used as an educational tool to provide training, opportunities to practise, immediate feedback on performance, and a means to standardise assessment of the skill.

4.4 Design Requirements

The abdominal palpation simulator was required to:

- Simulate an average male abdomen
- Identify whether students palpate all regions of the abdomen with a systematic approach using both light and deep palpation
- Assist students in the development of palpation skill procedures, technique, and tactile sensitivity
- Provide useful feedback to students about their ability, skill level and development of abdominal palpation skills
- Be a legitimate tool for palpation training
- Provide a means for teaching and practicing a skill without harm or discomfort to the patient, allowing repeated practise to improve confidence and ability, and quantifying testing.

4.4.1 Design Approach

The approach to achieving the design requirements was to:

- Identify the forces required (CHAPTER 5),
- Design, develop and build an abdominal palpation simulator (CHAPTER 6),
- Test the simulator across medical students and medical graduates (CHAPTER 7),
- Analyse the results (CHAPTER 8),
- Make recommendations regarding future work (CHAPTER 9),
- And answer the research questions (CHAPTER 8):
    - Does the AbSIM prototype sufficiently simulate an average male abdomen?
    - Do participants palpate the whole abdomen in a systematic way and what forces do they use when palpating?

4.5 Summary

The aim of this research was to develop a sensor-enabled abdominal palpation simulator and test it across a range of participants to evaluate if it was sufficiently realistic to use as a support for training. This chapter has identified the project scope, specifications, and design approach for the simulator.

CHAPTER 5. Preliminary investigation: How Hard Do Clinicians Press (HHDCP)?

5.1 Introduction

To develop a palpation simulator, it was necessary to know what forces are commonly applied to the abdomen during abdominal palpation. As was found in searching the literature and described in CHAPTER 3, there have only been very basic tools used to quantify the forces applied during abdominal palpation, and quantitative data in the literature were not sufficient from which to develop the AbSIM model. Thus, an investigation into the forces applied during abdominal palpation had to be conducted to quantify typically applied palpation forces prior to development of the simulator.

The objectives of the investigation "How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique" [143] (abbreviated to HHDCP) were to evaluate the different abdominal palpation techniques of experienced clinicians and investigate the reproducibility of applied force on the same subject by a clinician (intra-examiner), and variability between clinicians on the same subject (inter-examiner).

Ethics approval for "How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique" was reviewed and approved by the Flinders Clinical Research Ethics Committee (FCREC Research Application: 104/2007) and Repatriation General Hospital Research and Ethics Committee (RGH Protocol Number: 75/07) (0 10.1).

The investigation, conducted in 2008, was separated into three parts to assess different aspects of a clinician's technique:

Part 1: The sequence of a clinician's normal technique.
In the first part, the clinicians were asked to perform palpation of the abdomen as per their usual personal technique, to capture the different techniques of examiners.

Part 2: Variability between examiners, using a standardised sequence.

In this part, the clinicians were asked to palpate the abdomen as per a specified standard sequence to control for technique variations. This would enable the data between clinicians to be compared more easily to look at inter-examiner variability.

Part 3: Repetitive palpation.

Finally, the clinicians were asked to perform “light” palpation repeatedly in a specified region, then “deep” palpation repeatedly in a specified region. The consistency of examinations for light and deep palpation could then be compared both intra- and inter- examiner.

The investigation involved the clinicians performing each of the abdominal examinations for the three different parts in a single session. This was to reduce the need for them to return, which was proving to hamper recruitment. A healthy male subject with no known pathologies was examined by all participants. Sensors were attached to both the subject’s abdomen and the clinician’s dominant hand (see Figure 19 and Figure 20) to record the position of their hand relative to subject’s abdomen. The clinicians answered a series of questions about the techniques they used, and the abdomen of the subject was videoed throughout the examinations.

5.2 Methods

5.2.1 Location, Materials and Equipment Setup

The HHDCP preliminary investigation took place at the Repatriation General Hospital in the South Australian Movement Analysis Centre (SAMAC). The laboratory had an 8-camera VICON 612 three-dimensional motion analysis (3DMA) system[10] that recorded the position of reflective markers attached to specific landmarks in the room. There were four AMTI forceplates in the floor which recorded the directional force applied. There was also the facility for recording video input. The positional, force and video inputs could all be synchronised.

The forceplates were arranged in the floor positions as indicated in Figure 18. The examination table was then placed so that each leg was on a forceplate; four markers were placed on the table above each table leg. The video camera was suspended above the table and placed in position to record the abdomen (see Figure 21).

[10] An infrared camera system set up that could record the position of reflective markers in the room.

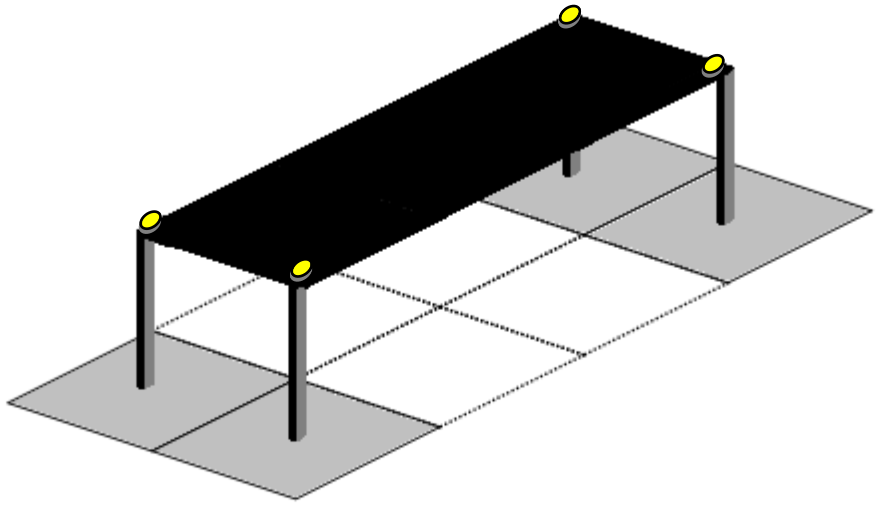


Figure 18. Examination table legs positioned on floor force plates (grey). Reflective markers (yellow in image) on table in line with each table leg.

The subject lay on the exam table. Reflective markers were attached to the subject's abdomen and the clinician's dominant hand (see Figure 19, Figure 20, Figure 21) using medical tape to define the abdominal regions and record the location of the clinician's hand relative to subject's abdomen. 16 markers were used in total.

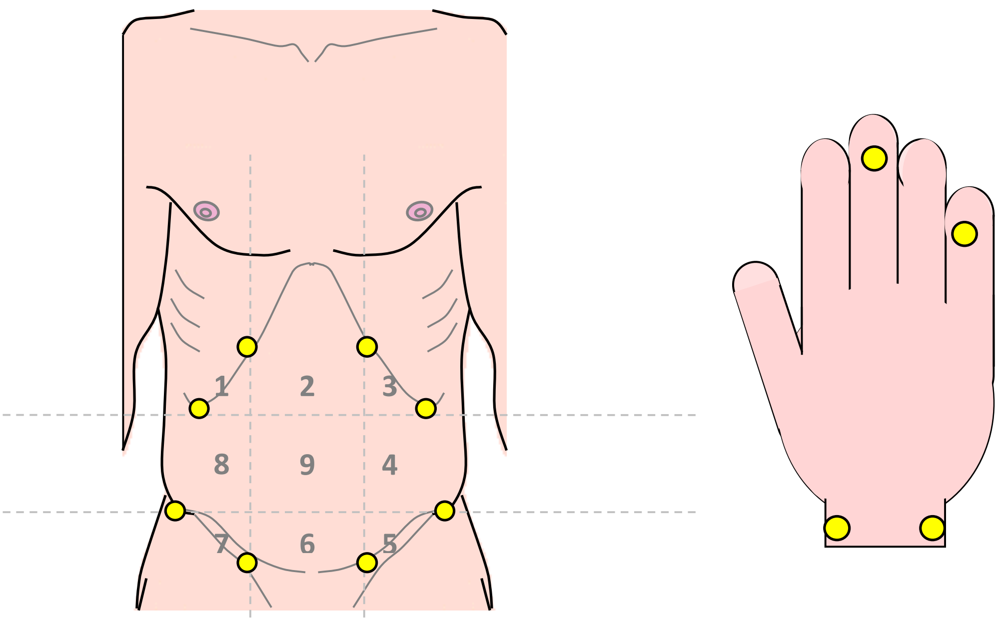


Figure 19. Marker placement on bony landmarks of subject's abdomen to identify lines for the nine abdominal regions. Markers on third and fifth fingers of clinician's hand and either side of wrist to define the plane of the hand.

Figure 20. The reflective markers were attached to the subject's abdomen with medical tape.

Figure 21. Still frame from video of clinician palpating subject's abdomen for Part 1

5.2.2 Procedure of data collection

The following protocol (see Appendix A 10.1) was followed by the researcher to instruct the clinicians and record data.

Part 1: Palpation examination as per clinician's usual technique

a) The clinicians were asked to perform palpation examination using their usual technique, giving verbal cues as to the area to which they were applying force.

b) Clinicians were then asked the following series of questions about the examination:

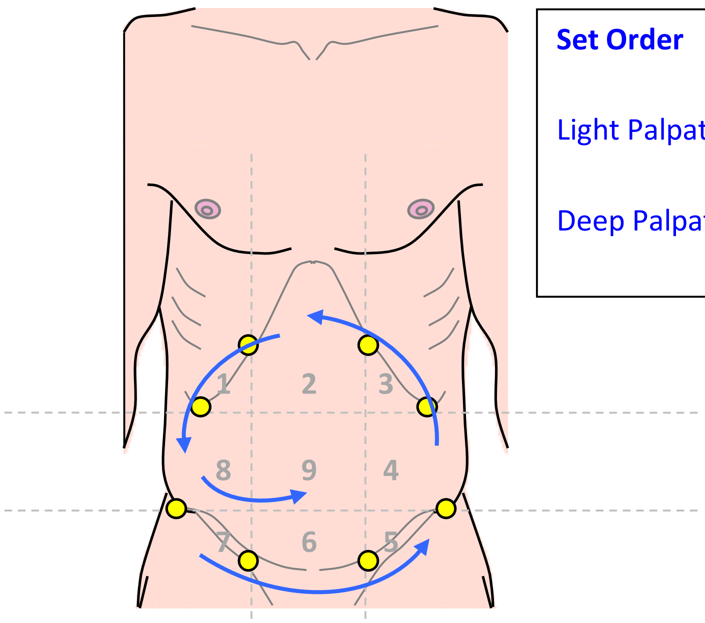
- *Do you initially examine a patient's abdomen the same way every time?*
- *Why/Why not?*
- *Why did you use the sequence just performed today to examine the abdomen?*

Part 2: Palpation examination as per sequence specified by investigator

a) Clinicians performed palpation examination in a specified order as per Figure 22, where the numbers correspond to arbitrary labelling of the 9-regions. Once finished, they performed the same examination again, repeating this step until they had completed it three times in total. This sequence was set as an anticlockwise sequence for ease of comparison of data.

b) Clinicians were then asked a series of questions about this method and their answered recorded. The questions were:

- *If this was not the sequence you normally use to examine the abdomen:*
    - *How was it different?*
    - *Do you think it is more/less effective?*
    - *Why/Why not?*



Set Order

Light Palpation: 7 – 6 – 5 – 4 – 3 – 2 – 1 – 8 – 9

Deep Palpation: 7 – 6 – 5 – 4 – 3 – 2 – 1 – 8 – 9

Figure 22. Nine regions identified by arbitrary numbers 1-9, Blue arrows indicate the direction of the specified palpation sequence as indicated in the textbox "Set Order", Yellow circles indicate location of reflective markers.

Part 3: Light and deep palpation repeated in a specified region

a) Clinicians performed "light palpation" in one region, and were asked to repeat this examination three times.

b) Clinicians performed "deep palpation" in the same region, and were asked to repeat the examination three times.

c) Clinicians were then asked the following questions about their consistency and their responses recorded:

- *Do you think you were consistent in the amount of force applied?*
- *In a clinical setting do you think you are consistent?*
- *Why/Why not?*

5.2.3 Data Analysis Methods

Data were collected at 1000 Hz in the proprietary format of the VICON 3DMA system and exported by the SAMAC manager to .csv and .avi files for processing in Excel [144] and MATLAB 7 [145]. Responses to questions asked were annotated on the participant record sheet, and transcribed to Excel and SPSS [146].

Because this was an exploratory investigation, the sample size was limited and not powered for statistical testing. Qualitative observations were made regarding the clinicians' technique, and the basic statistical measures of the mean and standard deviation were used to summarise the quantitative data. Two-tailed independent t-tests were used to determine if the light and deep palpation forces for individual clinicians were statistically different using GraphPad online calculator [147].

The data were pre-processed manually to clean the data (i.e. remove sections where the examiner stepped on the force plate), address missing values, and resolve inconsistencies. Where a clinician stepped on a force plate during a task, and if detected at the time, they were asked to repeat the sequence again so the data could be rerecorded to confirm that the data analysed were free from other forces applied accidentally.

For each dataset, custom written MATLAB [145] code[11] to process the data was used to:

- Import the force data, where assumption was that Total Force (N) = $F_{Z1} + F_{Z2} + F_{Z3} + F_{Z4}$ (where F_{Z1} is z component of force plate 1, etc.)
- Set variable names: Clin no, Trial no, Description of trial, axes limits, plot titles
- Set values < 0 to equal 0N to resolve inconsistencies
- Smooth the force data to reduce noise and outliers (by using an averaging window of 300ms)
- Find the indices of local minima and maxima (force troughs and peaks), using the derivative to find the critical points and the double derivative to determine if it is a trough or a peak (see 10.3.1 for details)
- Find duration of palpations by calculating the time between minimums where the force between the minimum points are above a set threshold (see 10.3.2 for details)
- Plot data depending on parameters set (see example in Figure 23), including options of:
    - Raw data (blue)
    - Smoothed data (red)
    - Palpation duration
    - Local minima (yellow down triangle)
    - Local maxima (aqua up triangle)
    - Duration of single palpations (distance between black crosses)
    - Axes and labels
- Where data were separated into "light" and "deep" sections or a task (i.e. Part 2 sequence or Part 3 repeats), this was done manually by observation of the data and comparison with the video recording to identify different sections.

[11] Coded by Lynne Langman using functions from the MATLAB library and original coded functions.

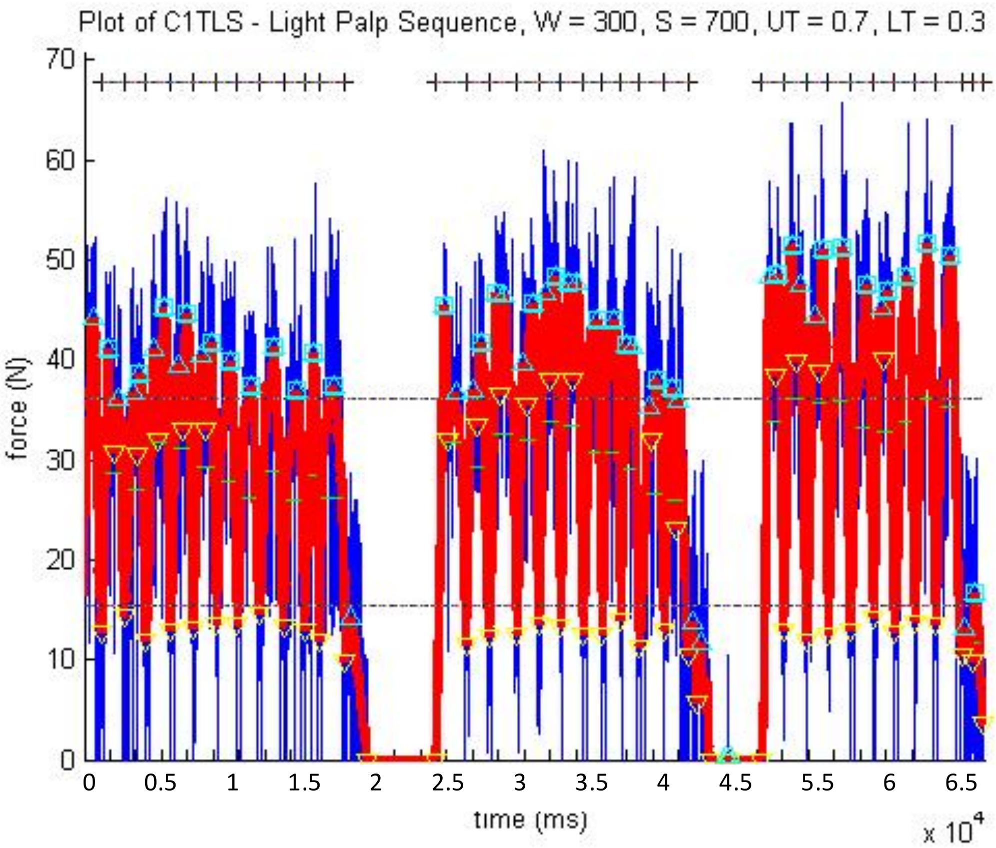
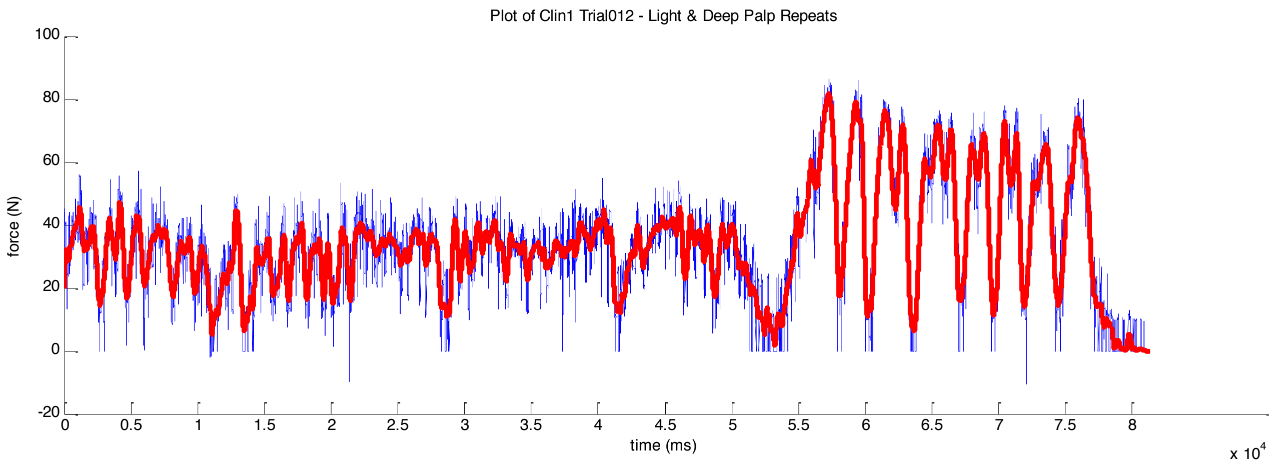
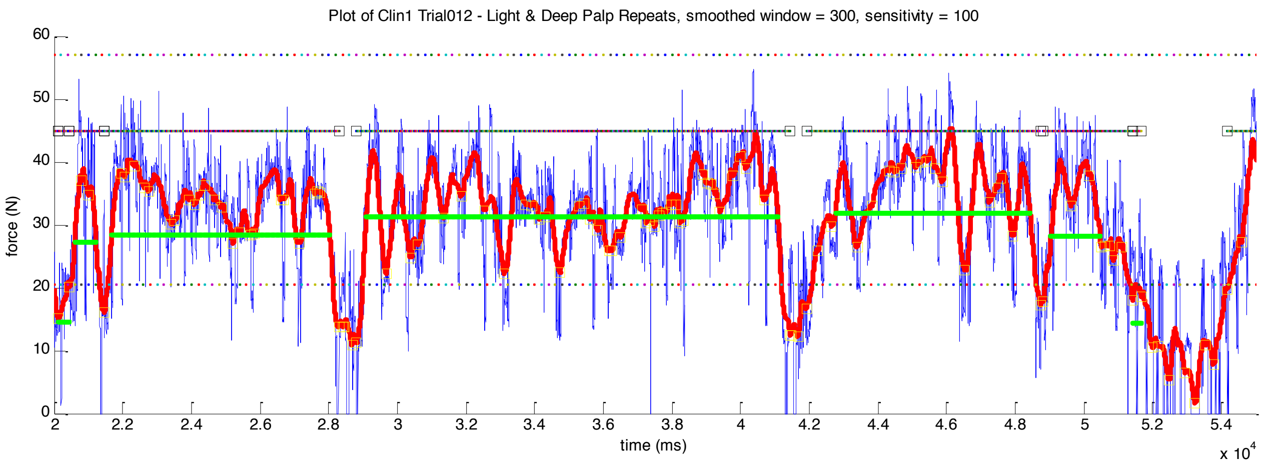


Figure 23. Total Force (N), Clin1-Part2 Light Palpation Sequence repeated 3 times, W = window, UT = upper threshold, LT = lower threshold

Figure 24 shows an example of the Part 3 dataset for Clin1, where peaks represent presses or palpations by application of force to the subject's abdomen by the clinician.

The top graph, displays the raw data (blue) overlayed by the processed smoothed data (red) with light palpation repeats from the beginning and deep palpation repeats from about the 5.4×10^4 ms timepoint to the end. The middle graph pictures the "light palpation" section of the data and shows in green the duration of each of the clusters of the repeated light palpations. The bottom graph shows the "deep palpation" section of the examination.





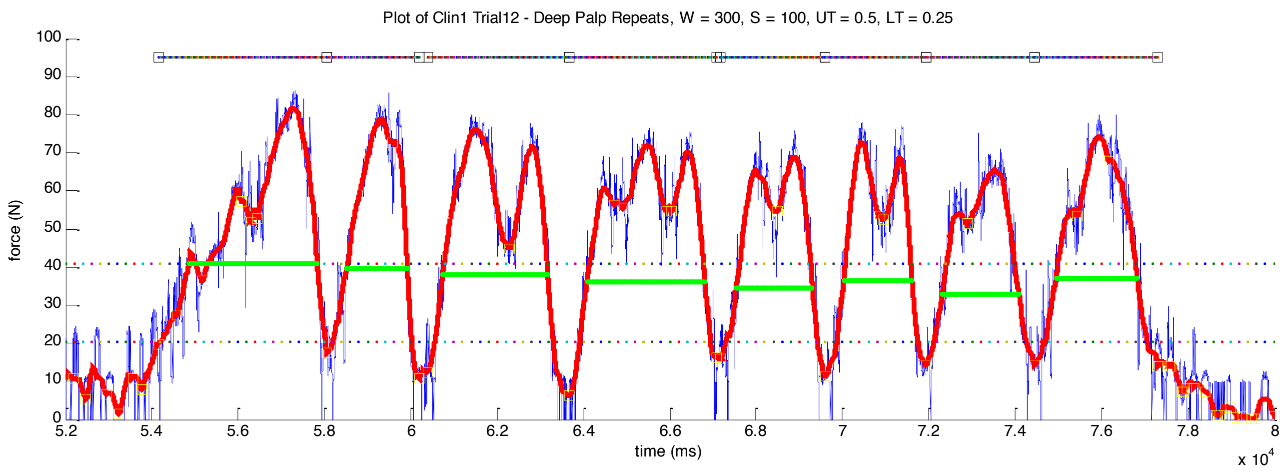


Figure 24. Total Force Clin1-Part3, Top: Light and Deep Palpation Repeats, Middle: Light Palpation Section of examination Bottom: Deep Palpation section of examination

5.3 Results and Discussion

5.3.1 Data Sample

20 clinicians and one subject were approached, resulting in recruitment of a total of 7 clinician volunteers and one healthy male palpation subject for this investigation, however only 5 clinicians attended as arranged. Five clinicians attended and participated, four male and one female, all had 25 years of experience or more and had done their medical school training at an Australian University. The summarised demographic data for the participants is presented in Table 2.

Table 2. HHDCP preliminary investigation Clinician participant demographics

ID	Gender	Position	Specialty Field	Medical School Attended	Years Since Graduation	Height (cm)	Weight (kg)
Clin1	Male	Consultant Specialist	Rehabilitation	Adelaide University	30	170.2	77.6
Clin2	Male	Consultant	General Medicine (Geriatrics)	Adelaide University	39	180	92
Clin3	Male	Consultant	Endocrinology	Adelaide University	25	180	76
Clin4	Male	<information not provided>	Rheumatology	UNSW, Adelaide University, Flinders University SA	37	179	80
Clin5	Female	Consultant Physician	General Medicine/ Immunology	Melbourne University	37	170	69

The recruited subject was a 31-year-old male, with no known pathologies and a body mass index (BMI) of 23.5 (healthy weight range), on whom abdominal palpations by all five clinicians were performed.

The data sample is limited as this was an exploratory investigation and recruitment of clinicians was limited due to the location of the laboratory and corruption of some datasets and restricted access to analysis tools for proprietary software system. Only one female clinician participated and unfortunately the “Part 3” data from her session were corrupted and had to be removed from the analysis.

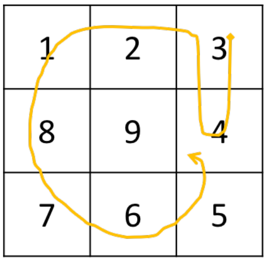
5.3.2 Part 1: Palpation examination as per clinician's usual technique

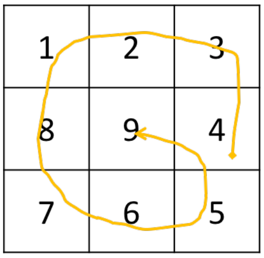
Clinicians were first asked to perform an abdominal palpation examination as per their usual method so that their natural sequence and format could be examined.

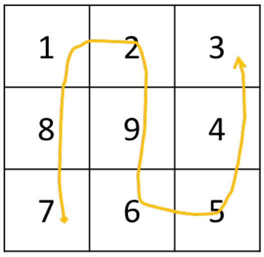
Observations of technique in Table 3 showed that all examiners had a reasonably systematic approach to the examination to cover the whole area of the abdomen.

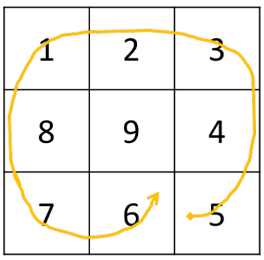
Table 3. Part 1 observations of Clinicians natural sequence on video recording

Clinician ID	**Clinician Normal Sequence observations**
Clin1	Starts clockwise from Region 3, then anti-clockwise: 3-4-3-2-1-8-7-5-4
Clin2	Starts at Region 4, palpates anticlockwise to 4 (4-3-2-1-8-7-6-5-9), then (not in diagram) performed a few checks, then spleen, liver, right kidney, left kidney
Clin3	Starts in Region 5 then palpates 7-8-1-2-9-6-3-4-3 with light palpation, deep palpation, then percusses liver
Clin4	Data error
Clin5	Light palpation - Starts in Region 5 goes anticlockwise Deep palpation - Starts in Region 4/5 anticlockwise uses two hands until region 1 then returns to one hand (note doesn't palpate Region 9)









5.3.3 Part 2: Palpation examination according to specified sequence

The clinicians were asked to palpate the abdomen systematically in an anti-clockwise direction as per the specified palpation sequence in Figure 25. This was specified to standardise the sequence and ensure the clinicians covered all nine-regions of the abdomen in their examination. It was also to minimise variations and facilitate comparison of similar datasets to explore the inter-clinician variability later.

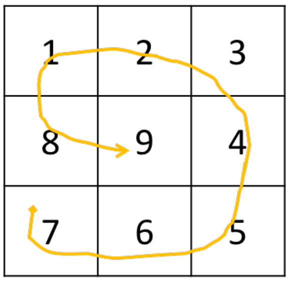


Figure 25. Specified sequence of palpation, set order = 7-6-5-4-3-2-1-8-9

In general, the clinicians palpated as per the specified sequence (see Table 49 and Table 50 in Appendix A 10.4) sufficiently for comparison in this section.

Table 4 shows the results of the mean light palpation and mean deep palpation forces in the specified sequence, pictured graphically in Figure 26. Clin1 applied more pressure during deep palpation compared to the other clinicians and Clin4 and Clin5 had a much softer touch for light palpation. Overall the mean deep palpation force in sequence was 1.46 times greater than the light palpation force. This mean deep palpation force was influenced by Clin1's mean deep force and its variability (standard deviation), while Clin4 influenced the mean light palpation force.

Table 4. Comparison of light and deep forces in specified sequence

	Light Sequence Mean Force		Deep Sequence Mean Force	
Clinician ID	**F (N)**	**Std. Dev**	**F (N)**	**Std. Dev**
Clin1	37.96	5.91	75.58	8.94
Clin2	39.41	5.49	41.80	5.45
Clin3	36.25	7.50	37.25	4.74
Clin4	14.10	4.35	35.33	7.00
Clin5	21.50	4.62	27.59	5.46
Overall Mean	**29.84**	**11.36**	**43.51**	**18.65**

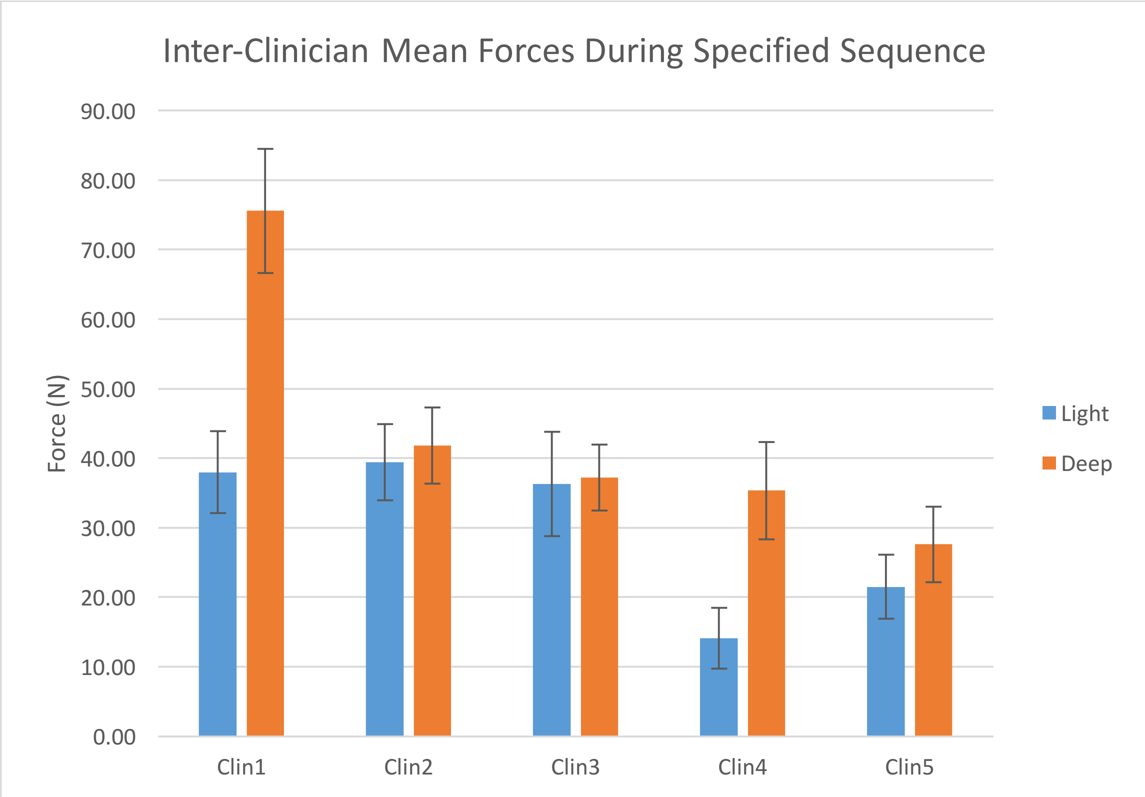


Figure 26. Mean Light and Deep Forces during specified sequence

Figure 27 shows the intra-clinician picture of the light and deep forces (see Table 49 in Appendix A for full list of values) within the routine specified sequence, and the two-tailed independent t-test significance values for each clinician. Each clinician was quite consistent within themselves for both "light" and "deep" palpation, however there was larger variation between clinicians. It is interesting to note that the intra-clinician magnitude of light and deep applied forces are similar for Clin2 and Clin3 and the two-tailed p-value of the independent t-test comparing light and deep mean palpation forces in sequence were not significant for Clin2 (p=0.3374) and Clin3 (p=0.7067). The difference for the same t-test for Clin1 (p<0.0001) and Clin4 (p=0.0030) were significant as there are marked differences between light and deep forces within themselves, while Clin5 (p=0.0134) has a more moderate difference between light and deep forces in comparison. This range of significance values between light and deep palpation for each Clinician highlights the difficulty the investigator experienced in trying to determine "typical" forces for light and deep palpation. While there were similarities in the Australian Medical Education background of these participants, that appeared to influence their methodical approach to sequence, there was wide variation in their interpretations of light and deep palpation forces. The range of mean light forces in sequence was 12.75-41.29N and range of mean deep palpation forces was 26.22-74.79N.

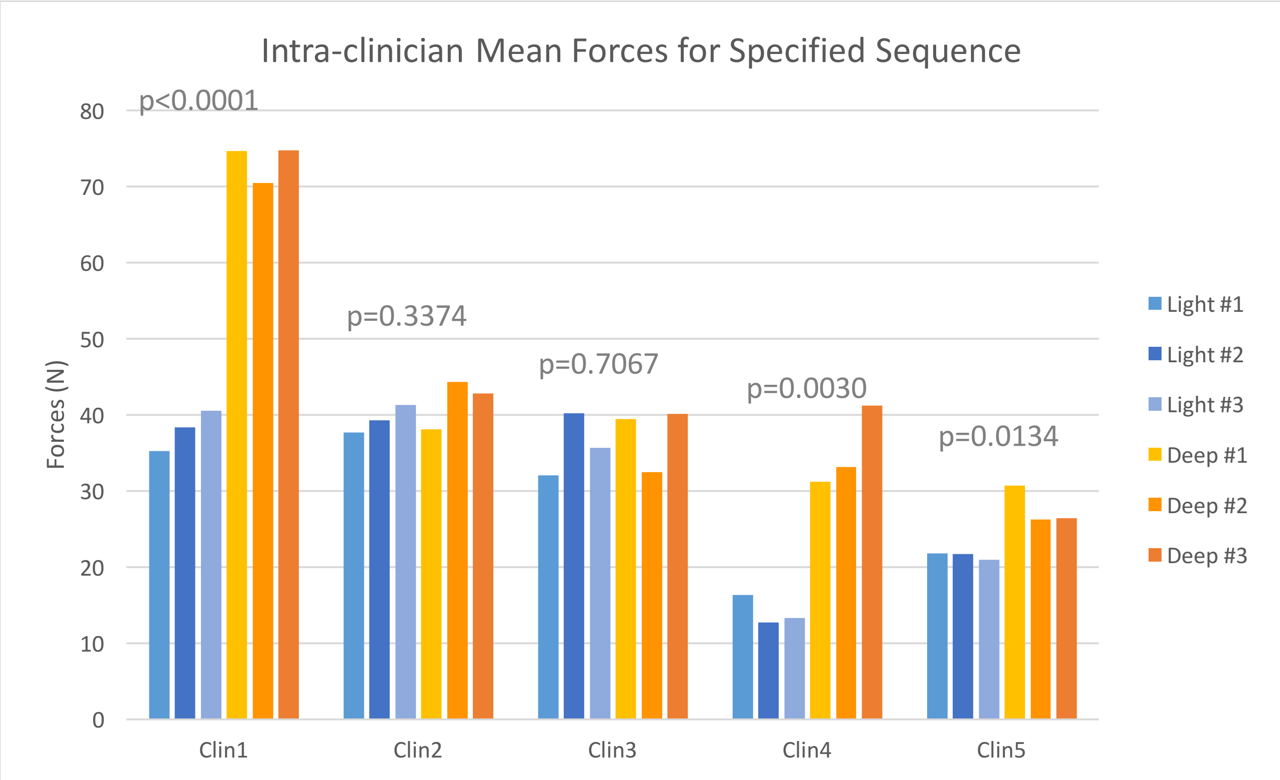


Figure 27. Intra-examiner and inter-examiner forces for specified sequence of forces

Table 5 shows a comparison of the mean duration of the specified sequence for both light and deep palpation, pictured graphically as in Figure 28. Overall the average deep sequence duration was 1.3 times the total duration of the light palpation sequence. Only Clin2's deep palpation was observably shorter than their light palpation.

Table 5. Comparison of durations for light and deep full sequences

	Light Sequence Mean Duration		Deep Sequence Mean Duration	
Clinician ID	**t (s)**	**Std. Dev**	**t (s)**	**Std. Dev**
Clin1	18.18	1.73	28.29	3.38
Clin2	26.57	0.82	23.32	1.95
Clin3	21.77	5.19	25.90	2.19
Clin4	14.65	0.78	26.63	1.79
Clin5	16.14	2.12	21.01	0.99
Overall Mean	**19.46**	**4.79**	**25.03**	**2.87**

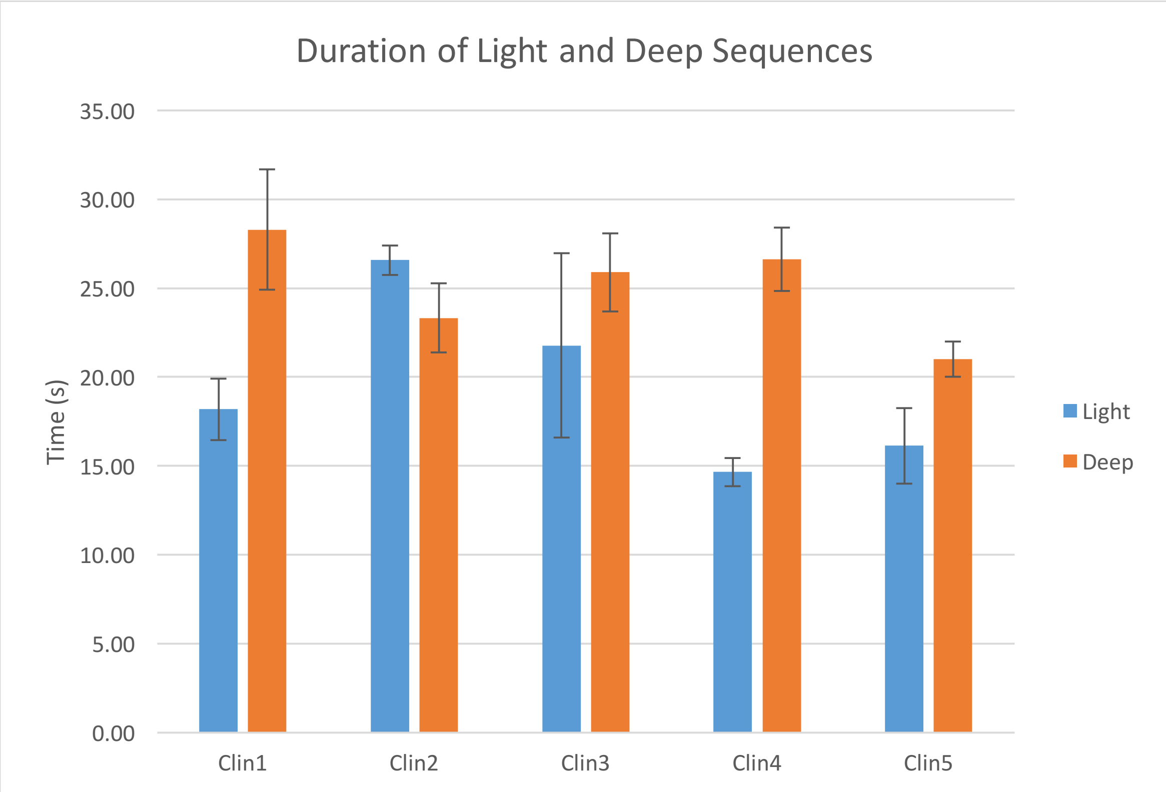


Figure 28. Total duration of Light and Deep Sequences

Table 6 shows a comparison of the mean durations for a single palpation press for both light and deep palpation during the specified sequence (see Figure 29). For a single press, a deep palpation press is 1.53 times longer than a light palpation press.

Table 6. Comparison of Individual Palpation durations in Light and Deep Sequence

	Light Sequence Mean Single Palpation Duration		Deep Sequence Mean Single Palpation Duration	
Clinician ID	**t (s)**	**Std. Dev**	**t (s)**	**Std. Dev**
Clin1	1.70	0.28	3.03	1.44
Clin2	1.66	0.65	1.84	0.44
Clin3	2.42	0.83	2.99	0.46
Clin4	1.19	0.39	2.75	0.42
Clin5	1.42	0.97	2.25	1.10
Overall Mean	**1.68**	**0.46**	**2.57**	**0.51**

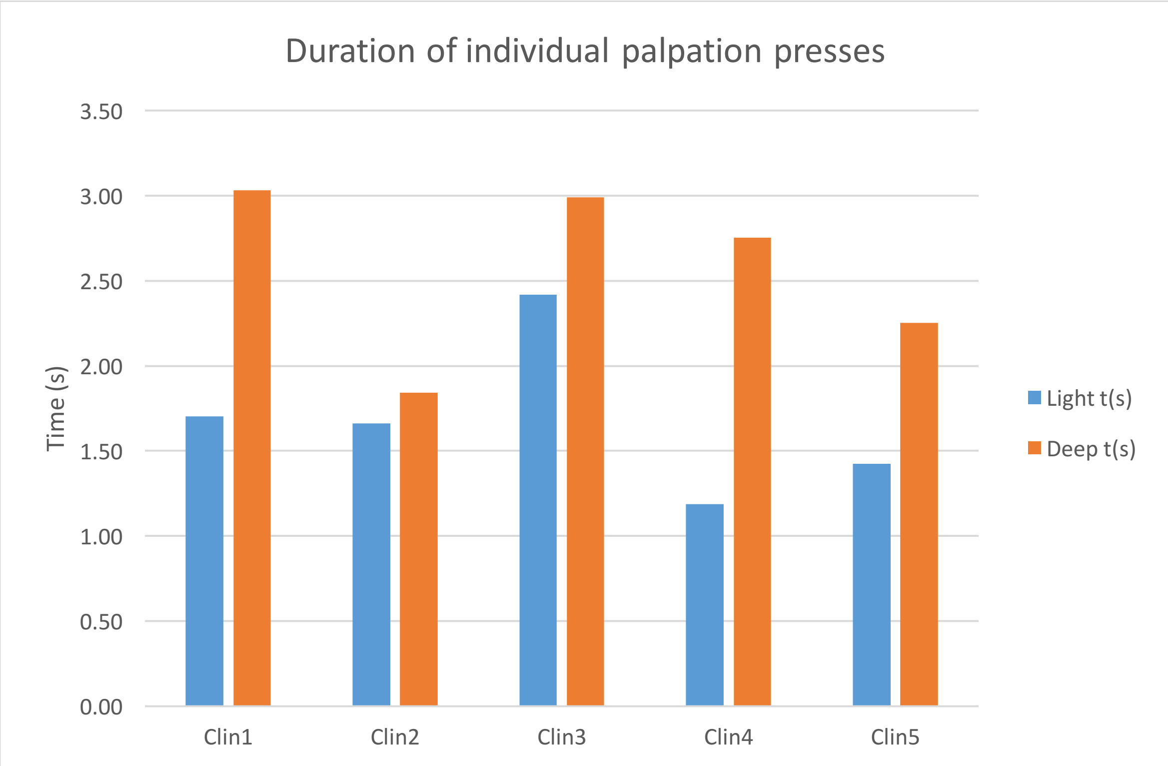


Figure 29. Durations of Individual palpation presses within the specified sequence

To summarise, for the standardised sequence:

- Mean Light Palpation Force for all clinicians = 29.8 ± 11.4 N
- Mean Deep Palpation Force for all clinicians = 43.5 ± 18.7 N
- Overall, Deep Palpation is a factor of 1.46 times greater than light
- Mean total duration for the light sequence for all clinicians = 19.5 ± 4.8s, with 1.68 ± 0.46s for a single palpation press
- Mean total duration for the deep sequence for all clinicians = 25.0 ± 2.9s, with 2.57 ± 0.51s for a single deep palpation press
- Deep palpation takes 1.28 times longer than light palpation for the whole sequence, taking more time on individual palpations with a single deep palpation 1.53 times longer than a lighter palpation.

So, for deep palpation (versus light palpation) a greater force is applied, but over a larger duration of time.

5.3.4 Part 3: Light and deep palpation repeats in specified region

In this section of the investigation, the participants were asked to palpate the abdomen with a "light" palpation in one region and to repeat this three times, then to palpate with a "deep" palpation in the same region repeating this task three times also. Figure 30 shows an example of the data for "light" and "deep" palpation repeats from Clin2. The data were manually sectioned to separate the light and deep palpation portions of the data.

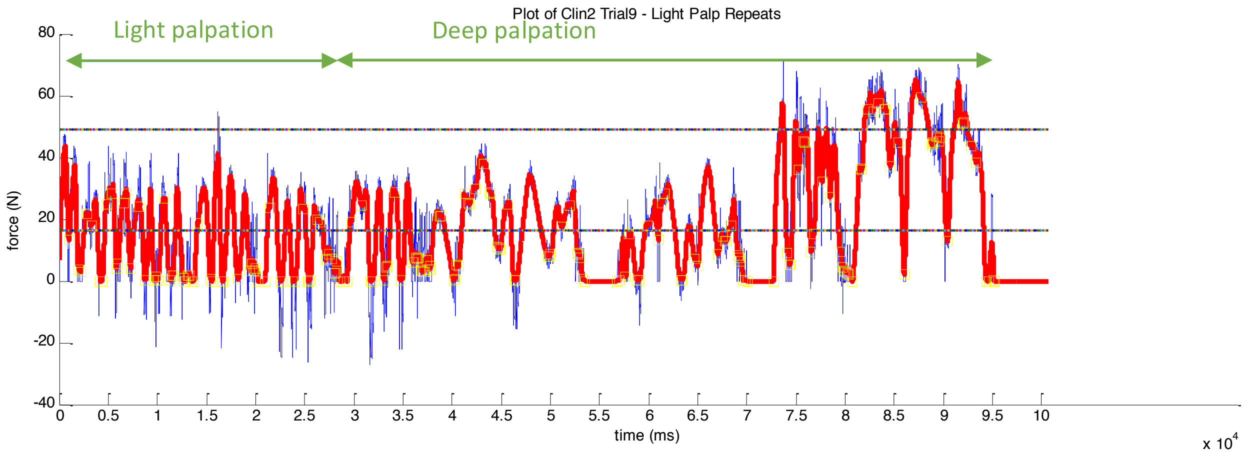


Figure 30. Clin2 Light and Deep Palpation repeats

Figure 31 shows the "light" palpation repeats for Clin1, Clin2, Clin3, Clin4 (the data from Clin5 were corrupted) and the different techniques used by the clinicians in application of force. In general, it was observed that "light" palpation was done in "clusters" (indicated in green on Figure 31), with examiners applying force and then removing it in groups (see Clin1, Clin3, Clin4). The application of force was completely removed (to 0N) between "clusters" by Clin3, while two of the participants (Clin1, Clin4) maintained a baseline applied force for the whole of the light palpation and only fully removed the force at completion. The technique of Clin2 was different to the other participants, whereby he applied force and released it with larger breaks between application of force. Examiners showed marked differences in their techniques, evidenced in the graphs.

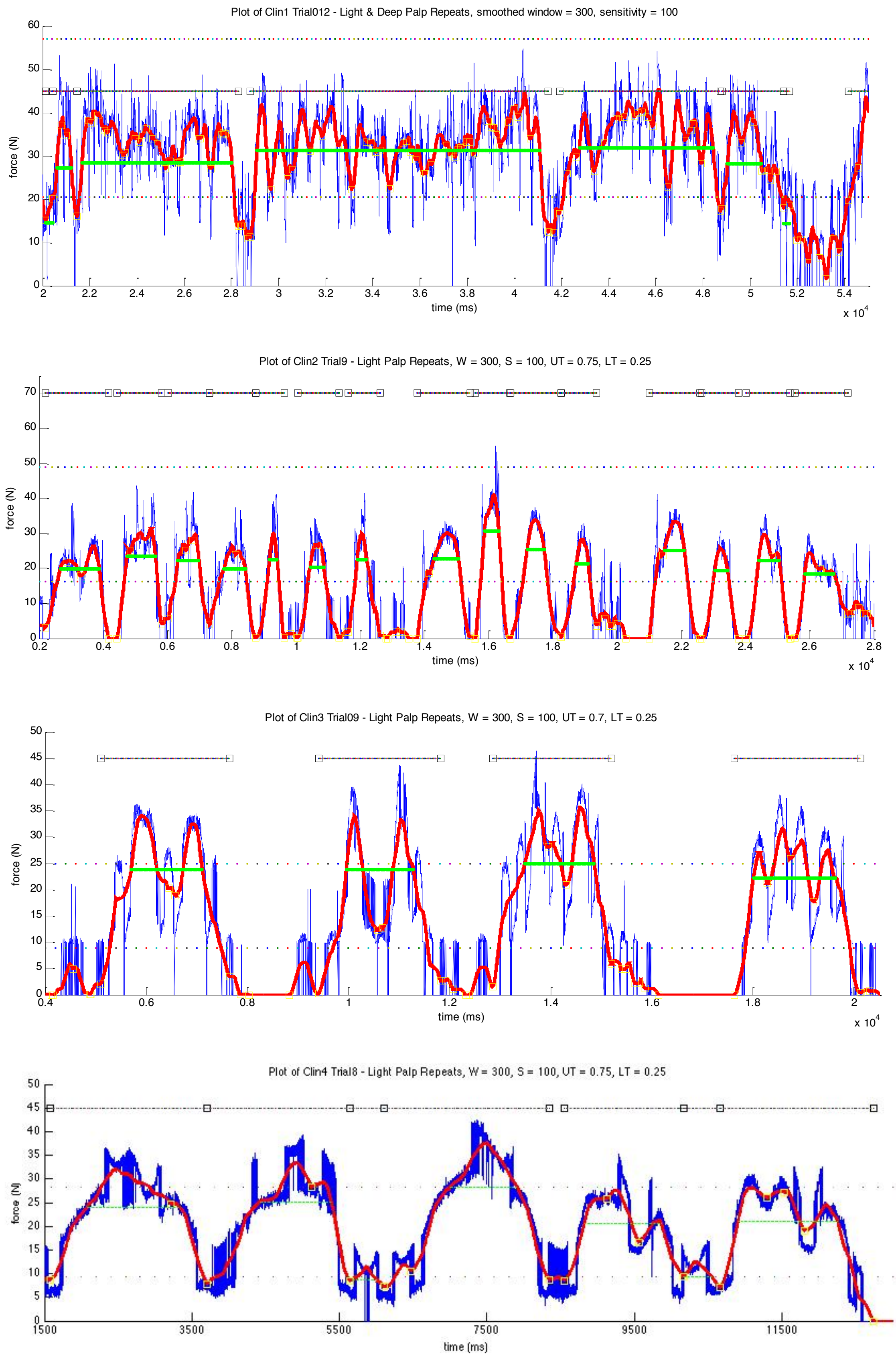


Figure 31. Clin1, Clin2, Clin3, Clin4 Light Palpation Repeats

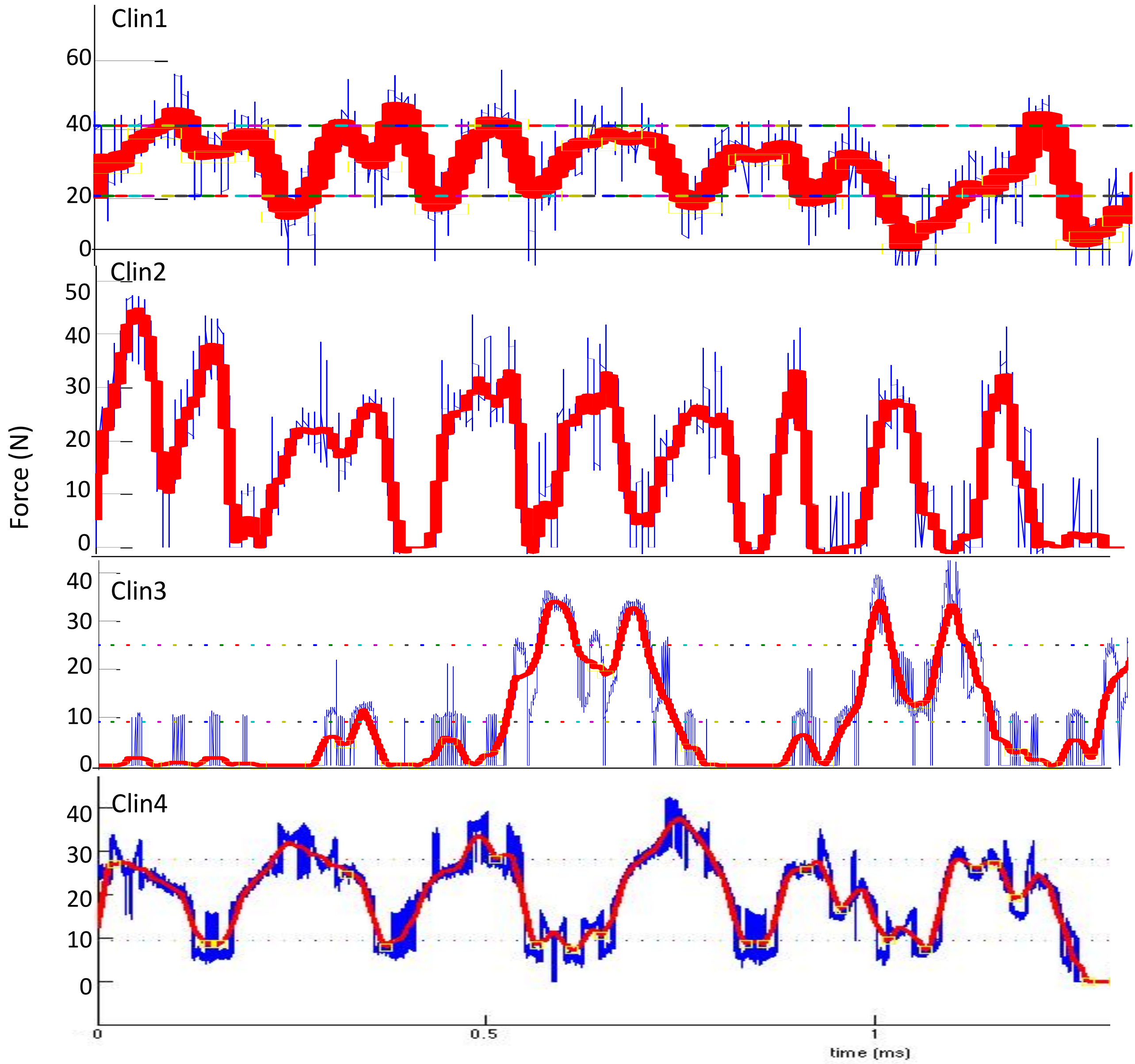


Figure 32. Clin1, Clin2, Clin3, Clin4 Light Palpations with the same timebase highlights the different patterns/techniques

Figure 32 illustrates the force profile of the "light" palpation repeats with time normalised, to highlight the different techniques in application of force by each clinician and the differing patterns and shapes of the force waveforms.

Figure 33 shows deep palpation repeats for Clinicians 1-4. Observations from Figure 33, in comparison with Figure 31, shows that the duration of the “deep” palpation presses were significantly longer than for light palpation, which correlates with data in Table 6. Instead of palpating in “clusters” where force was generally released, clinicians kept a strong consistent force applied and “bounced/oscillated” in their application of deeper force while maintaining a larger retained force. Overall the pattern for deep palpation was more similar between clinicians than for light palpation, while the examiners still had their own nuances and differences in overall techniques.

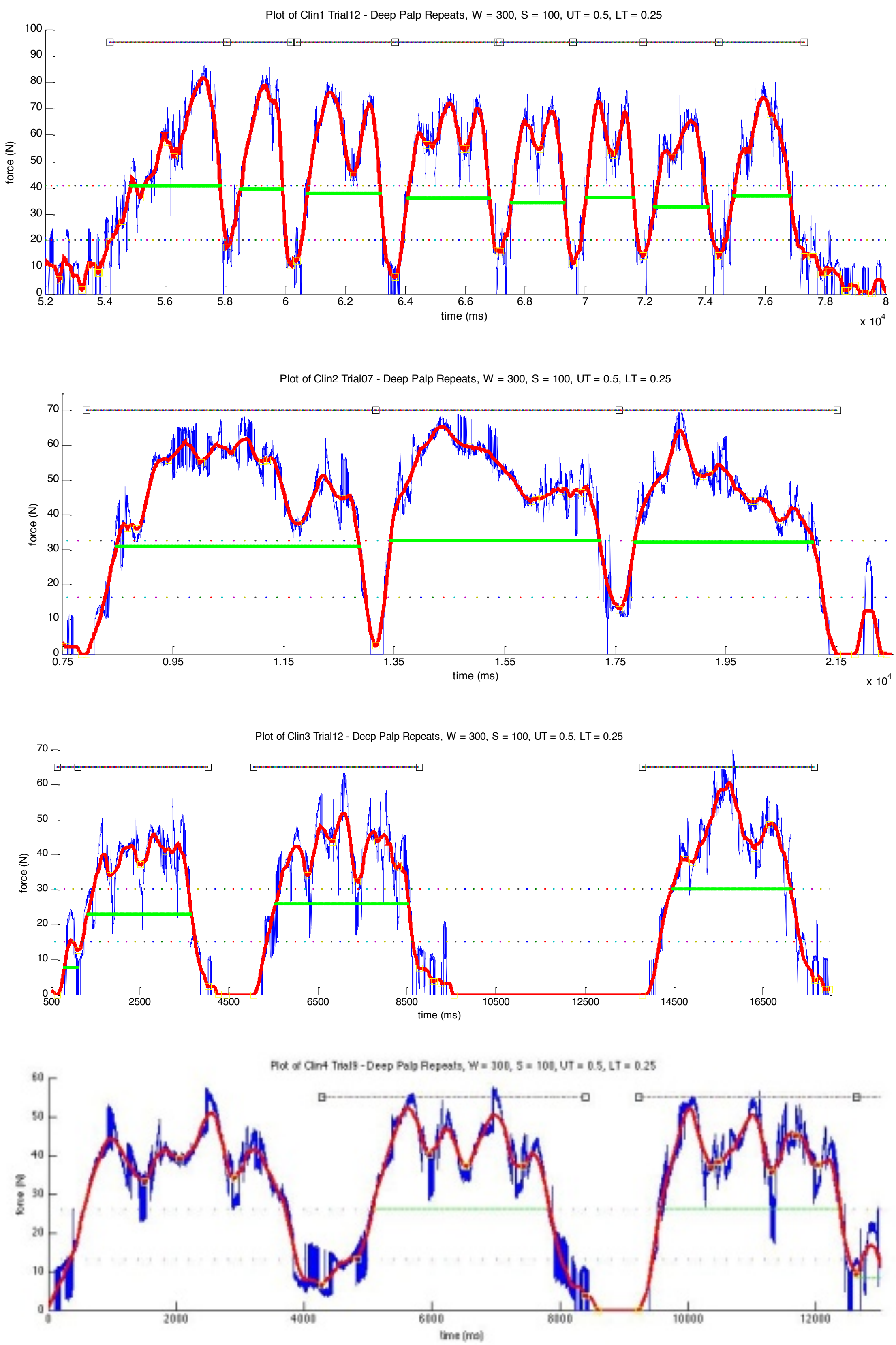


Figure 33. Clin1, Clin2, Clin3, Clin4 Deep Palpation Repeats

Table 7 details the summarised mean force data for light and deep palpation repeats in a single region. In this scenario, when palpating in the same region, the difference between the light and deep forces is more uniform across the clinicians (see Figure 34) with the mean light palpation force 28.28 $\pm$ 4.41N and the mean deep palpation force 45.31 $\pm$ 10.86N. In this task, the mean deep palpation force was a factor of 1.60 times greater than the mean light palpation force. The two-tailed p-value of the independent t-test was extremely significant for Clinicians 1, 2 and 3 and not statistically significant for Clinician 4.

Table 7. Mean Palpation Force for repeated palpation in a single region

	Mean Force (N)				**T-test**
Clinician ID	**Light**	**Std. Dev**	**Deep**	**Std. Dev**	**p value**
Clin1	34.86	3.97	59.45	3.37	< 0.0001
Clin2	26.63	3.48	46.57	5.16	< 0.0001
Clin3	25.98	7.51	41.69	3.66	0.0010
Clin4	25.64	7.86	33.52	14.82	0.1488
Clin5	-	-	-		
Overall Mean	**28.28**	**4.41**	**45.31**	**10.86**	

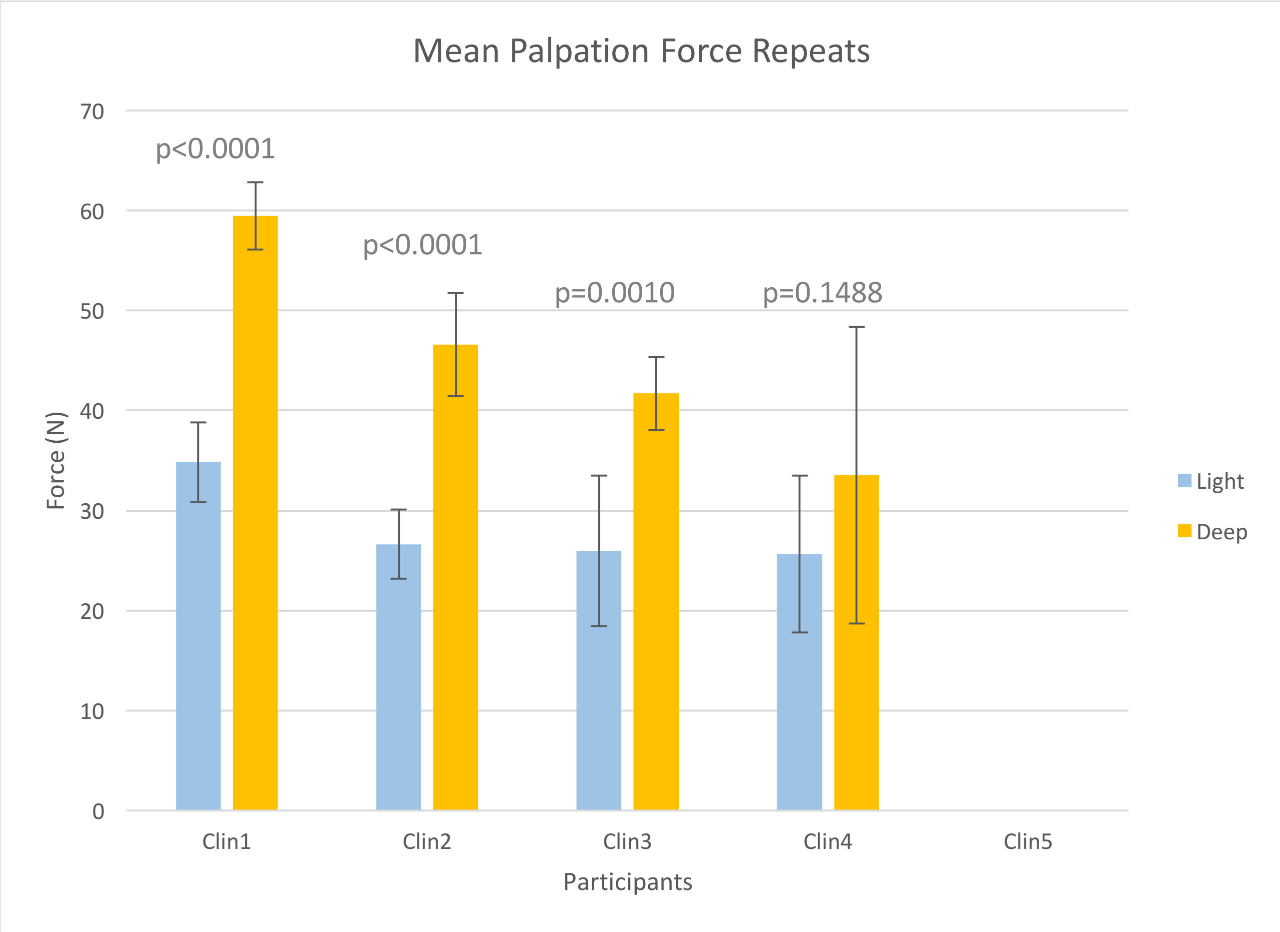


Figure 34. Mean Palpation forces for repeated palpation in a single region

Figure 35 shows the comparison of light and deep palpation forces, in sequence and repeated in the same region. The distinction between light and deep palpation for all clinicians for Part 3 was extremely significant for Clin1, Clin2 and Clin3 when light and deep palpation was repeated in the same region one after the other. However, in Part 2 where clinicians palpated with light and deep palpation in sequence, Clin2 and Clin3 had no statistical significance between light and deep forces. This suggests that their perception of light and deep palpation was different when focused on it with a repetitive action (Part 3), compared to when they palpated in sequence (Part 2) and were probably concerned more with the sequence.

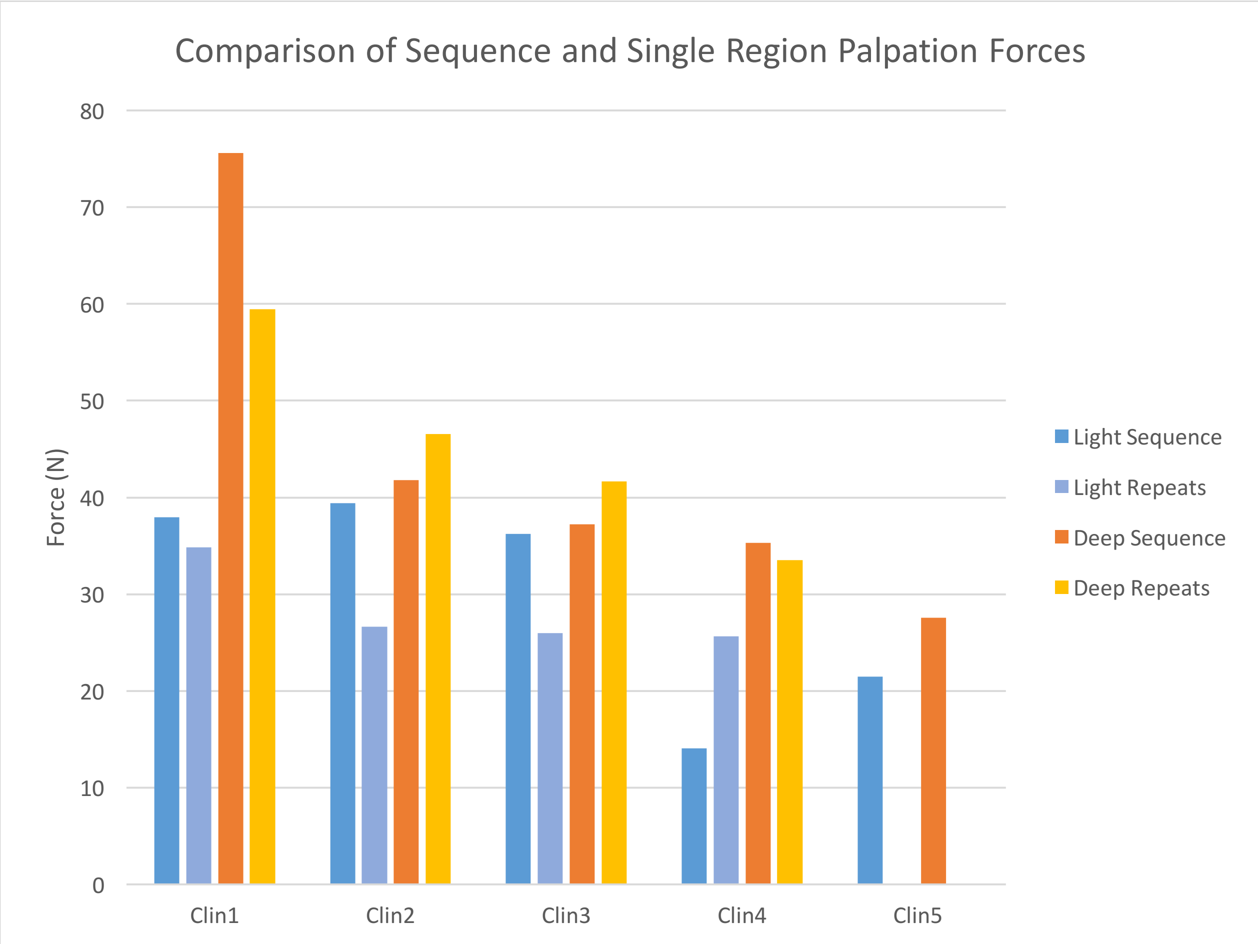


Figure 35. Comparison of Light and Deep Forces both in sequence and repeated in one region

Table 8 shows a comparison of the mean durations of repeated light and deep palpation in a single region. Figure 36 shows clearly that the duration of the deep palpation presses are longer than light palpation presses. Overall the average deep palpation duration was 2.67 times the total duration of the light palpation duration for single presses in the same region.

Table 8. Mean duration of light and deep palpation repeats

	Mean Duration (s)			
Clinician ID	**Light**	**Std. Dev**	**Deep**	**Std. Dev**
Clin1	1.15	0.06	3.01	0.76
Clin2	1.47	0.36	3.96	1.17
Clin3	1.37	0.37	4.29	0.43
Clin4	1.44	0.64	3.24	1.58
Clin5	-	-	-	-
Average	**1.36**	**0.14**	**3.63**	**0.60**

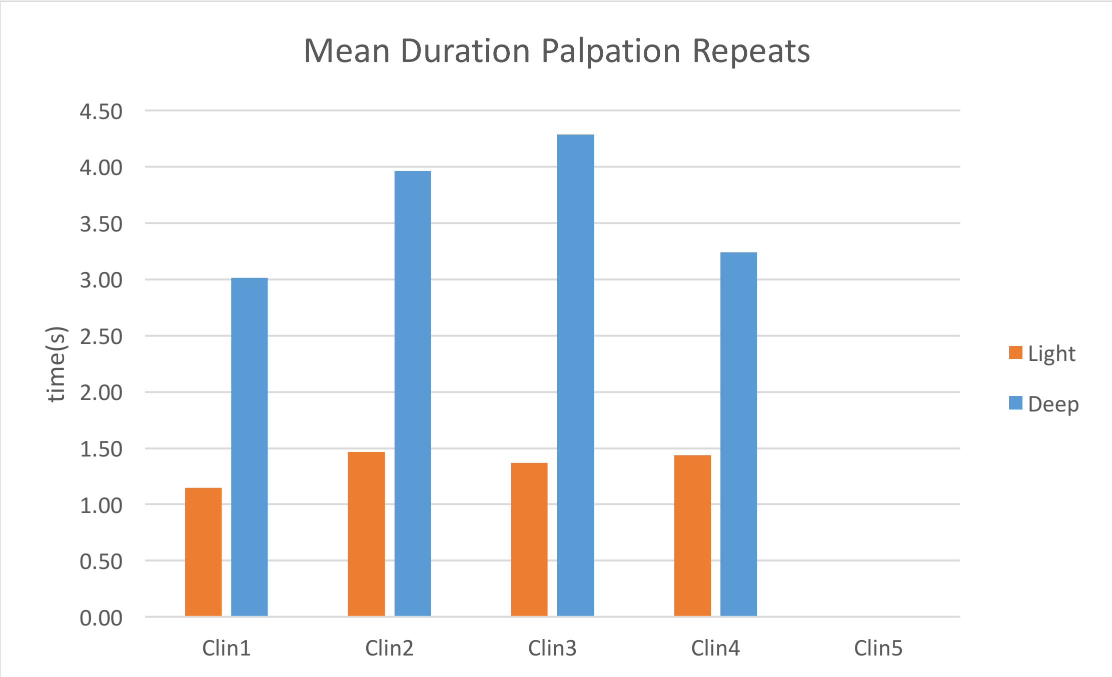


Figure 36. Mean duration of Light and Deep Palpation repeats

To summarise, for force applied repeatedly in the same region:

- Mean Light Palpation Force for all clinicians = 28.28 $\pm$ 4.41N
- Mean Deep Palpation Force for all clinicians = 45.31 $\pm$ 10.86N
- Overall, Deep Palpation is a factor of ~1.5 times greater than light

- Mean Duration of Light Palpation press for all clinicians = 1.36 $\pm$ 0.14s
- Mean Duration of Deep Palpation press for all clinicians = 3.63 $\pm$ 0.60s
- Overall, duration of Deep Palpation is a factor of 2.67 times greater than for light palpation.

The comparison of patterns in technique of clinicians for light and deep palpation repeats show the use of observed "clusters" for light palpation, and a maintained force with bounces/oscillations for deep palpation. It is more difficult to compare the duration of the light and deep palpation repeats due to these different techniques observed for each. However, observation of the light and deep palpation repeats in series (such as Figure 30) show that for deep palpation a greater force is applied over a larger amount of time.

5.3.5 Clinician Feedback

Clinician feedback was less revealing than anticipated (as in Table 51, Appendix A 10.7).

Answers to the question: “Part 1a) Do you initially examine a patient's abdomen the same way every time? Why/Why not?” were generally yes (Clin1-4 “Yes”, Clin5 “Generally, but not necessarily”). Where the answer was not yes, the caveat was that they are always methodical to cover the 9 zones.

The question: “Part 2b) If this was not the sequence you normally use to examine the abdomen: Do you think it was more/less effective?” had minimal responses, as the sequence set was an anticlockwise sequential method to cover all nine regions, which was similar to the methods used by the participants.

The questions for Part 3: “Part 3a) Do you think you were consistent in the amount of force applied? Part 3b) In a clinical setting do you think you are consistent?” revealed they all thought they were consistent on the day, and in clinical settings they believed they were consistent for screening patients with no abnormalities, but with variations due to patient conditions, symptoms, etc.

These self-assessments by the clinicians were consistent with the intra-clinician data in Figure 27 and Table 49 (Appendix A.10.4) where there was observed consistency within individual examiners for light and deep forces.

5.4 Conclusion

Five clinicians participated in a preliminary investigation to determine “How Hard Do Clinician’s Press?”. The sequence of a clinician’s natural technique was observed, comparing light and deep palpation forces and duration of an examination using a specified standardised sequence, and reviewing light and deep palpation repeated actions. The clinicians’ natural techniques were all observed to be systematic, but they used different sequences.

For the standardised sequence, the mean light palpation force was 29.8 $\pm$ 11.4 N, and the mean deep palpation force was 43.5 $\pm$ 18.7 N, 1.5 times greater than light palpation. While individual clinicians were consistent, there was more variation between clinicians and 2 out of 5 clinicians had only small variation between light and deep forces.

The mean duration of the light palpation sequence was 19.5 $\pm$ 4.8s, and 25.0 $\pm$ 2.9s for the deep palpation sequence, whereby deep palpation takes 1.3 times longer than light palpation for the whole sequence.

In a single region, the mean force for light palpation repeats was 28.3 $\pm$ 4.4N, and mean deep palpation force repeats was 45.3 $\pm$ 10.9N, 1.6 times greater than light palpation. The comparison of patterns in technique of clinicians for light and deep palpation repeats reveal the use of observed “clusters” for light palpation, and a maintained force with bounces/oscillations for deep palpation.

The marked inter-clinician variation in an examination sequence, versus greater consistency between them when focussing on palpation in a single region, emphasises the need for an educational device such as a simulator to train medical professionals in consistency of applied forces and touch. The results of the investigation provided sufficient data to determine the specification for the range of forces the simulator needed to be able to receive and measure. They also provided interesting observations of clinician technique and variability.

Based on the maximum forces recorded, the minimum specification force range for the simulator should be 0-75N.

CHAPTER 6. Prototype Design and Development

6.1 Introduction

The “AbSIM” prototype is an abdominal palpation training simulator. It consists of a custom-moulded model of a male torso integrated with a rigid force-sensing platform that is interfaced via Bluetooth to a laptop with custom-developed software (see Figure 37).

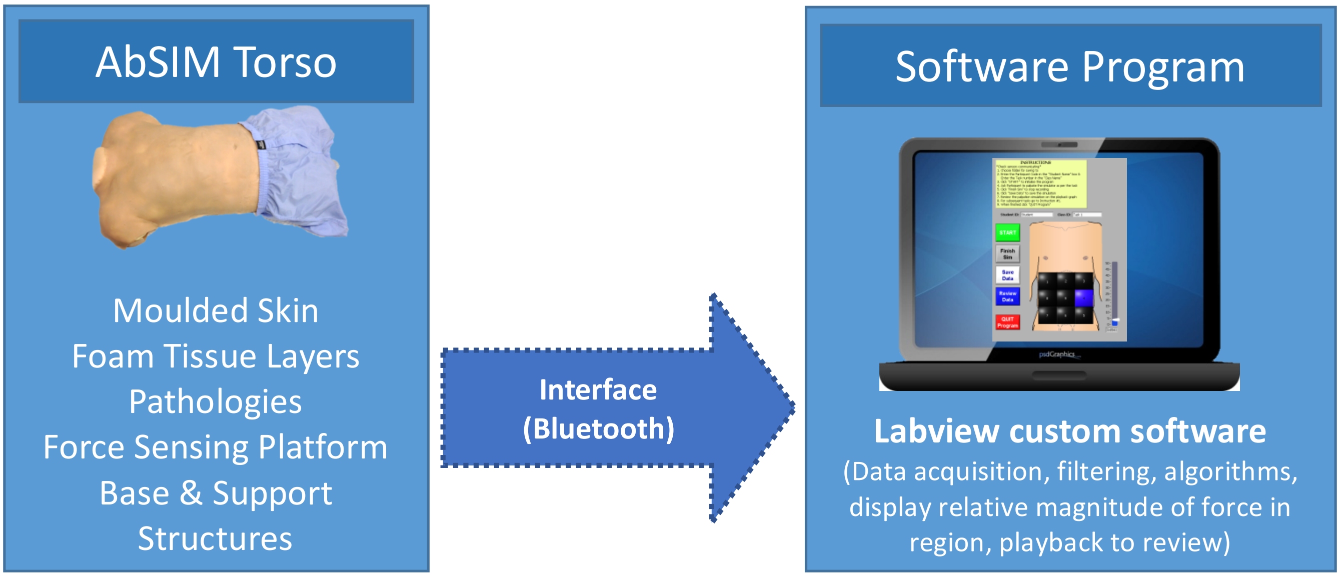


Figure 37. AbSIM system including physical abdomen model and custom software

The model was developed by creating the mould; casting foam and a silicone-rubber skin to the right shape using the mould, and cutting backing material in a silhouette of the shape for mounting the layers of foam and skin. Inside the model, mouldable fibreglass cast material was used to simulate the bony landmarks of the ribs and the pelvis. The final force sensing platform utilised was a Nintendo Wii Balance Board (Nintendo, Kyoto, Japan), and it was positioned and secured beneath the foam layers to record palpation in the nine abdominal regions. Layers of different foam and hard plastics were used to define the soft and hard tissue structures of the abdomen, and to allow for interchangeable placement of lesions and abnormalities.

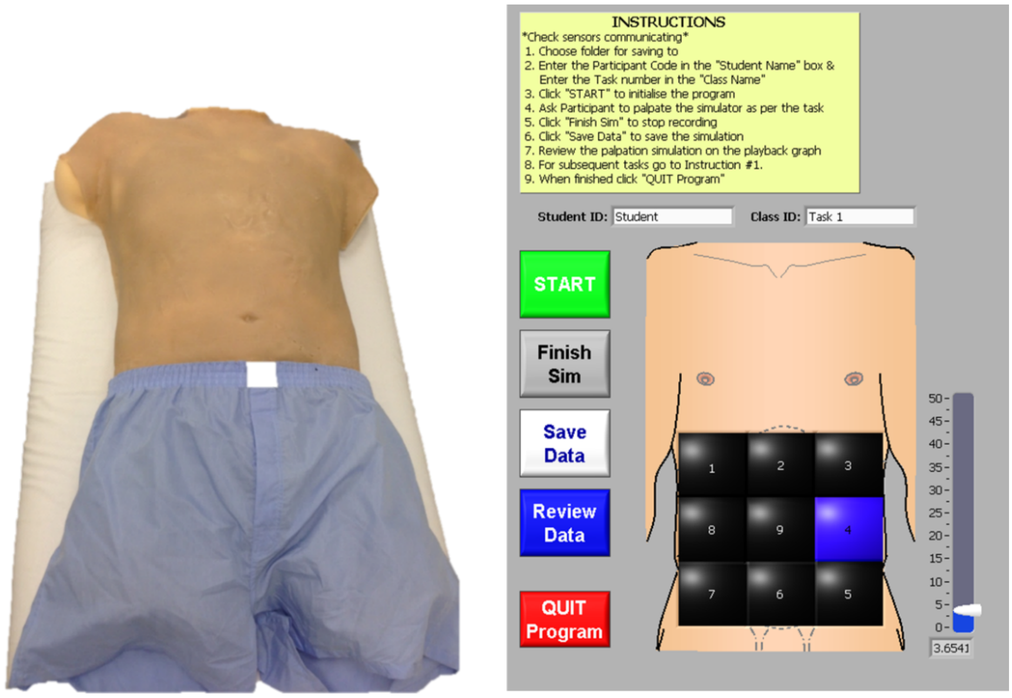


Figure 38. AbSIM Prototype and LabVIEW GUI

The custom software developed in LabVIEW (LabVIEW Professional Development System Version 8.0, National Instruments, © 2005) [148] was interfaced to the Nintendo Wii Balance Board (WBB) using Bluetooth technology. The software enables the user to enter identifiers for the student and task, and then start recording the location and magnitude of applied forces as the learner palpates the abdomen. While this is occurring, the position and force, relative to the nine abdominal regions, can be viewed on the screen (see Figure 38). Once the learner has finished the simulation scenario, data can be saved and played back (via the “Review Data” button) to observe the student’s performance.

6.2 Prototype Construction

6.2.1 Torso Development

The torso was made from a mould of an "average" male, who was selected primarily on volunteer subject availability and a willingness to participate. The foams and skins were selected to look and feel life-like. The materials used were designed for special effects applications, and are particularly resilient to repetitive motions and degradation.

6.2.1.1 Torso Moulding Process/Creating the Mould/Mould Casting

To create a realistic model of the abdomen for the simulator, a mould of an average male volunteer was made, from which skin and foam could be cast (see Appendix B 10.8.1 for materials list).

To create the mould, the following procedure was carried out [149]:

- The volunteer was prepared by wrapping plastic film around the groin area over his underwear and applying a layer of mould release agent onto the exposed skin surfaces, to ensure that body hair would not stick to the mould.
- Smooth-on Body Double® Lifecasting silicone rubber was mixed and applied methodically over the torso from the neck to upper thigh with a thickness of approximately 1cm (see Figure 39.A).
- Thin silicone tubing was placed on top of the Body Double to help give it structure and landmarks for the cast (see Figure 39.B).
- The Body Double was left to cure.
- Fibreglass casting bandages were wetted and applied over the Body Double and silicone tubing to give structure to the mould cast and to provide a support shell for shape maintenance. The mould cast was then left to dry.
- After the cast had become firm, the support shell was removed and the silicone rubber peeled back carefully (see Figure 39.B and Figure 39.C).
- The flexible silicone rubber layer was then placed back inside the support shell, to restore the body shape (see Figure 39.D).

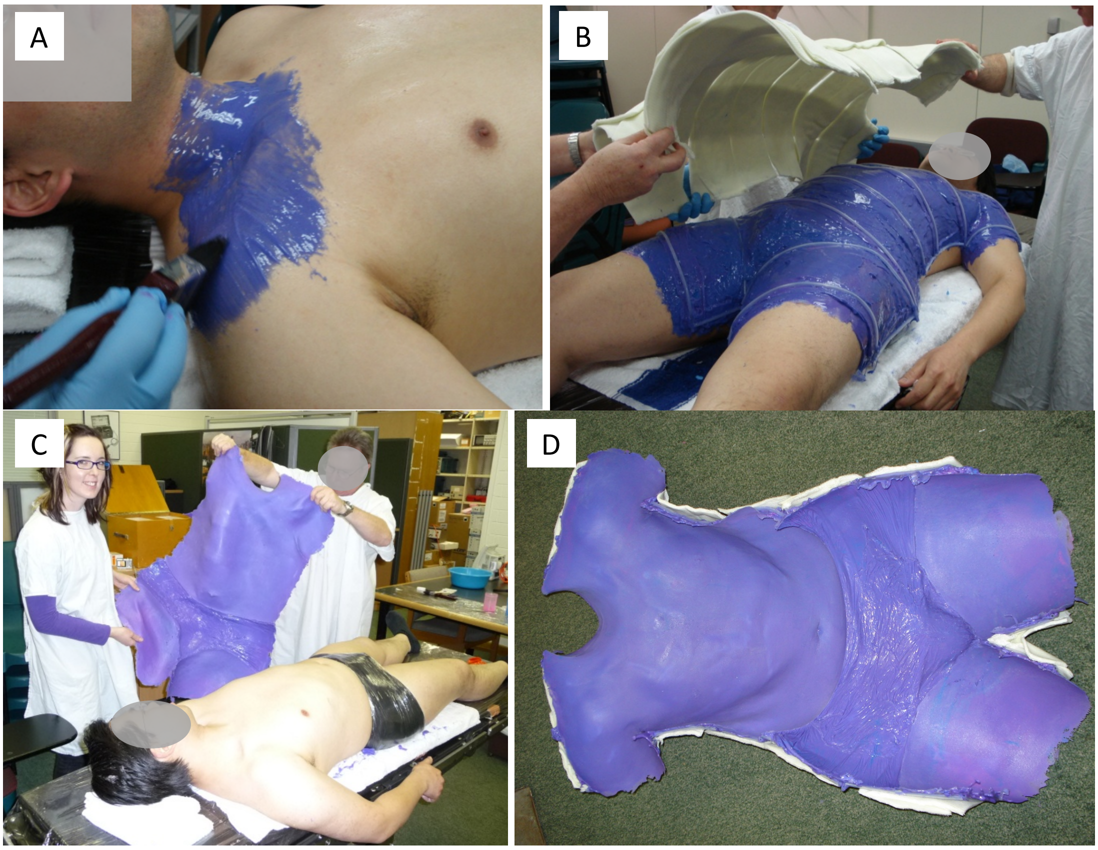


Figure 39. The moulding process: A) Applying the Body Double to the volunteer. B) Removing the supporting shell. C) Demoulding. D) The finished Body Double mould inside the support shell.

6.2.1.2 Skin Casting

Palpation is a very repetitive motion requiring a simulator skin that is flexible, that can be stretched and return to its original state, and that looks and feels like human skin. Dragon Skin® (Smooth-On, Inc. Pennsylvania, USA) platinum cure silicone rubber was cast in the mould to form the skin of the abdominal simulator. Dragon Skin® was chosen because it is very strong and stretchy and recommended for applications where repetitive motion is required. It is reported to stretch many times its original size without tearing and rebound to its original form without distortion [149] and can be tinted to any colour.

Dragon Skin® was found to be a difficult material to work with, with many problems encountered when trying to cast the skin in the mould. A Dragon Skin kit consists of two solutions, “A” and “B”. To prepare it, the two parts are added together in equal volumes and mixed until evenly combined, then it is spread over a prepared surface to make a mould cast and allowed to set/cure. It is at this point the selected die can be added to colour the overall solution. When the two solutions are mixed, it is a relatively viscous substance (with a pot life of 20 minutes), which when applied and spread over the moulded torso, did not stay in place and pooled at the bottom of the mould. As the substance had a long curing time (5 hours), when applying the mixed material, it was difficult to make the solution stay on the side walls of the mould which resulted in irregular skin thickness at room temperature. The solution used in industry is to continually rotate the mould so the rubber sets with an even thickness. This was not a viable option for the size of the model, the equipment available at the time, and as it was an open mould.

A thickener was used to reduce this problem, and minimise the mixture pooling at the bottom of the mould, however this introduced a new issue of striations. These striations were formed on the back of the skin during the process of spreading the thicker substance with a spatula, and as a result, there were still some inconsistencies in skin thickness.

Other problems encountered included a “stickiness” of the skin with some batches after they cured due to the nature of the thickener and material. Table 9 describes the problems encountered in casting the Dragon Skin and how they were mitigated.

Table 9. Problems encountered in casting the body double mould

Casting Problems	**Reason/s**	**Mitigation**	**Outcome**
Pooling of substance	Long curing time of viscous substance.	Add a thickener	Able to get mixture to “stick” to sides of mould. Some striations in mould.
Irregularities in skin thickness	Pooling of substance during curing.		
	Original mould thickness irregularities	Prepare mould as best as possible, filing/carving to make even.	Minimise affect of Body Double mould on skin casts.
Skin “stickiness”	Batch irregularities	New batch	-

However, despite these issues, a reasonable ‘skin’ was achieved for the torso. The final result is illustrated in Figure 40.

Figure 40. Dragon Skin layer produced from the Body Double mould

6.2.1.3 Foam Casting

To simulate the soft tissues of the abdomen, layers of foam with different mechanical properties were used to provide form and to represent the appropriate "feel" an abdomen has during palpation. Polyurethane open cell foams can simulate the texture and mechanical behaviour of soft tissue [150].

Three layers of foam were used (see Figure 41):

- The top layer was a flexible "thin foam" 12mm thick peeled foam, which provided a thin soft foam layer under the skin for skin surface movement.
- The middle layer simulated the rectus abdominis muscles. This layer was made using Soma Foama® 15 (Smooth-On, Inc. Pennsylvania, USA), a soft, two-component flexible platinum silicone foam [151].
- The base layer simulated the transverse abdominus and the oblique muscles, and used a polyurethane expanding foam FlexFoam-iT!® X (Smooth-On, Inc. Pennsylvania, USA), a flexible, durable foam [151].

The middle and base foam layers were cast using the Body Double mould. The Soma Foama® 15 foam was cast for the shape of the rectus muscles. Once the foam was cured, a release agent was painted on top and the FlexFoam-iT!® X layer cast on top of that (see Appendix B 10.8.2), so that the foams fitted together precisely but could be separated later.

The multiple foam layers also allowed for placement of lesions and abnormalities between them.

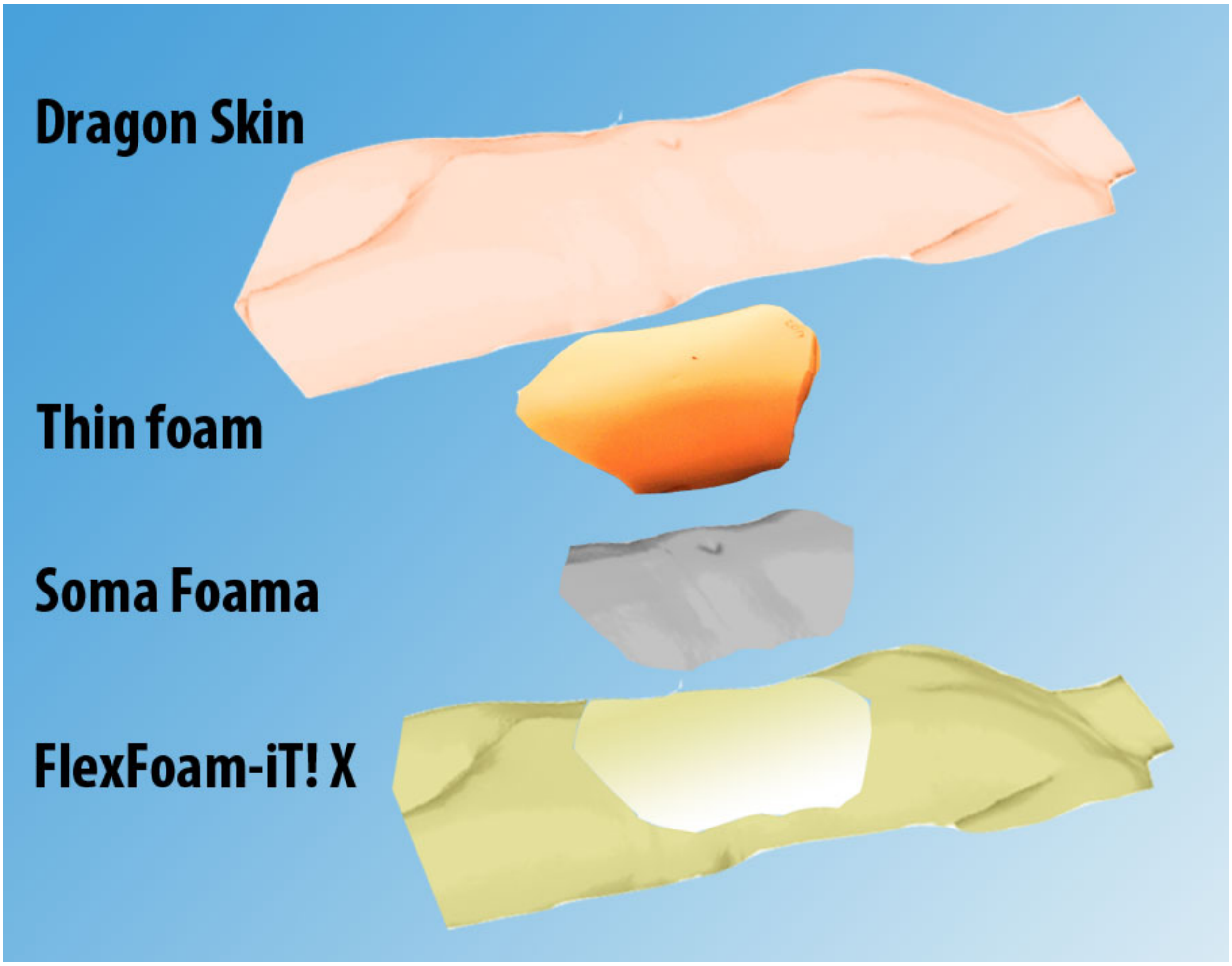


Figure 41. AbSIM layers of skin and foam to produce a realistic feel during palpation

Figure 41 shows the layers of skin and foam including: Dragon Skin silicon rubber 'skin'; Thin foam peeled foam to enable skin surface movement; Soma Foama soft silicone foam that characterises rectus abdominus muscles, and FlexFoam-iT!X polyurethane foam to represent transverse abdominus, oblique muscles and general body structure.

6.2.1.4 Anatomical Landmarks and abnormalities

In an abdominal examination, the user identifies anatomical landmarks as reference points. To create the bony landmarks of the abdomen, fibreglass cast tape [152] (used for orthopaedic casts) was moulded across the foam chest and pelvis then cut to shape, to represent the ribcage, pubic bones and the right and left iliac fossa (see Figure 42).

Foams of various densities and hardness were cut to assorted sizes and shapes to simulate types of lesions, and other abnormalities.

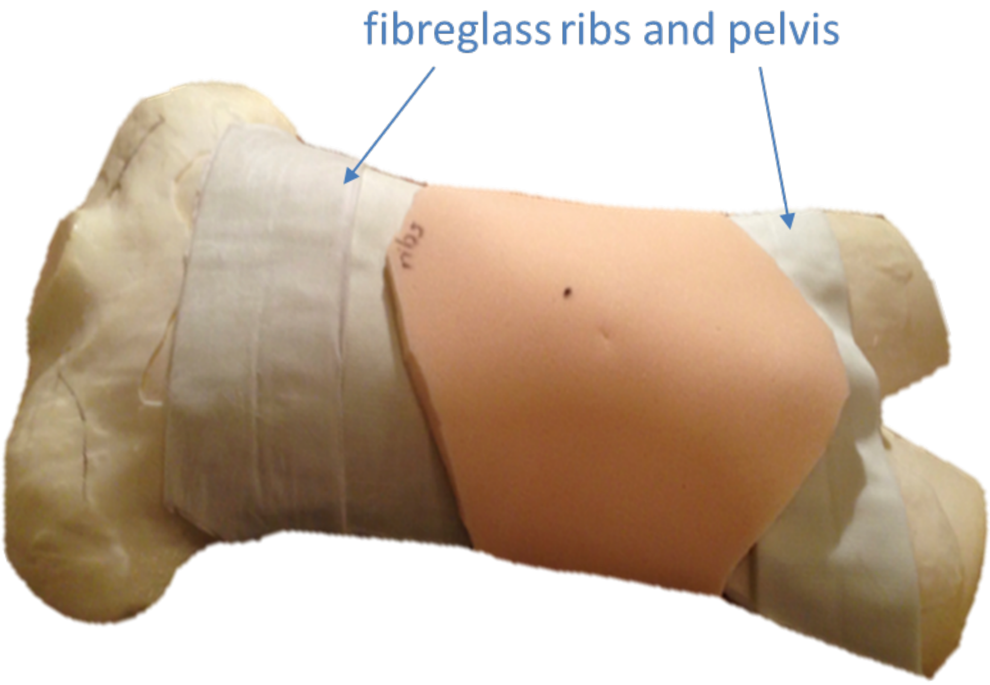


Figure 42. Flex-iT! X Foam, Soama Foama, Ribs & Pelvis bony landmarks, Thin Foam layers

6.2.1.5 Torso model

The collective components of the torso are shown in Figure 43 with the exploded views of the model shown both photographically and with further details graphically, showing the skin, foam layers, bony anatomical landmarks and WBB.

Figure 43. Exploded view of the various moulded layers in AbSIM

6.2.2 Force sensing platform

The core requirement of the abdominal palpation training simulator (AbSIM) was to record the magnitude and determine location of applied palpation forces.

The results of the "How Hard Do Clinician's Press (HHDCP)" Study presented in CHAPTER 5, provided guideline ranges for the forces used by clinicians when palpating (see CHAPTER 5 Table 4, Table 7). These helped give an estimate of the forces that would need to be recorded with the abdominal palpation simulator and thus specify the minimum requirements of the force sensing platform. The design was also restricted by a low budget.

A number of design options were considered (see Appendix B 10.9) including: pressure sensing mats, force sensor arrays, force plate system, load cells, strain gauges, wireless arrays, shape memory alloys, and artificial muscles. Most of these options were cost prohibitive, would be damaged or deformed under palpation, or were unsuitable for the contours and depth of the abdomen.

The method chosen to record the force and determine its location was that of a force sensing platform with four force sensors, one in each corner. This system was chosen in line with budget, size, and time constraints.

With such a system, the points of force application can be determined as per Figure 44, and equations (1), (2) and (3).

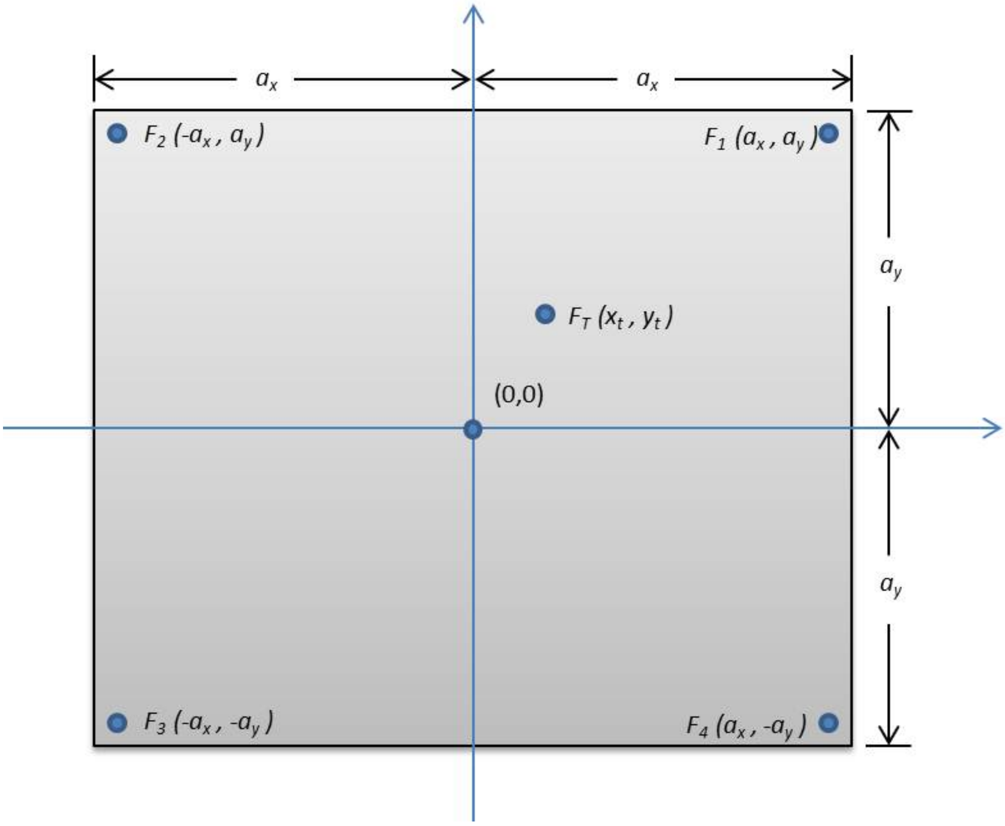


Figure 44. Force platform sensors and coordinates

$$F_T = F_1 + F_2 + F_3 + F_4 \tag{1}$$

$$x_t = \frac{a_x(F_1 - F_2 - F_3 + F_4)}{F_T} \tag{2}$$

$$y_t = \frac{a_y(F_1 + F_2 - F_3 - F_4)}{F_T} \tag{3}$$

The total force F_T at time t, in equation (1), is the sum of the force readings from the corner sensors where $F_1 .. F_4$ are the forces from the sensors in each corner of the force platform as per Figure 44. In equation (2) x_t is the x-coordinate at time t, where a_x is the distance between the origin and the force platform sensors along the x-plane. The y-coordinate at time t is y_t (3), where a_y is the distance between the y-axis and the sensors.

Assumptions: $F_T = F_z = \sum_{i=1}^{4} F_{i,z}$

and $F_x = \sum_{i=1}^{4} F_{i,x} = 0$, or negligible

and $F_y = \sum_{i=1}^{4} F_{i,y} = 0$, or negligible

The assumptions for (1), (2) and (3) is that the total force applied is equal to the sum of the forces applied to the force platform in the z-plane and that the forces in the x and y planes are zero or negligible.

6.2.2.1 Custom Force Sensing Platform

In the initial stages of research investigation, a custom force sensing platform was developed, using aluminium plates and mounted strain gauges (see Appendix B 10.10).

The resolution of the force and position was however not accurate enough due to noise at low forces and limited budget. It was decided to explore other commercial options and a comparable solution was found in the low-cost commercially available Nintendo Wii Balance Board (Nintendo, Kyoto, Japan) product, utilising its similar size and force ranges as an alternative method with reproducible quality and results plus fast accessibility.

6.2.2.2 Wii Balance Board

The Nintendo Wii Balance Board (WBB) was a portable inexpensive (~AUD$100 in 2012) accessory to the Nintendo Wii game console [153], intended to measure activities and movements for games and applications with the Nintendo Wii based on balance, leaning, rotating, and moving the body by tracking and monitoring the user’s weight and movement during a “game” acting as the Wii Fit game controller [154].

The WBB is a rigid platform, with design origin from bathroom scales [155], with four uniaxial vertical force transducers located in the feet at corners of the board [156] (see Figure 45).

Figure 45. Nintendo Wii Balance Board, left: top view, right: bottom view

Each transducer is a load cell consisting of a cantilevered metal bar with a strain gauge [157], measuring vertical ground reaction forces. It utilises the Bluetooth wireless protocol, as Nintendo RVL-WBC-01.

The validity and reliability of the WBB as a measurement tool was shown in studies for assessment of balance and balance rehabilitation [156, 158-162]. Bartlett, Ting [156] showed the repeatability of a single measurement within a single WBB device to be $\pm 4.5N, \pm 1.5mm$. Clark, Bryant [159] found the WBB to be comparable to a force plate when assessing centre of pressure path lengths.

The WBB specifications as per the manufacturer's operation manual in Table 10, show that the normal body weight range is from 0-150kg with 500g units[12] which met the required specifications for the abdominal palpation simulator in the conclusion of CHAPTER 5.

[12] 500g equivalent to ~4.9N, where F=ma and m=0.5kg, $a=9.8ms^{-2}$

Table 10. Wii Balance Board Specifications [153]

Model No.	RVL-021
Power Source Used	Alkaline AA batteries (LR6), 1.5V x 4
Power Consumption	Approx. 180mW
Wireless Frequency	2.4 GHz band
Power Output (Antenna Power)	Approx. 1mW
Communication Standard	Bluetooth Ver. 1.2
Weight Capacity	Max 150kg
Body Weight Display	From 0-150kg: 500g units
Usable Temperature Range	10-40°C
Usable Humidity Range	20-80%
Outer Dimensions	511mm wide/ 316mm long / 53.2 mm thick
Mass	Approx. 3.5kg (not including batteries)
Battery Duration	About 60 hours (when using AA batteries)

6.2.3 Definition of abdominal regions for model

The challenge in matching up the WBB and mould was that the WBB had set dimensions and locations of sensors as it was a commercial off-the-shelf product, and the mould was based on the real body of the volunteer. The distance between the WBB sensors width was 238mm which closely matched the dimension of the mould.

The dimensions of the abdominal model as pictured in Figure 46 has 9-regions where:

- a_x is the distance from the centreline to the edge of the abdomen, the width is $2a_x$ = 238mm, therefore the width of each region in the x-plane on the model torso is: $\frac{2a_x}{3} = 79.3\dot{3}\text{mm}$

Matching the length of the WBB and regions of the abdominal model as in Figure 46 was more difficult, as the length of the WBB was longer than the area required for the 9-regions. For the abdominal model:

- a_y is the distance from the midline of the 9-regions to the bony landmarks, and in the model $2a_y$ = 400mm so the length of each region in the y-plane on the model torso is: $\frac{2a_y}{3} = 133.3\dot{3}\text{mm}$

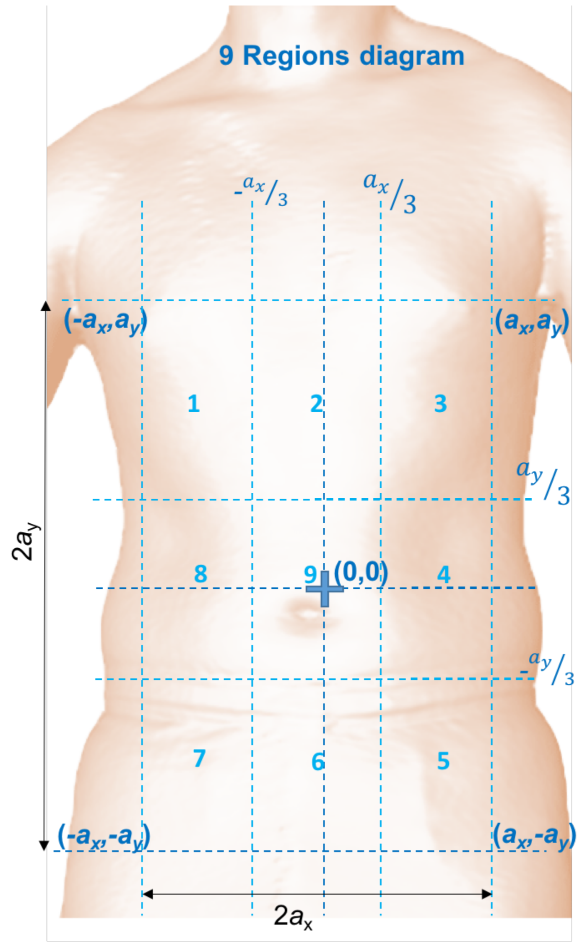


Figure 46. Abdominal regions x-plane coordinates

For the WBB, each sensor came labelled from Nintendo (as in Figure 47):

- LB = left bottom
- LT = left top
- RB = right bottom
- RT = right top

The distance between LB and LT (or RB and RT) or the width of the platform was 238mm ($2a_x$ = 238mm as for the abdomen). To align the WBB and mould, it was decided to match RB and RT with the bottom corners of the regions of the abdomen (see Figure 48). This meant that the top corners were offset between the mould and the abdomen by a constant which was designated "*k*".

Sensors RB and RT were set at points ($-a_x$, $-a_y$) and (a_x, $-a_y$) respectively (as per Figure 47 and Figure 48), LB and LT were at ($-a_x$, a_{wy}) and (a_x, a_{wy}) respectively, where $a_y = a_{wy} - k$*, and* $k = 12mm$.

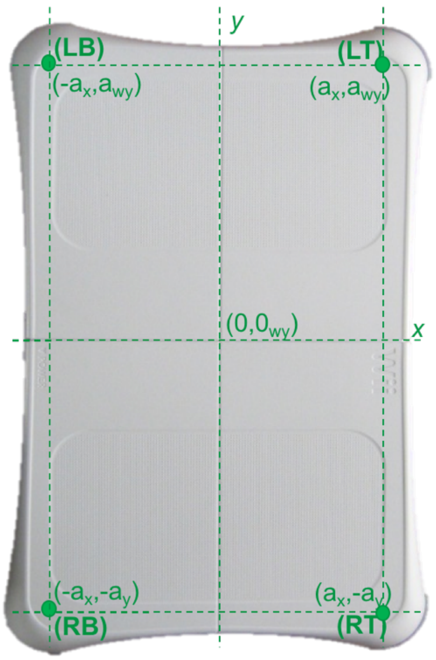


Figure 47. WBB sensor coordinates (top view)

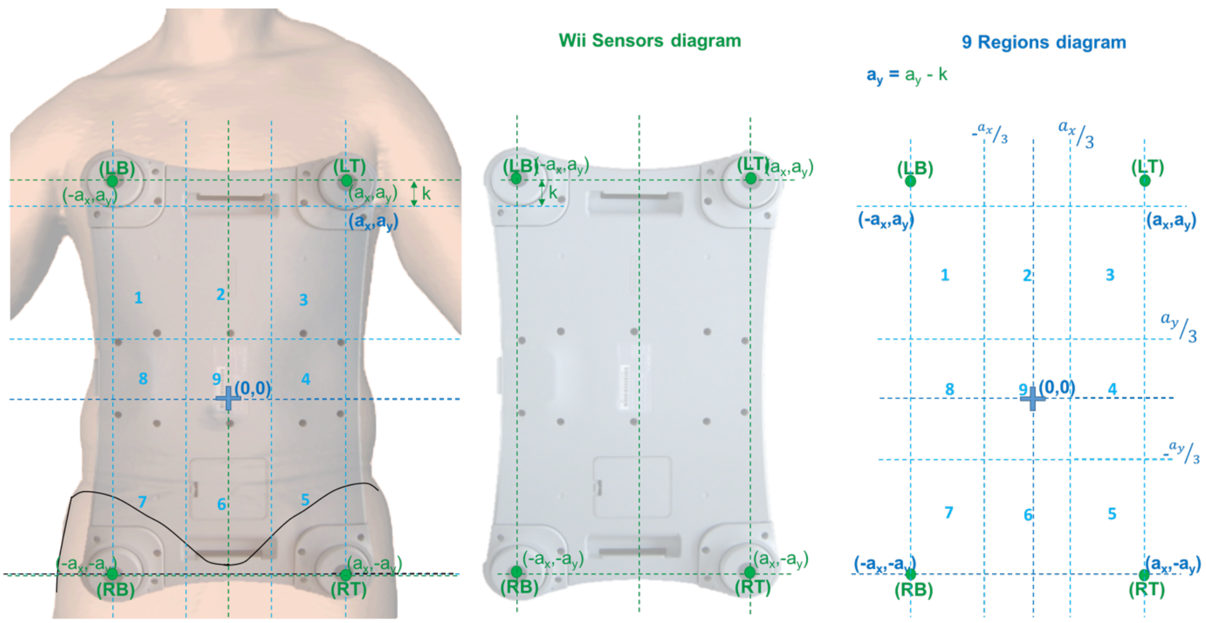


Figure 48. WBB, 9-regions coordinates reference

Figure 48 illustrates how the abdominal model and regions are cross-referenced with the WBB sensors. To determine the abdominal region a participant was pressing at time *(t)*, the coordinate locations for each region were defined as in Table 11, with x-y coordinates as per the abdominal model (Figure 48). This lookup table (Table 11) is used in the LabVIEW 8 [148] custom code (see 6.2.4.2) to determine the region a participant is palpating at time (*t*).

Table 11. Region lookup table, coordinate definitions

Region	x-coordinate	y-coordinate
Region 1:	$-a_x \leq x_t \leq {}^{-a_x}/_3$	${}^{a_y}/_3 \leq y_t \leq a_y$
Region 2:	$-{}^{a_x}/_3 < x_t < {}^{a_x}/_3$	${}^{a_y}/_3 \leq y_t \leq a_y$
Region 3:	${}^{a_x}/_3 \leq x_t \leq a_x$	${}^{a_y}/_3 \leq y_t \leq a_y$
Region 4:	${}^{a_x}/_3 \leq x_t \leq a_x$	$-{}^{a_y}/_3 < y_t < {}^{a_y}/_3$
Region 5:	${}^{a_x}/_3 \leq x_t \leq a_x$	$-a_y \leq y_t \leq -{}^{a_y}/_3$
Region 6:	$-{}^{a_x}/_3 < x_t < {}^{a_x}/_3$	$-a_y \leq y_t \leq -{}^{a_y}/_3$
Region 7:	$-a_x \leq x_t \leq -{}^{a_x}/_3$	$-a_y \leq y_t \leq -{}^{a_y}/_3$
Region 8:	$-a_x \leq x_t \leq -{}^{a_x}/_3$	$-{}^{a_y}/_3 < y_t < {}^{a_y}/_3$
Region 9:	$-{}^{a_x}/_3 < x_t < {}^{a_x}/_3$	$-{}^{a_y}/_3 < y_t < {}^{a_y}/_3$
Note: $a_y = a_{wy} - k$, k=12mm		

6.2.3.1 WBB Calibration

The WBB acts as the force sensing platform inside the abdominal model, from which data from its four sensors can be accessed via Bluetooth using the software developed in LabVIEW. The raw data from each of the four sensors is converted into a force value by applying known loads to each of the sensors individually to find a trendline and determine the scaling factor. The maximum forces measured in CHAPTER 5 were 75N and the WBB was rated up to 150kg. Therefore, the WBB was calibrated to ensure it was linear from 0-200N to ensure the possible range of forces to be recorded by the simulator were covered. The linear regression equation for each sensor was linear with the R^2 value >0.99 for each (see Appendix B 10.11). With the data from these sensors x, y, and F can be determined at any point in time, and from this the region in which the force is applied determined via the lookup table (Table 11) in the Labview code.

6.2.4 Software and Interface

The WBB used the Bluetooth wireless protocol to talk to the Wii control. In the simulator design, this was utilised by using Bluetooth to communicate between the WBB and a laptop.

The laptop used was a Toshiba Tecra[13], with an inbuilt Toshiba Integrated Bluetooth3 module. The WBB broadcasted as “Nintendo RVL-WBC-01” which was paired to the laptop.

[13] MSAK010ACP05, Intel ® Pentium ® M, 2.13GHz processor, 786MHz 1GB RAM, running Microsoft Windows XP Professional Version 2002 Service Pack 3

The data from the WBB were then acquired and processed using a custom made graphical user interface (GUI) developed using LabVIEW 8 [148].

6.2.4.1 Bluetooth/Wiimote pairing

To connect the board to the laptop, the Wii-mote Bluetooth interface with a downloaded patch was used [163]. For the WBB to be detected by the laptop as a nearby Bluetooth device, the red pairing button on the underside of the WBB needed to be pressed, allowing the WBB and laptop to be paired. To pair these each time the simulator was started would be cumbersome, as the red pairing button was inside the battery case. To avoid this, the Wiimote/WBB and the windows laptop were permanently paired by running prebuilt C++ code [164] that automatically paired a Wiimote/WBB to a Windows computer running the Microsoft Bluetooth stack. After installing this and initial pairing, to subsequently connect the WBB and laptop at the beginning of each use only required pressing the easily accessible SYNCHRO button on the side of the WBB.

6.2.4.2 Labview Custom developed software and GUI

Custom software was developed in LabVIEW 8 to record data from the sensors in the force platform, filter it, perform algorithms to determine the abdominal region in which force was applied, and to record the relative magnitude and location of the applied force.

Figure 50 shows a flowchart of the program and the different processes involved are explained in Table 12. The GUI (see Figure 49) enables the user to step through the different stages of the simulation at their own pace.

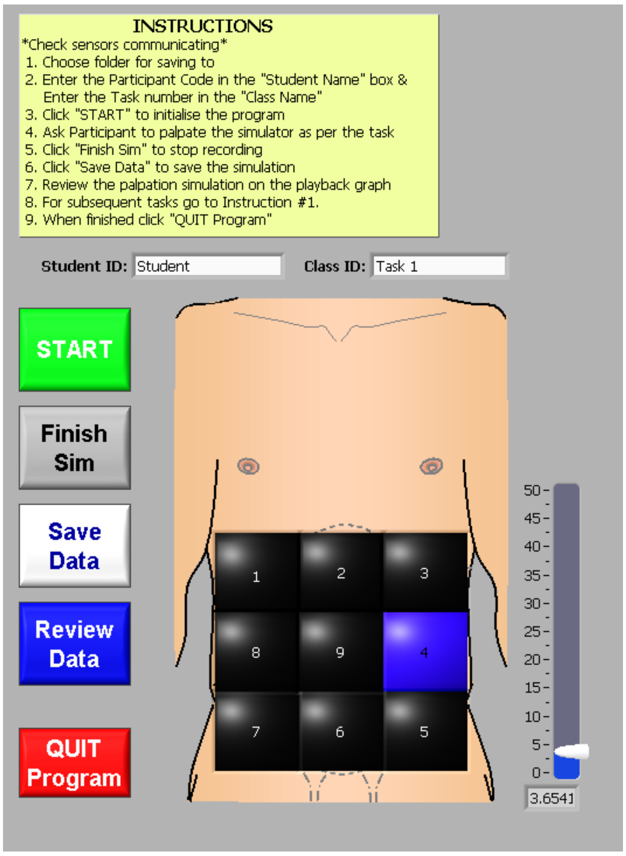


Figure 49. AbSIM Graphical User Interface developed in LabVIEW

The GUI start screen displays an image of an abdomen with nine boxes to represent the different numbered regions.

On the start screen, once the program is running, the user enters the student name and class or task name, then when ready presses the “START” button to start the simulation.

After this, when the student palpates the abdominal palpation simulator, the GUI displays a force-bar in real-time and a colour gradient in the region where they are pressing as a visual indicator of increasing applied pressure. Once they have finished, they select the “Finish Sim” button, then decide whether they would like to save the data by clicking on the “Save data” button and/or “Review Data” before they exit by pressing “QUIT Program” or begin another simulation again by pressing “START”. The “Review Data” button provides the ability to play back the palpation session on the screen, providing learners with visual feedback of the sequence and force colour gradient in the region palpated, and magnitude of force on the slider.

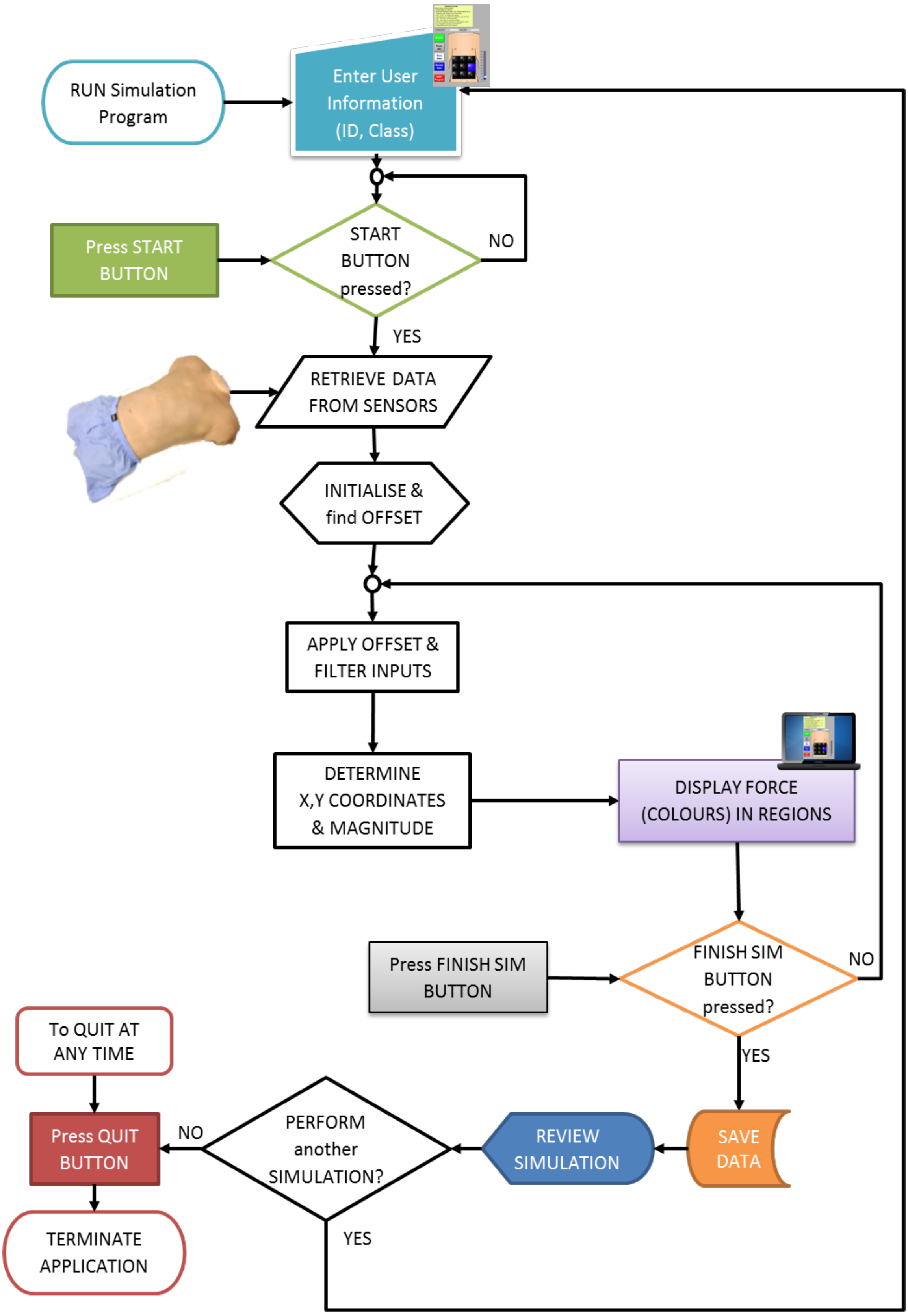
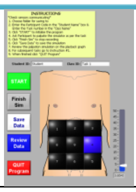


Figure 50. AbSIM Labview Software Program Loops

Table 12. AbSIM flowchart stages explained

RUN Simulation Program 	The software must be executed so it is running and waiting for input from the user via the GUI. At this stage the user performs checks that the Bluetooth communication interface between the laptop and the WBB is connected.
Enter User Information (ID, Class)	The user enters their identification number or username, and class/task identifier into the input boxes on the GUI for saving alongside the force data.
START BUTTON pressed?	The simulator waits in standby mode until the start button on the GUI is pressed.
RETRIEVE DATA FROM SENSORS	Once the start button is pressed, data is retrieved from the sensors. See Figure 47 for diagram of WBB sensors.
INITIALISE & find OFFSET	The force data from each sensor are then initialised and an offset found for each to zero them.
APPLY OFFSET & FILTER INPUTS	The offset is applied and the data filtered.
DETERMINE X,Y COORDINATES & MAGNITUDE	In LabVIEW, the applied force, and x and y coordinates are calculated using equations (1), (2) and (3), to determine x(t), y(t), F(t), and Region (t) at any point in time (t).
 DISPLAY FORCE (COLOURS) IN REGIONS	Forces within different ranges are displayed as colour gradient on the corresponding region box on the GUI abdomen according to region and force.
FINISH SIM BUTTON pressed?	Simulator keeps recording until the FINISH SIM BUTTON is pressed.
SAVE DATA	Pressing the Save Data button records the data from simulation and stores them in the database.
REVIEW SIMULATION	Pressing the REVIEW button, enables the user to replay their simulation, playing back the simulation showing the region palpated with corresponding force gradient colour in real time.

PERFORM another SIMULATION?	The simulator waits for the user to press a button to determine the next step.
Press QUIT BUTTON	The QUIT Button pressed at any time, stops the application from running.

See Appendix B 10.12 for details of the LabVIEW code for each part of the block diagram.

6.3 Summary

To summarise, the AbSIM physical prototype was constructed by moulding an "average" male, casting foam and skin from the mould to simulate skin and musculature, and adding bony landmarks for anatomical reference (Figure 43). Software was developed using LabVIEW 8 to interface with the WBB that acts as a force platform within the physical model. Users interact with the simulator through the GUI and by applying force to the model which is recorded.

A user interacting with the simulator can run the program, check everything is connected/communicating, enter in their details, start the simulation and palpate the simulated abdomen, then save and review the data from their session.

CHAPTER 7. Evaluation and Testing of the Abdominal Palpation Simulator: Methods

7.1 Introduction

The development of the abdominal palpation simulator “AbSIM” prototype, as detailed in the previous chapter, provides the ability to simulate abdominal palpation, quantify applied forces, record their location, and provide visual feedback to the user. To test its use as a reasonable tool for abdominal palpation training and assessment, a trial of the ABSIM prototype with medical students and medical graduates was conducted.

7.1.1 Research Questions

A trial was designed to evaluate the palpation techniques of medical graduates and medical students, by collecting usage data from the simulator, and then surveying their impressions of using it after the clinical scenario was complete. The Medical Graduates, as the more experienced medical practitioners, were considered the “control” group and referenced for their “expert” technique and opinions. Medical students were studied as the potential users of this device for learning.

The following research questions were investigated:

1) Does the AbSim prototype sufficiently simulate an average male abdomen?
    i. After using the abdominal palpation simulator, when surveyed, do medical graduates find the abdominal palpation simulator sufficiently realistic for the purposes of teaching and training abdominal palpation?
    ii. How realistic do medical students find the abdominal palpation simulator?
    iii. What are the participants comments regarding the physical realism?
2) Do participants palpate the whole abdomen in a systematic way and what forces do they apply when palpating?
    i. Does the coverage data from the simulator show participants palpated the whole abdomen?
    ii. When the sequence and pattern of examinations are reviewed, do results demonstrate if the participants used a systematic approach?

iii. What do the data reveal about the technique of medical students versus medical graduates, the forces they applied, and the time they took to complete the examination?
iv. Were they able to detect any abnormalities (e.g. pathologies) in the simulator?

7.2 Approvals – Human Ethics Committee and Flinders University School of Medicine

Ethics approval was obtained for the clinical trial entitled “A trial of a prototype clinical educational tool for training medical students in abdominal palpation” [165] from the Flinders University Social and Behavioural Research Ethics Committee (SBREC) (see Appendix C for full documentation).

Approval was also obtained from the Flinders School of Medicine (SOM), to approach and involve students from the School in the study.

Further approvals were sought from the relevant clinical people in charge of the areas where the trial was conducted; the Flinders University School of Medicine Clinical Skills and Simulation Unit (CSSU) and the Flinders Medical Centre Post-Anaesthesia Care Unit (PACU).

7.3 Methods – Simulator Testing

7.3.1 Location and Materials

Data were collected in the Flinders University SOM CSSU and the Flinders Medical Centre PACU.

The investigator set up the abdominal palpation simulator in a non-clinical area for medical graduate participants and in the clinical skills area for medical student participants on days that room availability and bookings were allowed by clinical area managers within the trial period. The simulator was placed on a standard patient examination table in the CSSU and on a trolley at a similar height in the PACU. Prior to recruiting participants each session, a small 1-2cm diameter lesion was added to the abdominal region of the simulator under the top soft foam layer. The region location of the lesion was recorded as a task number against the participant (i.e. T5 = task: lesion in region 5).

7.3.2 Inclusion Criteria of Study Participants

The following criteria had to be met for participants to be included in the study:

- "Medical Students" were to be from the Flinders University SOM Graduate Entry Medical Program (GEMP).
- "Medical Graduates" had completed their medical studies and graduated and were working at Flinders Medical Centre (FMC).
- Both participant types had to be willing to participate for approximately 7-8 minutes at the times and locations available for the study, and not be taken away from patient care or studies.
- They had to perform abdominal palpation on the simulator, and answer some brief questions about their experience level, and fill in a questionnaire regarding the simulation as per the response sheet (see Appendix C 10.13.7).

7.3.3 Recruitment and Data Collection

Recruitment of participants was by direct approach face-to-face with a standard verbal script. Medical student and graduate participants who were in the vicinity of the CSSU room allocated for the studies at the times the room was available to be used for the studies were approached according to the script approved by SBREC. Medical graduates were also recruited from the break room near the PACU at the times it was available for use for the clinical study.

Participants were briefed by the principal investigator, introducing herself, introducing the study, and providing the information sheets and forms (see Appendix C 10.13.3, 10.13.4, 10.13.5).

The investigator assigned each participant an ID code, prefixed by either MG (for medical graduate) and St (for medical student) and the next available sequential number for that participant type.

After reading the information sheets and giving informed consent, participants were briefed by being given a card with the clinical scenario to read. They were then asked to palpate the abdomen as they would in that situation as if it were a real patient, and record their findings on the patient notes sheet. They were told they only needed to perform palpation, no other aspects of an examination. The principal investigator also explained to participants that since the ability to breathe was not a feature of the model at this time, there was no need to ask “the patient” to do this.

Participants were asked to complete the simulation after reading the scenario given, then respond to the feedback questions immediately after they had finished.

Clinical Scenario: *“This abdomen is of a young man, who was playing football. During the game, he was kicked and fell and complained of abdominal pain. The coach told him to go to the Emergency Department.”*

During each trial, the simulator system recorded the position and magnitude of the forces applied to the abdomen by the participants (see 6.2.2 and 6.2.4 for description of how this is achieved) and data were saved against the assigned participant ID code.

The total palpation simulation time varied from subject to subject, but was typically less than 1 minute.

The participants were then asked to provide general information regarding their personal experience, qualifications and background, and feedback about their experience with the simulator, via a short paper-based questionnaire (see Appendix C 10.13.7) that included a multiple-choice question regarding how realistic they found the abdominal palpation simulator, and space for additional comments regarding the physical realism.

Participants were provided the opportunity to see the recorded data on screen if they wished, thanked for their time, and asked not to share their experience with other potential participants.

7.3.4 Design Limitations

Sample size limited by approval time-frame

The time period granted to collect data was restricted to two months, due to concerns of the Flinders School of Medicine (SOM) regarding the many clinical studies involving students at that point in time and the SBREC approval timeframes. The sample size was limited to the number of participants able to be recruited within the permitted data collection period of two months.

Limitation of "control" group

The sample of medical graduates recruited to the study was skewed towards anaesthesia and surgical disciplines due to the locations in the hospital in which the study was performed. Graduates within these disciplines would not regularly palpate the abdomen, and as such their practical experiences were limited.

Number of questions on Multiple Choice Question

Due to the time limitations of the potential participants and concerns from SOM about taking them away from patient care or studies, the questionnaire assessment tool part of the trial was limited to only one multiple choice question.

Lesion Location

To change the location of the lesion required removing the skin and layers of foam from the simulator, so it was only changed at times of convenience (such as the start of the day) to maximise the number of participants able to be recruited in the allowed timeframe. Therefore, the lesion location (recorded manually) was not randomised introducing limitations to be addressed in the statistical analysis. This also introduced a risk that participants who had completed the study would share information about lesion location, despite being instructed not to do so.

Clinical Scenario

The limitations of the clinical scenario were that the patient was unresponsive and therefore unable to provide any information about where he had been kicked, or to breathe in and out on request.

7.4 Data Analysis Methods

The data collected for each participant included:

- Consent Forms (see Appendix C 10.13.5)
- Response sheets with participant information data - gender, year level and palpation experience or years since graduation (dependent on whether medical students or medical graduates) – and responses to multiple choice question, patient notes, comments (see Appendix C 10.13.7).
- Recorded simulation data, saved to individual excel files with the participant ID, task, force data, location, region, time and a datestamp.

All data were transcribed in excel and imported into MATLAB [166] and SPSS [167] for further analysis. The data were truncated manually prior to importing into MATLAB, so that the time point zero corresponded to the time the participant started palpating, defined by the first application of force, rather than the time the data recording began.

7.4.1 Data processing with MATLAB

7.4.1.1 Processing of data files

For each participant dataset custom written MATLAB code was used to process the data as follows:

- Import the data
- Label all the variables i.e. `[ID,DateTime,Task,Ts,LT,LB,RB,RT,f1,f2,f3,f4,xt,yt,F,Region,FN,Reg,Lesion,PType]`[14]

[14] ID = Participant ID, DateTime = Date Stamp, Task = Lesion Location, Ts = time (s),
LT = left top sensor, LB = left bottom sensor, RB = right bottom sensor, RT = right top sensor
LT, LB, RB, RT are Wii Balanceboard raw sensor outputs, data kept for reference, but not used for calculations.
f1, f2, f3, f4 are the values from the Wii sensors converted to forces in the Labview software of the simulator.
xt = x(t), yt = y(t): these are coordinates of applied force (determined in Labview software)

- Smooth the force data to reduce noise and outliers (by using the convolution function to create an averaging window of 0.25s).
- Calculate the total time force was applied in each region[15]
- Find the order of the first time the participant palpates each of 9 regions.
- Find indices of local minima and maxima (force peaks), using the derivative to find the critical points and the double derivative to determine if it is a maxima or minima.[16]
    - Determine the (smoothed) force at palpation peaks
    - Find the region number corresponding to each peak
    - Count the number of peaks in each region
    - Calculate the average forces at the peaks in each region
- Assign data to "force bands"
    - Define force bands at 20% increments of maximum peak smoothed force
    - Total the time force is applied in each band
    - Count the number of force peaks in each band
- Output the total time for the palpation exercise, where the end is defined as the point after which no more force is applied
- Define plot parameters
- Plot figures (see 7.4.1.2)
- Save data to files

7.4.1.2 Plot 1 – Force (N) versus Time (s)

The first plot produced for each dataset was a basic force versus time graph labelled by the Participant Identifier e.g. "MG1" and appended with the task "T5"[17] and "-fig1.png".

FN = F (N) = sum of f1, f2, f3, f4: this is the force value used in the calculations and processing of data.
Reg = Region, the Region number (1-9) that the force is applied to. If Region = 0 no force is applied.
Lesion = region number in which the lesion was located for the participant.
PType = Participant Type: Student (St) or Medical Graduate (MG)

[15] The simulator collected data at 0.05s intervals (frequency = 20Hz).

[16] A sensitivity factor of 0.35s was used in the code that only critical points that are >0.35s apart are distinguished.

[17] Corresponding to the region location of the lesion e.g. T5 = lesion in region 5

Figure 51 shows an example of this "Plot 1" graph. The plot includes:

- Raw data (blue)
- Smoothed force data (red)
- Local minima (black down triangle)
- Local maxima (black up triangle)
- Reference grid lines at 20%, 40%, 60%, 80%, 100% of maximum smoothed peak force
- Reference lines at mean peak force and median peak force
- Axes and labels

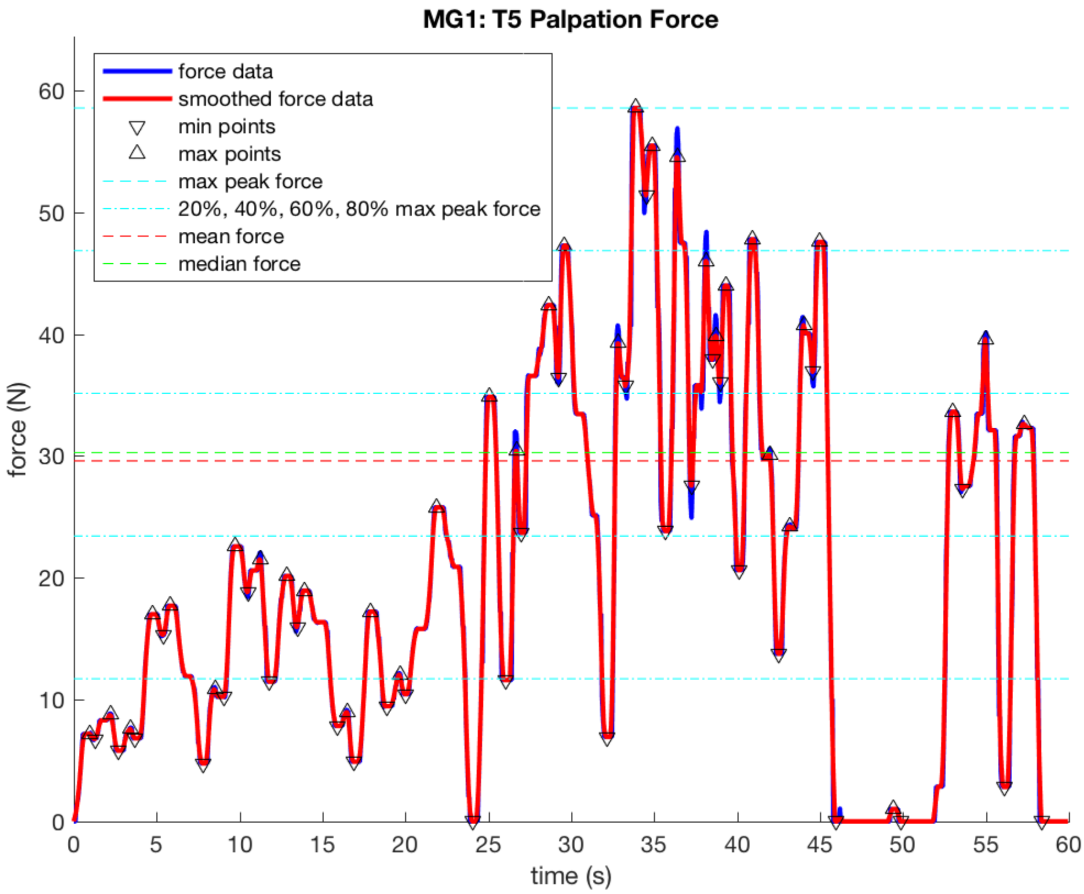


Figure 51. MG1-T5-fig1.png "Plot 1"

Figure 51 shows three sections of palpation. At the beginning from 0-25s the Medical Graduate is likely using "light palpation" below the 40% of maximum peak force line to survey the abdomen, deeper palpation from 25-45s, and after 52s the Medical Graduate may have been performing a more targeted palpation of specific areas of interest for further diagnosis.

7.4.1.3 Plot 2

The second plot produced for each participant in MATLAB allows visualisation of the force applied over time alongside information on the abdominal regions to which force is being applied. It also shows the total time spent in each region for the whole examination, illustrating the coverage of regions by the participant.

Figure 52 shows an example of the second plot "Plot 2" produced for each dataset. The plot includes three subplots that display different features of the data:

- Subplot 1 – Force (N) versus time (s) graph (for reference)
    - A simplified version of plot 1 for reference
- Subplot 2 – Region number versus time (s)
    - The abdominal region corresponding to the location of the applied force (blue)
- Subplot 3 – Total time in Region (s) versus region number
    - The total time the participant spent palpating each abdominal region (dark blue)

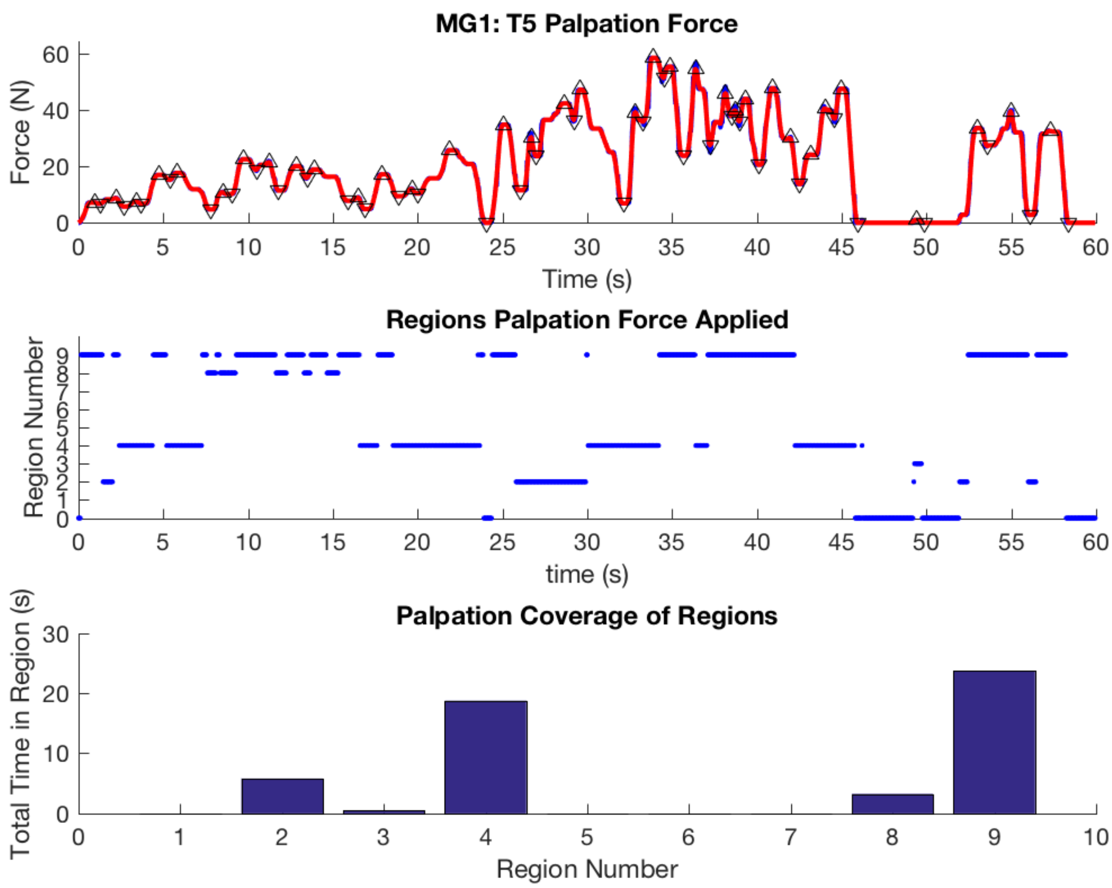


Figure 52. MG1-T5-fig2.png "Plot 2"

Figure 52 indicates that the Medical Graduate, while they appeared to have a good technique for applying light, deep then more targeted force from the force data, they did not have a very good coverage of the whole abdomen, with most their time spent palpating regions four and nine, and minimal time spent in the other regions.

7.4.1.4 Plot 3

The third plot produced shows the peak palpation forces over time as Force (N) and as a percentage of the maximum peak force. The bar chart indicates the number of palpation peaks counted in each band representing a percentage of the maximum peak force.

To categorise the force data in a way that would enable analysis of whether the forces were considered “light” or “deep” palpation or somewhere in-between, the force data were categorised into five groups.

100% was set as the maximum peak palpation force a participant applied. From this value, 20%, 40%, 60% and 80% of the maximum peak palpation force were calculated and the palpation peaks were counted and grouped in these bands, according to their value (using MATLAB).

> *i.e. If Max force = 100 N, and peak value in the dataset is 25N – it would be counted in the 20-40% of peak force band.*

Figure 53 shows an example of “Plot 3” for each participant dataset. It includes three subplots to illustrate the components of the palpation “force bands”.

- Subplot 1 – Palpation peak forces versus time (s) graph
    - Raw data (blue)
    - Peaks (magenta)
- Subplot 2 – Force at Palpation Peaks
    - Peaks (magenta)
    - Scatter plot of peaks joined with straight line (magenta)
    - Reference lines at 20%, 40%, 60%, 80%, 100% of maximum peak force
- Subplot 3 – Number of peaks in each force band
    - Count of Palpation peaks in each 20% band of maximum peak force

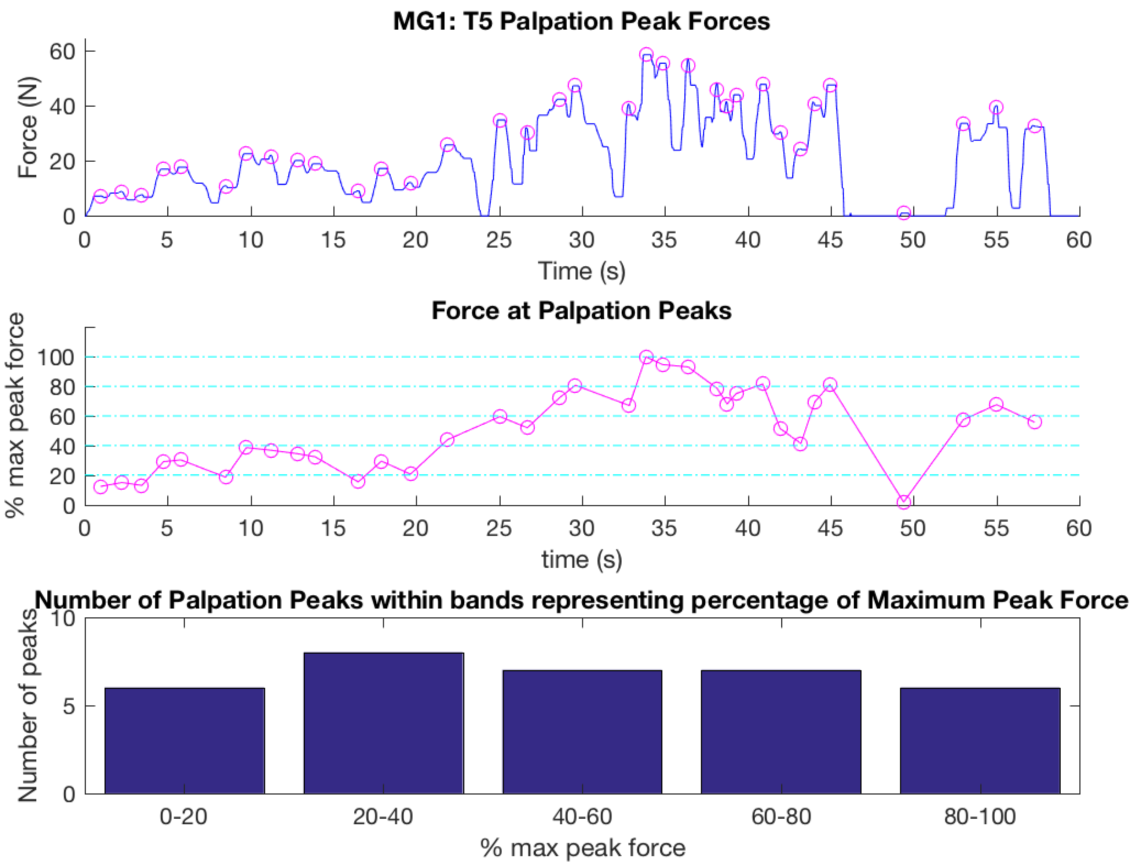


Figure 53. MG1-T5-fig3.png "Plot 3"

Figure 53 highlights that the medical graduate (MG1) had consistent coverage in each force band, palpating using similar numbers of peaks across all bands.

7.4.2 Statistical Analyses

Data were checked for normality following typically used tools [168], however data was so severely skewed that a graphical histogram was sufficient to identify this. The statistical significance was set at 5% (α = 0.05), and appropriate effect sizes reported alongside. For sections where the population mean was estimated, confidence intervals (CI) were reported. Where sections report categorical variables, Chi-Square or Fisher's Exact Test were utilised as measures of association and standardised effect sizes were reported alongside significance, using Cramer's V. To provide estimates of force, time, and peak counts in each region a Generalised Linear Mixed Model (GLMM) was used. The T-test was used to determine if there was a statistical significance between Medical Graduates and Students for average force values in each force band (0-20%, 20-40%, 40-60%, 60-80%, 80-100% maximum peak force).

7.4.2.1 Descriptive Stats and Confidence Intervals

General descriptive statistics, such as counts and frequencies were used to compare the different categorical variables (gender, participant type, year level, years since graduation, number of human abdomens palpated, total number of regions palpated, first region palpated, second region palpated) within the study participant results. Percentages of categorical variables and totals were also used to summarise values for the sample.

The 95% confidence interval (Wilson) was used to interpret the data for the whole population, versus the participants sampled from the population. The EpiTools [169] "confidence limits for a sample proportion" calculator using the "Wilson" score interval [170] was used to calculate the Confidence intervals, and SPSS [167] was used when estimating the confidence intervals of the effect size or GLMM.

7.4.2.2 Statistical Significance and Measures of Association

Chi-square Tests of independence were used to examine whether there was an association between any two of the categorical variables to generalise for the population. The null hypothesis assumes there is no association between the two variables compared. Where the value of the Chi-Square Test was significant ($p < 0.05$), the null hypothesis could be rejected and some level of association/relationships between the categorical variables assumed. Pearson's Chi-Square Test assumes that the cell values expected frequency should be greater than 5. For the recorded data, this assumption was not satisfied for many tests as some of the cell sample sizes were small for some variables, particularly for the Medical Graduates. Therefore, where the cell value frequencies did not satisfy these assumptions the Fisher Exact Test was used, as it does not assume an expected frequency per cell [171]. Where the significance value of the Chi-Square or Fisher's Exact Test was greater than 0.05 for a test between two categorical variables, the null hypothesis of independence was accepted, and there would unlikely be a relationship between the two variables. The size of the standardised effect size by Cramer's V was interpreted as per Cohen's [172] recommendation (cited in Pallant [173]).

The independent two-tailed T-test was used to compare average force values in each force band for the independent samples of Medical Graduates and Students to determine if there was any association between the values in each group.

7.4.2.3 Generalised Linear Mixed Models

The outcome measures of interest for technique were the average force of peaks in each region, the count of peaks in each region and the time spent in each region. When exploring the data, it was found that the distributions of the data were extremely different from region to region, with some highly skewed and large frequencies of zeros (e.g. Region 5 in Figure 54a) and others more normally distributed (e.g. Region 9 in Figure 54b) (addressed in more detail in CHAPTER 8).

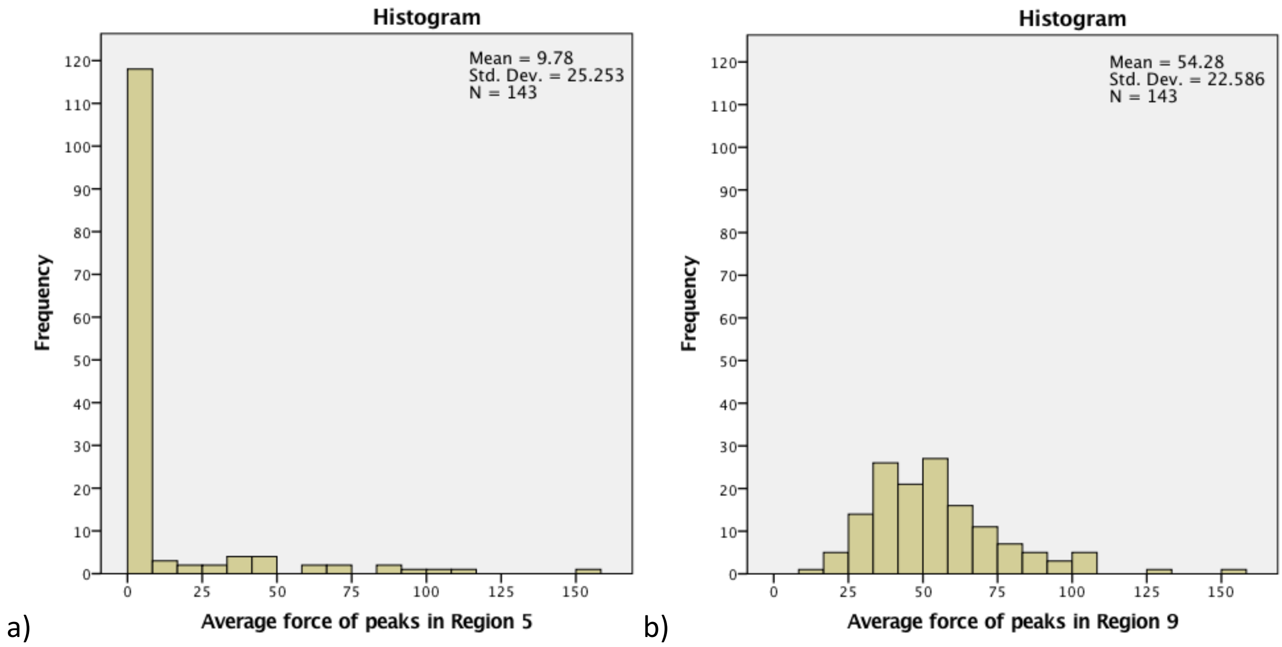


Figure 54. Example distributions of data a) Average force of peaks in region 5. b) Average force of peaks in region 9.

Finding an approach to suit all outcomes was challenging, therefore in order to provide estimates of force, time, and peak counts in each region, the Generalised Linear Mixed Model (GLMM) was utilised. This more complex GLMM framework [174] was used to address the following characteristics of the data collected:

1) Distribution: The GLMM does not require the assumption that the dependent variables follow a normal distribution [174].
2) Regions within factor: The nine regions in the model for each dataset were all related to the same person and cannot be analysed as independent regions. This meant the data needed to be modelled as “within factor”.
3) The final challenge was that the location of the lesion was not randomised, so the modelling within GLMMs controls for this variable.

GLMMs "describe models for categorical data where the subjects are nested within groups or where repeated measures are nested within individuals (and perhaps within group studies)" [175].

The GLMM was used to estimate:

- Average force of peaks in Region 1-9
- Time (s) in Region 1-9
- Count of peaks in Region 1-9

The model addresses the within factor variables, controls for the potentially confounding factor of the lack of lesion randomisation of subjects under the lesion location, and corrects for where it is.

Initially the data were examined for normality using the Explore function in SPSS, excluding cases pairwise (for missing data) and displayed in results using frequency histograms.

The GLMM requires the specification of fixed factors (responsible for systematic variation in responses), random factor (from the sampling structure), distribution of the dependent variable, and the relationship between the fixed factors and the dependent variable [174].

Using the GLMM function in SPSS, the variable "Region" was modelled as within factor, a diagonal covariance type was used, with the standard linear model applied. Pairwise table with multiple comparisons used sequential Bonferroni, and transformations were saved using Pearson Residual. Each model produced tables with averages of each of the categorical variables and confidence intervals for these values. The Pearson Residuals of the models were examined [176] to find a normal distribution, without too many outliers, to give assurance that the confidence intervals and averages were credible.

CHAPTER 8. Evaluation and Testing of the Abdominal Palpation Simulator: Results and Discussion

8.1 Introduction

The data from the study were collected and processed as detailed in CHAPTER 7. The amount of data and the complexity of the data were such that the results and discussion are presented in this chapter in six sections to address the research questions in 7.1.1. Within each section, results are presented with respect to the different categorical variables: Gender, Participant Type, Student Year Level, Medical Graduate Years of Experience.

The first two sections cover the qualitative data from participant response sheets:

- Results Section 1: Multiple Choice Question Response, shows the data from the questionnaire given to participants.
- Results Section 2: Participant Comments, includes the other comments and patient notes from the participant response sheets.

The last four sections cover the quantitative data from the abdominal palpation simulator:

- Results Section 3: Coverage, details the total number of regions palpated and missed by participants.
- Results Section 4: Systematism, examines the sequence order of regions palpated, order patterns, and specific regions covered or missed.
- Results Section 5: Technique, uses GLMM to look at the average force in each region, average time spent per region and the average count of palpation peaks in each region.
- Results Section 6: Force bands, groups the palpation peaks into force bands to look at force patterns in participants.

8.2 Exclusions of Data

A total of 118 medical students and 35 medical graduates (MGs) were recruited for this study. Of these, data from 118 medical students and 26 medical graduates were considered valid for the response questionnaires and data from the simulator were valid for 117 medical students and 26 medical graduates.

Data from eight of the graduate participants were excluded from different parts of the study. Seven were disqualified all together, because previous participants had talked to them about the prototype feel and questionnaire before they participated and so they were considered biased. The data from one medical graduate were excluded because the prototype had a flat battery, so data recording was incomplete. One medical graduate's questionnaire answers were excluded, as they had circled two of the multiple-choice options instead of one. One student's simulation data were excluded as there was an error in saving the data.

8.3 Data Sample – Participant Information

The summarised demographic data for the 144 valid participants are presented in Table 13, Table 14, Table 15 and Table 16, detailing the participant type, gender and experience-levels.

Table 13 shows 118 medical student volunteers from years 1-4 of the Flinders University Medical School Graduate Entry Medical Program participated in the clinical trial. 49% (58) of participants were male and 51% (60) were female. 26 medical graduate volunteers with 1-25 years of experience from Flinders Medical Centre were recruited to participate in the "expert" grouping of the trial. 61.5% (16) of medical graduate participants were male and 38.5% (10) were female.

Table 13. Frequencies of Clinical Study Participant Sample: Participant Types and Gender (n=144)

		Gender Count (%)		
		Male	Female	Total
Participant Type	Student	58 (49.2%)	60 (50.8%)	118 (81.9%)
	Medical Graduate	16 (61.5%)	10 (38.5%)	26 (18.1%)
Total Count		74 (51.4%)	70 (48.6%)	144 (100.0%)

Table 14 shows the experience of medical graduates who participated, where 50% had over 10-years' experience and 50% under 10 years.

Table 14. Medical Graduates years since Graduation frequencies

		Gender Count (%)		
		Male	Female	Total
Years since graduation	<5	5 (83.3%)	1 (16.7%)	6 (23.1%)
	5-10	3 (42.9%)	4 (57.1%)	7 (26.9%)
	10+	8 (61.5%	5 (38.5%)	13 (50.0%)
Total Count		16 (61.5%)	10 (38.5%)	26 (100.0%)

Table 15 shows the disciplines of the medical graduate participants and highlights that a limitation caused by the time and location constraints of the study was that the majority of medical graduate participants came from the field of Anaesthesia. The non-Anaesthesia disciplines of medical graduates listed in Table 15 represent disciplines more likely to have more regular experience of abdominal palpation.

Table 15. Medical Graduate Disciplines

	Gender		
Discipline	Male	Female	Total
Anaesthesia	10	5	15
Clinical Teaching	0	1	1
Emergency	2	0	2
General RMO	0	1	1
General Surgery	0	1	1
GP/Obstetrics	0	1	1
Gynae oncology surgeon	1	0	1
Intern	2	0	2
Medicine	0	1	1
Orthopaedics	1	0	1
Total	**16**	**10**	**26**

Table 16. Medical Student Year Level Frequencies

		Gender Count (%)		Total
		Male	Female	(% within Total)
Year Level	First Year	18 (40.9%)	26 (59.1%)	44 (37.3%)
	Second Year	27 (50.0%)	27 (50.0%)	54 (45.8%)
	Third Year	8 (61.5%)	5 (38.5%)	13 (11.0%)
	Fourth Year	5 (71.4%)	2 (28.6%)	7 (5.9%)
Total		58 (49.2%)	60 (50.8%)	118 (100%)

Table 17. Number of abdomens palpated versus year level. Fisher's Exact Test Value is 70.069 with an exact significance of 0.000 which means p<0.05 and the null hypothesis of independence can be rejected, therefore year level does influence the number of human abdomens palpated as would be expected.

		Number of human abdomens palpated Count (%)			
		<10	10-50	50+	Total
Year Level	First Year	43 (97.7%)	1 (2.3%)	0 (0.0%)	44 (37.3%)
	Second Year	33 (61.1%)	20 (37.0%)	1 (1.9%)	54 (45.8%)
	Third Year	1 (7.7%)	9 (69.2%)	3 (23.1%)	13 (11.0%)
	Fourth Year	0 (0.0%)	2 (28.6%)	5 (71.4%)	7 (5.9%)
Total		77 (65.3%)	32 (27.1%)	9 (7.6%)	118 (100.0%)

Table 16 shows that the number of third and fourth year participants recruited were much lower than first and second years. For all analyses, they were combined into a single group for improved statistical analysis. Data in Table 17 show that the number of human abdomens palpated increases with year level of medical students. This coincides with the expectation that students would become more experienced as they progress in their medical degree.

8.4 Results # 1: Questionnaire Results

This section addresses research question 1 (i) and (ii) in 7.1.1:

1) Does the AbSim prototype sufficiently simulate an average male abdomen?

i. After using the abdominal palpation simulator, when surveyed, do medical graduates find the abdominal palpation simulator sufficiently realistic for the purposes of teaching and training abdominal palpation?
ii. How realistic do medical students find the abdominal palpation simulator?

The results in this section present the responses of the Multiple Choice Question (MCQ) on the questionnaire given to participants, and analyses the responses with respect to Participant Type, gender, medical graduate years since graduation and Student year level.

8.4.1 Is the simulator sufficiently realistic? - Multiple Choice Question Response

The overall results for how realistic Medical Graduates and Medical Students found the simulator are in Figure 55 and Table 18. These show that the majority of participants find the simulator "Sufficiently realistic to learn this technique".

Table 18. Responses to MCQ by Participant Type

Participants	Responses to multiple-choice question: "How realistic did you find the palpation trainer?"			
	a) Extremely realistic	b) Sufficiently realistic to learn this technique	c) Vaguely comparable to an abdomen	d) Not comparable at all
Medical students (n=118)	5.1 % CI: 2.35-10.65% (6)	57.6% CI: 48.6-66.2% (68)	31.4% CI: 23.7-40.2% (37)	5.9% CI:2.9-11.7% (7)
Medical graduates (n=26)	0.0% CI: 0.0-12.9% (0)	61.5% CI: 42.5-77.6% (16)	38.5% CI: 22.4-57.5% (10)	3.9% CI: 0.7-18.9% (1)
Total	4.2% (6) CI: 1.9-8.8% (6)	58.3% CI: 50.2-66.1% (84)	31.9% CI: 24.9-39.9% (46)	5.6% CI: 2.8-10.6% (8)

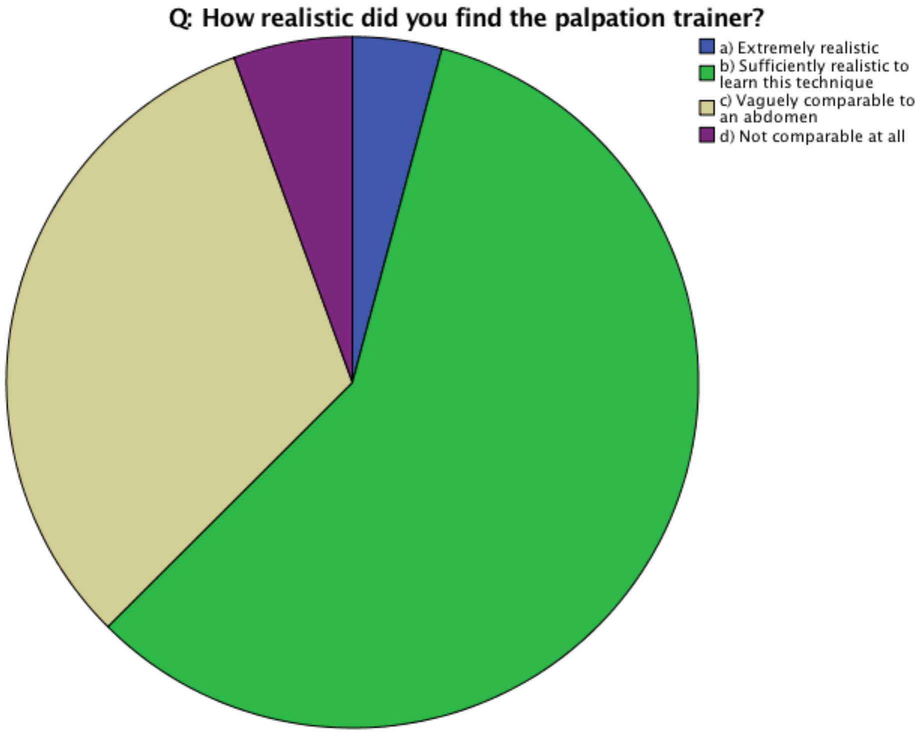


Figure 55. Overall Participant responses to MCQ

8.4.2 Questionnaire Responses by Gender

Table 19. MCQ Responses by Gender

			Gender		
			Male	Female	Total
Q: How realistic did you find the palpation trainer?	a) Extremely realistic	Count	5	1	6
		% within Gender	6.8%	1.4%	4.2%
	b) Sufficiently realistic to learn this technique	Count	37	47	84
		% within Gender	50.0%	67.1%	58.3%
	c) Vaguely comparable to an abdomen	Count	29	17	46
		% within Gender	39.2%	24.3%	31.9%
	d) Not comparable at all	Count	3	5	8
		% within Gender	4.1%	7.1%	5.6%
Total		Count	74	70	144
		% within Gender	100.0%	100.0%	100.0%

Fisher's Exact Test = 7.182, Exact Sig. (2-sided) = 0.062, Cramer's V = 0.226 (CI: 0.117-0.396)

Table 19 shows the responses to the MCQ by gender. The Fisher's Exact Test comparing MCQ and Gender is not statistically significant (p=0.062), however the Cramer's V effect size of 0.226 is medium, so it would appear that there is some influence from Gender on MCQ response. Females rate the simulator more sufficiently realistic than males, illustrated in Figure 56.

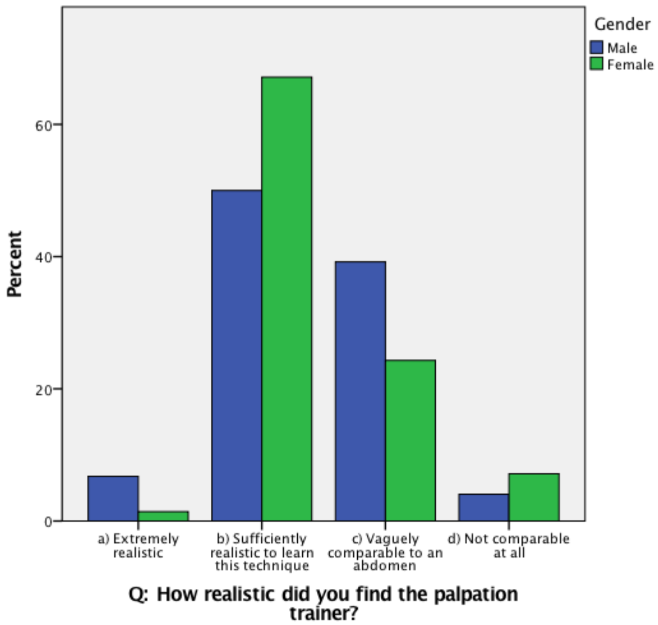


Figure 56. MCQ Responses by Gender

8.4.3 Questionnaire Responses by Participant Type

Table 20. MCQ Responses by Participant Type

			Participant Type		
			Student	Medical Graduate	Total
Q: How realistic did you find the palpation trainer?	a) Extremely realistic	Count	6	0	6
		% within Participant Type	5.1%	0.0%	4.2%
	b) Sufficiently realistic to learn this technique	Count	68	16	84
		% within Participant Type	57.6%	61.5%	58.3%
	c) Vaguely comparable to an abdomen	Count	37	9	46
		% within Participant Type	31.4%	34.6%	31.9%
	d) Not comparable at all	Count	7	1	8
		% within Participant Type	5.9%	3.8%	5.6%
Total		Count	118	26	144
		% within Participant Type	100.0%	100.0%	100.0%

Fisher's Exact Test = 0.968, Exact Sig. (2-sided) $p = 0.841$, Cramer's V = 0.106 (CI: 0.080-0.241)

Table 20 shows there was no statistical significance ($p = 0.841$) between the MCQ responses and Participant Type. Figure 57 shows the responses of medical graduates and students as a percentage of the Participant Type with approximately 60% of each responding that the simulator was sufficiently realistic to learn the technique.

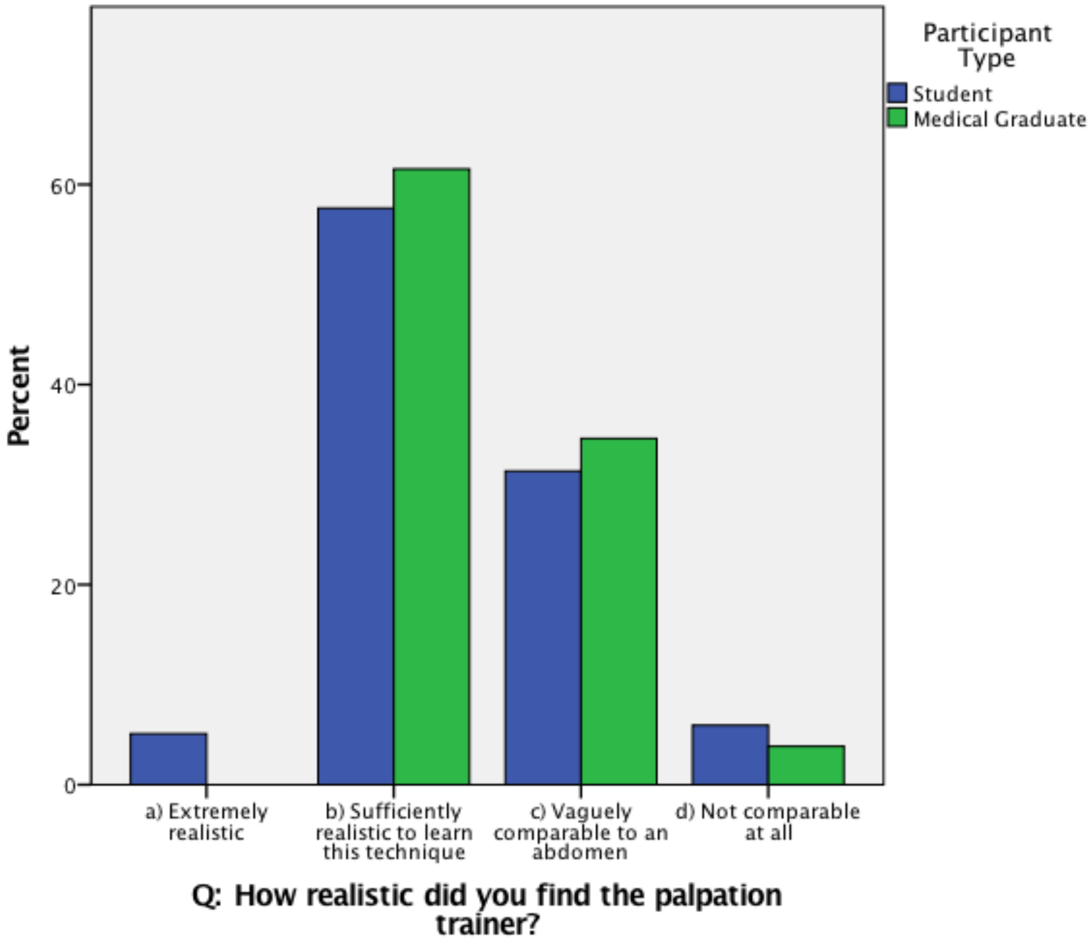


Figure 57. Participant Type MCQ Responses

8.4.4 Questionnaire Responses by Medical Graduate Years since Graduation

Table 21. MCQ responses of Medical Graduates by Years since Graduation

			Years since graduation			
			<5	5-10	10+	Total
Q: How realistic did you find the palpation trainer?	b) Sufficiently realistic to learn this technique	Count	3	5	8	16
		% within Years since graduation	50.0%	71.4%	61.5%	61.5%
	c) Vaguely comparable to an abdomen	Count	3	2	4	9
		% within Years since graduation	50.0%	28.6%	30.8%	34.6%
	d) Not comparable at all	Count	0	0	1	1
		% within Years since graduation	0.0%	0.0%	7.7%	3.8%
Total		Count	6	7	13	26
		% within Years since graduation	100.0%	100.0%	100.0%	100.0%

Fisher’s Exact Test = 2.125, Exact Sig (2-sided) = 0.875, Cramer’s V = 0.185 (CI: 0.092-0.520)

The data presented in Table 21 and Figure 58 shows there is only a small sample size for statistical comparison, with most of the cells with low values or zero cell count and only 26 medical graduate participants in total. The Fisher’s Exact test of medical graduate Years since Graduation versus MCQ responses has no statistical significance (p = 0.875) however this is likely impacted by the small cell counts.

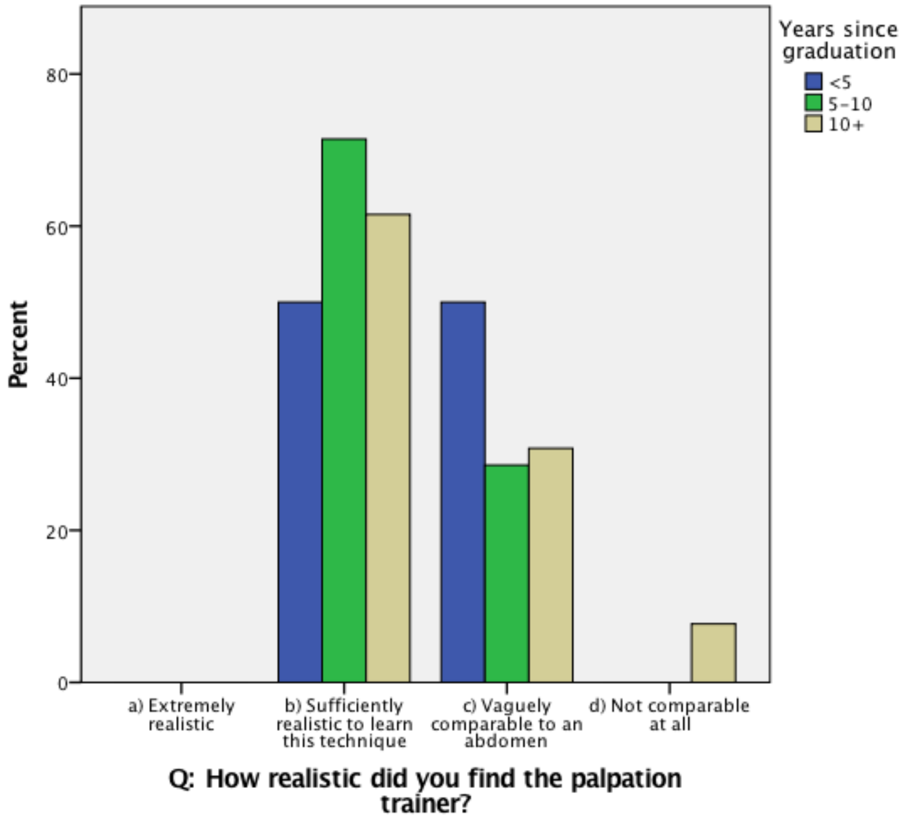


Figure 58. MCQ responses from Medical Graduates by years of experience

8.4.5 Questionnaire Responses by Student Year Level

Table 22. MCQ Responses by Student Year Level

			Year Level			
			First Year	Second Year	Third & Fourth Year	Total
Q: How realistic did you find the palpation trainer?	a) Extremely realistic	Count	4	2	0	6
		% within Year Level	9.1%	3.7%	0.0%	5.1%
	b) Sufficiently realistic to learn this technique	Count	33	28	7	68
		% within Year Level	75.0%	51.9%	35.0%	57.6%
	c) Vaguely comparable to an abdomen	Count	7	20	10	37
		% within Year Level	15.9%	37.0%	50.0%	31.4%
	d) Not comparable at all	Count	0	4	3	7
		% within Year Level	0.0%	7.4%	15.0%	5.9%
Total		Count	44	54	20	118
		% within Year Level	100.0%	100.0%	100.0%	100.0%

Fisher's Exact Test = 18.321, Exact Sig. (2-sided) = .002, Cramer's V = 0.282 (CI: 0.212-0.420)

The Fisher's Exact Test for Table 22 shows that the relationship between Student Year Level and the MCQ responses is statistically significant (p = 0.002). Figure 59 illustrates that students appear to be more critical in their responses in later levels of their medical degree. The small sample of third and fourth years (n=20) may also affect these results.

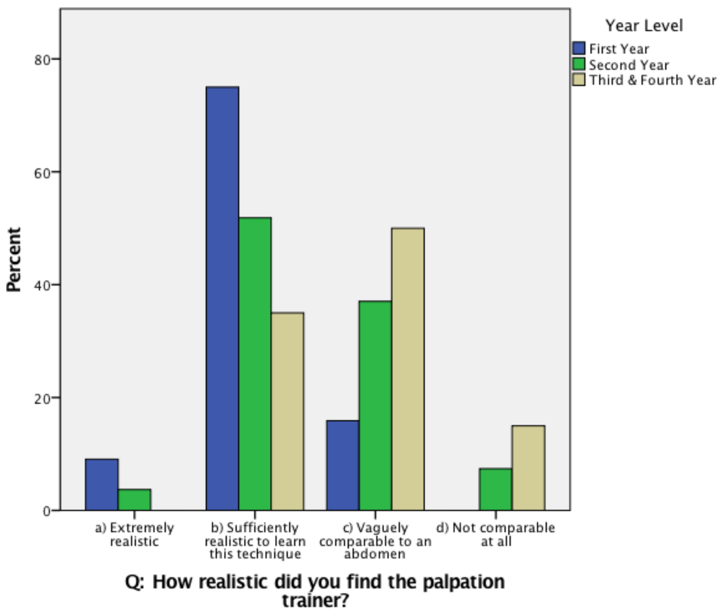


Figure 59. MCQ Responses from Students by Year Level

8.4.6 Questionnaire Responses by Skill level

Table 23. MCQ Response by Skill Level

			Regions Palpated		
			4-6	7-9	Total
Q: How realistic did you find the palpation trainer?	a) Extremely realistic	Count	3	3	6
		% within Regions Palpated	5.4%	3.4%	4.2%
	b) Sufficiently realistic to learn this technique	Count	38	45	83
		% within Regions Palpated	67.9%	51.7%	58.0%
	c) Vaguely comparable to an abdomen	Count	14	32	46
		% within Regions Palpated	25.0%	36.8%	32.2%
	d) Not comparable at all	Count	1	7	8
		% within Regions Palpated	1.8%	8.0%	5.6%
Total		Count	56	87	143
		% within Regions Palpated	100.0%	100.0%	100.0%

Fisher's Exact Test = 5.571, Exact Sig. (2-sided) = 0.124, Cramer's V = 0.128 (CI: 0.102-0.361)

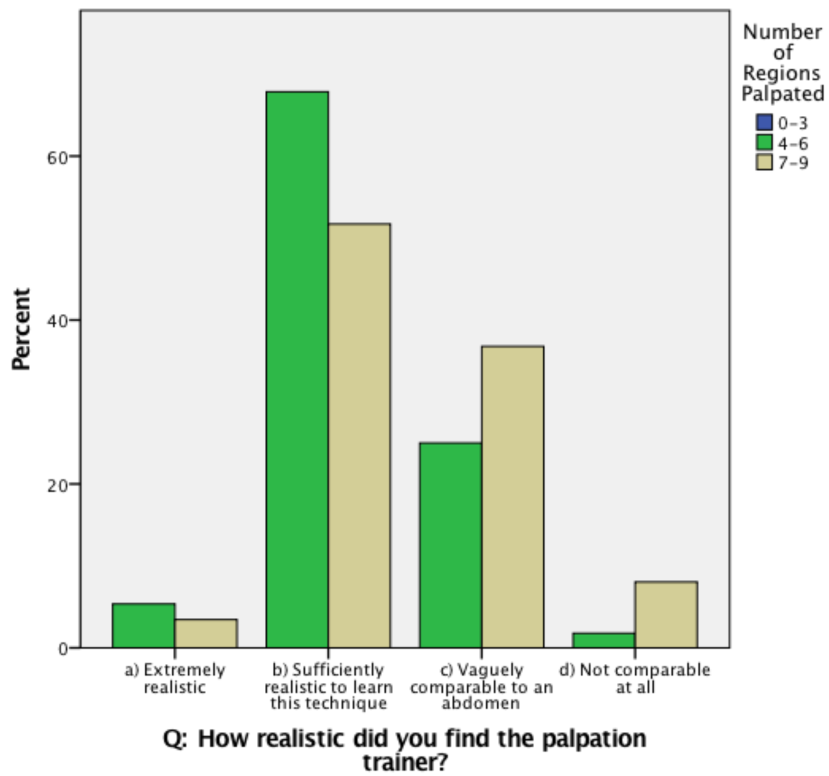


Figure 60. MCQ Responses by skill level

The final analysis of the MCQ data was to determine whether the response of participants was related to their skill level. A participant's skill level was defined by the total number of regions they had palpated. Participants were grouped into those who had palpated 0-3, 4-6, and 7-9 regions. Analysis revealed there was no significant difference (p = 0.124) (see Table 23 and Figure 60) between groups and that skill level did not influence MCQ response.

8.4.7 Results Section #1: Multiple Choice Question - Summary

The multiple-choice question "How realistic did you find the palpation trainer?" was asked of participants on a survey form following their use of the abdominal palpation simulator, to help in ascertaining whether the AbSIM Abdominal Palpation Simulator was in the medical graduates opinion sufficiently realistic for the purposes of teaching and training abdominal palpation.

The multiple-choice options to answer the question were as below:

a) Extremely realistic
b) Sufficiently realistic to learn this technique
c) Vaguely comparable to an abdomen
d) Not comparable at all

If answers a) and b) are categorised as being sufficiently realistic or better for the purposes of teaching and training abdominal palpation, and c) and d) are categorised as insufficient, then the responses can be grouped as in Table 24. This table shows that overall 62.5% (CI: 54.4-70.0%) of participants had the opinion that the simulator was sufficiently realistic for education of the abdominal palpation technique, with consistency between Medical Students and Medical Graduates and no statistically significant difference in their responses (p = 0.841 for Table 20).

Table 24. Is the abdominal simulator sufficiently realistic? Medical Student and Graduates combined responses

Participant Type	a) & b) Sufficiently realistic to learn this technique or better	c) & d) Vaguely or not comparable to an abdomen
Medical students (n=118)	62.7% CI: 53.7-70.9% (74)	37.3% CI: 29.1-46.3% (44)
Medical graduates (n=26)	61.5% CI: 42.5-77.6% (16)	42.3% CI: 25.5-61.1% (11)
Total (n=144)	62.5% CI: 54.4-70.0% (90)	37.5% CI: 30.0-45.6% (54)

Comparing responses with Gender revealed a statistical significance value of 0.062, with females marginally more inclined to respond that the simulator was sufficiently realistic than males.

The investigator also looked at whether skill level had an impact on the responses of the participants, with the number of Regions Palpated by a participant compared to their response in Table 23 but with no relationship found.

Overall the data suggests that both medical graduates and medical students find the abdominal palpation simulator sufficiently realistic (62.5% CI: 54.4-70.0) for the purpose of teaching and training abdominal palpation.

8.5 Results # 2: Other Comments Feedback, and Observations

This section addresses research question 1 (iii) in 7.1.1:

1) Does the AbSim prototype sufficiently simulate an average male abdomen?
    iii. What are the participants comments regarding the physical realism?

The results in this section include the participant "other comments" and "patient notes" from the participant response sheets where the questionnaire asked participants to "Please comment on the physical realism of the model" (see Appendix 10.13.7).

8.5.1 Participant Comments and Patient Observations

To evaluate participant comments, the responses were classified into the following categories based on common comment themes:

- Skin: thickness / rubbery texture / striations or variations in surface
- Abdomen firmness: firm / resistance / stiff / hardness / had to press more than usual
- Good tool: good / realistic / positive teaching tool
- Anatomically correct: comments regarding anatomical elements
- Extra features wanted: would like patient feedback / requests for additional features
- Blank: no comment given
- Other: individual comments not able to be classified into previous categories

Some participants commented on single aspects, many made more than one comment, so the counts of comments in Table 25 are not consistent with the number of participants, but rather the total comments made and classified. The transcribed results are included in in Appendix 10.14.2 and classifications are listed as "CommentType".

Common comments received regarding the skin related to its thickness, the rubbery texture or “sticky” feel (that moved differently to a human’s skin when trying to palpate), and striations in the moulded skin that were distracting. Comments regarding the “feel” of the simulator mentioned firmness and a larger resistance to palpation than expected, or that they needed to press harder than usual for deep palpation.

Generally, the comments regarding the skin and firmness of the abdomen were negative or suggested those elements be improved, while general comments regarding the simulator as a tool, its realism, or anatomical features were positive. A number of participants suggested additional features would improve the experience with the simulator, so these had both positive and negative aspects to them.

Table 25. Count of comment themes from participant responses

		Participant Type		Gender		
		Student (n=118) % St	**Medical Graduate (n=26) % MGs**	**Male (n=74) % males**	**Female (n=70) % females**	**Total (n=144)**
Comment Type	Skin Thickness/Rubbery	27 22.9%	7 26.9%	16 21.6%	18 25.7%	34 23.6%
	Firm/Resistance/Stiff	65 55.1%	13 50%	31 41.9%	47 67.1%	78 54.2%
	Good/Realistic/Teaching Tool	49 41.5%	8 30.8%	29 39.2%	28 40%	57 39.6%
	Anatomically correct	6 5.1%	3 11.5%	3 4.1%	6 8.6%	9 6.3%
	Would like patient feedback/extra features	11 9.3%	3 11.5%	9 12.2%	5 7.1%	14 9.7%
	Comments blank	9 7.6%	3 11.5%	11 14.9%	1 1.4%	12 8.3%
	Other	14 11.9%	1 3.8%	7 9.5%	8 11.4%	15 10.4%
Total		181	38	106	113	219

8.5.2 Results Section #2: Other Comments Feedback and Observations - Discussion

The participant response sheets included “other comments” and “patient notes” for open comments from the participants. These comments help to define the strengths and weaknesses of the abdominal simulator, the parts that were successful and those that need improvement.

The most common feedback from participants, in order of frequency, were comments regarding the firmness of the abdomen (54.2%), the realism of the simulator and its use as a teaching tool (39.6%) and the skin thickness/material (23.6%). Table 25 shows some variation between Participant Types and Gender, however the responses were fairly consistent across all groups considering the only direction to participants was to comment on physical realism.

Participant comments regarding the realism of the simulator, generally said it was realistic enough to cover aspects of examination required for patient assessment and that it was a good starting point for learning abdominal palpation. A number mentioned the physical realism or life-like appearance of the model and its anatomical accuracy for both surface anatomy, bony structures, and landmarks that would make it a good learning tool. Others commented that they thought it was bigger than a real human or that it visually didn’t look like a real abdomen.

Common participant comments regarding the skin included mention of its thickness being thicker than that of a real person, that it had a rubbery or “sticky” feel to the skin material that made it difficult to move around the abdomen, and that the superficial undulations or striations in the skin (that came from moulding process as discussed in 6.2.1.2 and Table 9) were distracting. Others said that they found the skin texture good and a more realistic material compared to other manikins, or that while the rubber was harder it gave a similar experience to real palpation. Some said it was loose and too mobile, others that it was rubbery with no movement. One suggested that due to friction on the surface a lubricant similar to body oils may make it easier to move around the surface.

Common comments regarding the “feel” related to firmness and a larger resistance to palpation than expected. Generally the consensus of these comments was that the resistance responded differently to a patient, where humans have more pliability and are easier to apply force to, and where resistance would normally ease off with gradual extra pressure, the simulator did not. Overall, consensus seemed that generally it was too firm and harder to palpate than a live human, and that participants may have used a greater force for deep palpation than usual (see 8.9 for discussion on forces).

Other suggestions or comments regarding what the participants (predominantly students) would like to see in future models of the abdominal simulator included: the addition of a face and with facial expressions in order to watch for responses to palpation; tensing or guarding of the abdomen; the ability to turn the simulator on its side to ballot kidneys; breathing with inspiration and expiration; the ability to percuss; a tutorial on how to use the simulator first.

Students are very familiar and comfortable with simulators due to the fact they train with them in normal practise. A number of the comments reflected their common tutorial practise with simulators, that in scenarios someone will generally give additional information either via the patient or an instructor will on behalf of the patient. Most of the manikins they use however look the same and are quite small sized. This simulator was of a different skin material, colour, size and appearance to the other simulators, reflected by one of the comments that said it “looked bigger than a real person”, while it was in fact moulded on a real, average-sized healthy male.

Generally the comments reflected well the strengths of the tool as a training aid, and the specific physical characteristics of the prototype simulator that could be improved with future developments.

8.6 Results Section #3: Coverage of the Abdomen

8.6.1 Total Regions Palpated

This section refers to research question 2 (i) in 7.1.1:

2) Do participants palpate the whole abdomen in a systematic way and what forces do they apply when palpating?

i. Does the coverage data from the simulator show participants palpated the whole abdomen?

The results in this section present participants' coverage of the abdomen by means of the total number of regions palpated out of the 9 abdominal regions. The coverage in this section is presented overall and for the different categorical variables of Participant Type, Gender Medical Graduates Years since Graduation, Student Year Level.

8.6.2 Total Regions Palpated Overall

Table 26. Total number of Regions Palpated, N=143

			Std. Error	95% Confidence Interval	
				Lower	Upper
Total number of Regions Palpated	Minimum	4			
	Maximum	9			
	Mean	6.92	.11	6.70	7.13

Table 26 shows that the overall range of total number of regions palpated (out of 9) for all participants was between 4 to 9 with a mean of 6.92 (CI: 6.70-7.13). So on average participants missed two regions when palpating.

8.6.3 Total Regions Palpated – by Participant Type

Table 27 shows the total number of regions palpated out of a possible 9 by medical graduates (MGs) and medical students (St). Figure 61 presents this graphically with the values of each bar displayed as the percentage within each participant type.

Table 27. Total Regions Palpated by Participant Type

			Total number of Regions Palpated						
			4	5	6	7	8	9	Total
Participant Type	Student	Count	2	17	26	34	18	20	117
		% within Participant Type	1.7%	14.5%	22.2%	29.1%	15.4%	17.1%	81.8%
	Medical Graduate	Count	0	3	8	6	8	1	26
		% within Participant Type	0.0%	11.5%	30.8%	23.1%	30.8%	3.8%	18.2%
Total		Count	2	20	34	40	26	21	143
		% within Participant Type	1.4%	14.0%	23.8%	28.0%	18.2%	14.7%	100.0%

Fisher's Exact Test value = 6.356, Exact Sig. (2-sided) p= 0.249, Cramer's V =0.218 (CI:0.134 - 0.394)

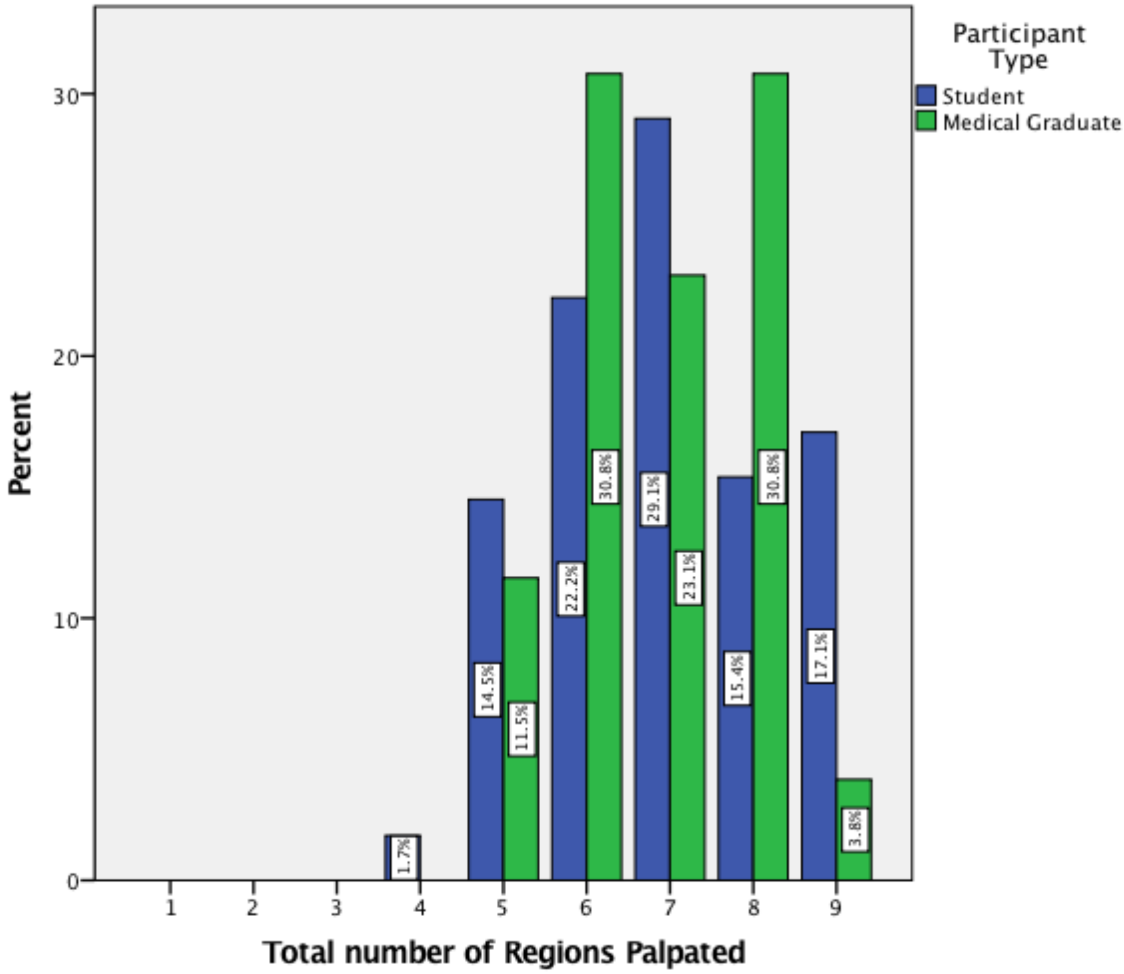


Figure 61. Total Number of Regions Palpated by Participant Type

Comparing the total number of regions palpated in Table 27 and Figure 61, we can see that all participants palpated at least 4 regions. However almost 40% of all participants missed palpating 3 regions, which shows poor coverage of the abdomen. There is no significance (p = 0.249) between Participant Type and the total number of regions palpated, so the number of regions palpated is not dependent on whether a participant was a medical graduate or student.

8.6.4 Total Regions Palpated – By Gender

Table 28 shows the total number of regions palpated according to the gender of participants, graphed in Figure 62.

Table 28. Total number of Regions Palpated by Gender

			Total number of Regions Palpated						
			4	5	6	7	8	9	Total
Gender	Male	Count	0	8	18	23	14	10	73
		% within Gender	0.0%	11.0%	24.7%	31.5%	19.2%	13.7%	51.0%
	Female	Count	2	12	16	17	12	11	70
		% within Gender	2.9%	17.1%	22.9%	24.3%	17.1%	15.7%	49.0%
Total		Count	2	20	34	40	26	21	143
		% within Gender	1.4%	14.0%	23.8%	28.0%	18.2%	14.7%	100.0%

Fisher's Exact Test = 3.614 Exact sig. (2-sided) $p = 0.628$, Cramer's V = 0.166 (CI: 0.119 – 0.348)

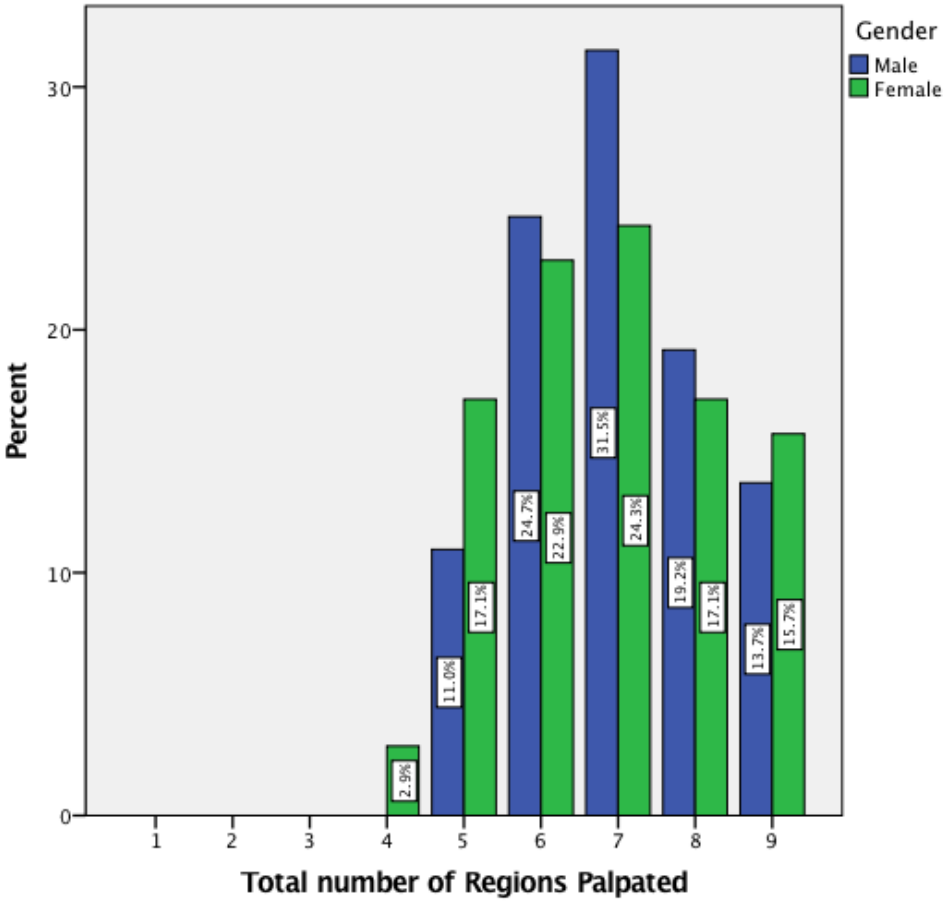


Figure 62. Total number of Regions Palpated by Male and Female Participants

Figure 62 and Table 28 show that the two participants who palpated the lowest number of regions were both female. 14 females and 8 males palpated 5 or less regions out of the possible 9. However, Fisher's Exact Test comparing gender and total regions palpated was not significant (p = 0.628) suggesting the total number of regions palpated was not dependent on gender.

8.6.5 Total Regions Palpated by Participant Type Subcategory: Medical Graduate - Years Since Graduation

Table 29. Total Number of Regions Palpated by Medical Graduates Years Since Graduation

			Total number of Regions Palpated					
			5	6	7	8	9	Total
Years since graduation	<5	Count	1	2	1	2	0	6
		% within Years since graduation	16.7%	33.3%	16.7%	33.3%	0.0%	23.1%
	5-10	Count	1	2	2	2	0	7
		% within Years since graduation	14.3%	28.6%	28.6%	28.6%	0.0%	26.9%
	10+	Count	1	4	3	4	1	13
		% within Years since graduation	7.7%	30.8%	23.1%	30.8%	7.7%	50.0%
Total		Count	3	8	6	8	1	26
		% within Years since graduation	11.5%	30.8%	23.1%	30.8%	3.8%	100.0%

Fisher's Exact Test = 2.878, Exact Sig. (2-sided) p = 1.000, Cramer's V = 0.175 (CI: 0.209 – 0.576)

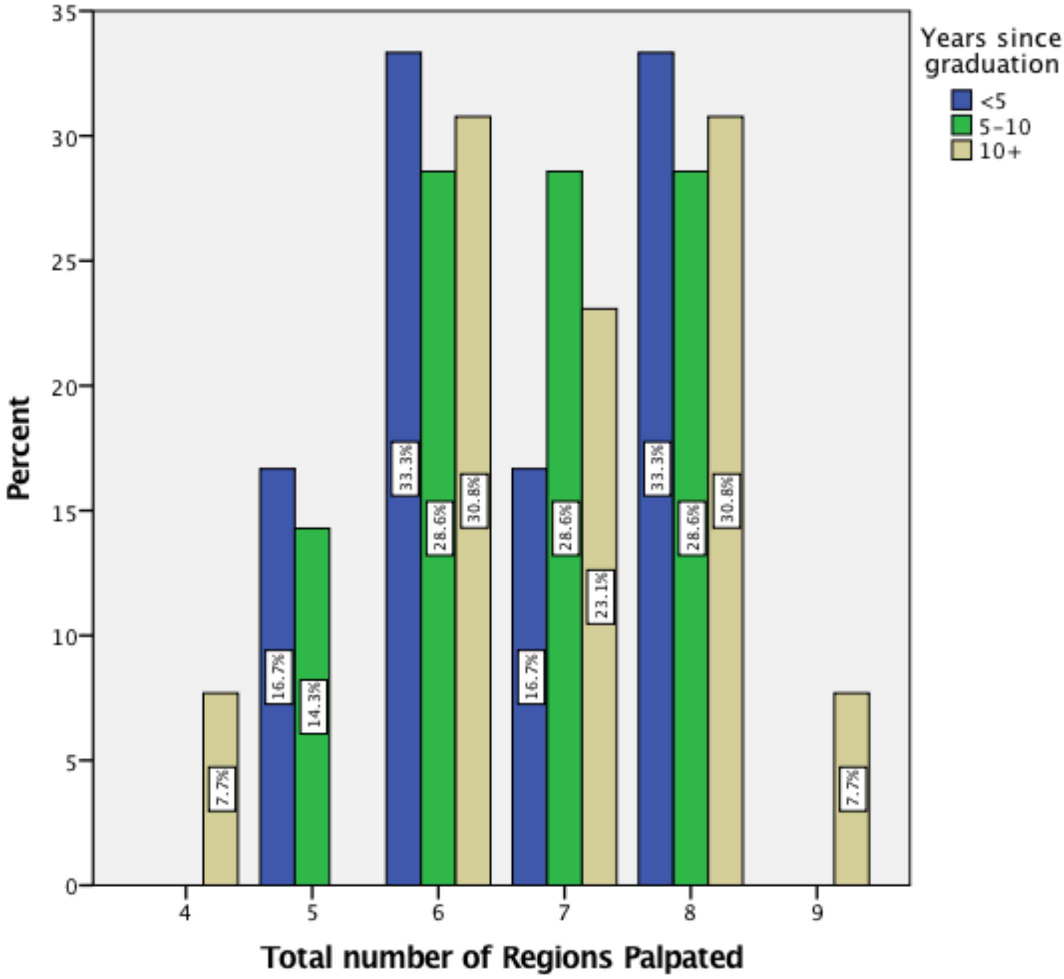


Figure 63. Total Number of Regions Palpated by Medical Graduate Years of Experience

Table 29 and Figure 63 show medical graduate years since graduation (as a measure of experience), against total number of regions palpated. The p value ($p = 1.0$) shows that the number of years of experience since graduating does not have an impact on the total number of regions palpated (noting that the sample size and frequencies in most cells in Table 29 are very small). In this group all participants palpated at least 5 regions, and only one palpated all 9 (acknowledging small sample size). Most palpated 6-8 regions (84.7%), which may be an indicator of experience informing the lack of need to palpate all regions, an indicator of poor technique more generally, or a limitation of the sample set of medical graduates and their disciplines.

8.6.6 Total Regions Palpated by Participant Type sub category: Students - Year Level

Table 30. Total number of Regions Palpated by Student Year Level

			Total number of Regions Palpated						
			4	5	6	7	8	9	Total
Year Level	First Year	Count	1	7	11	12	7	6	44
		% within Year Level	2.3%	15.9%	25.0%	27.3%	15.9%	13.6%	37.6%
	Second Year	Count	0	9	11	10	9	14	53
		% within Year Level	0.0%	17.0%	20.8%	18.9%	17.0%	26.4%	45.3%
	Third & Fourth Year	Count	1	1	4	12	2	0	20
		% within Year Level	5.0%	5.0%	20.0%	60.0%	10.0%	0.0%	17.1%
Total		Count	2	17	26	34	18	20	117
		% within Year Level	1.7%	14.5%	22.2%	29.1%	15.4%	17.1%	100.0%

Fisher's Exact Test = 18.630, Exact Sig. (2-sided) p = 0.027, Cramer's V = 0.288 (CI: 0.237-0.442)

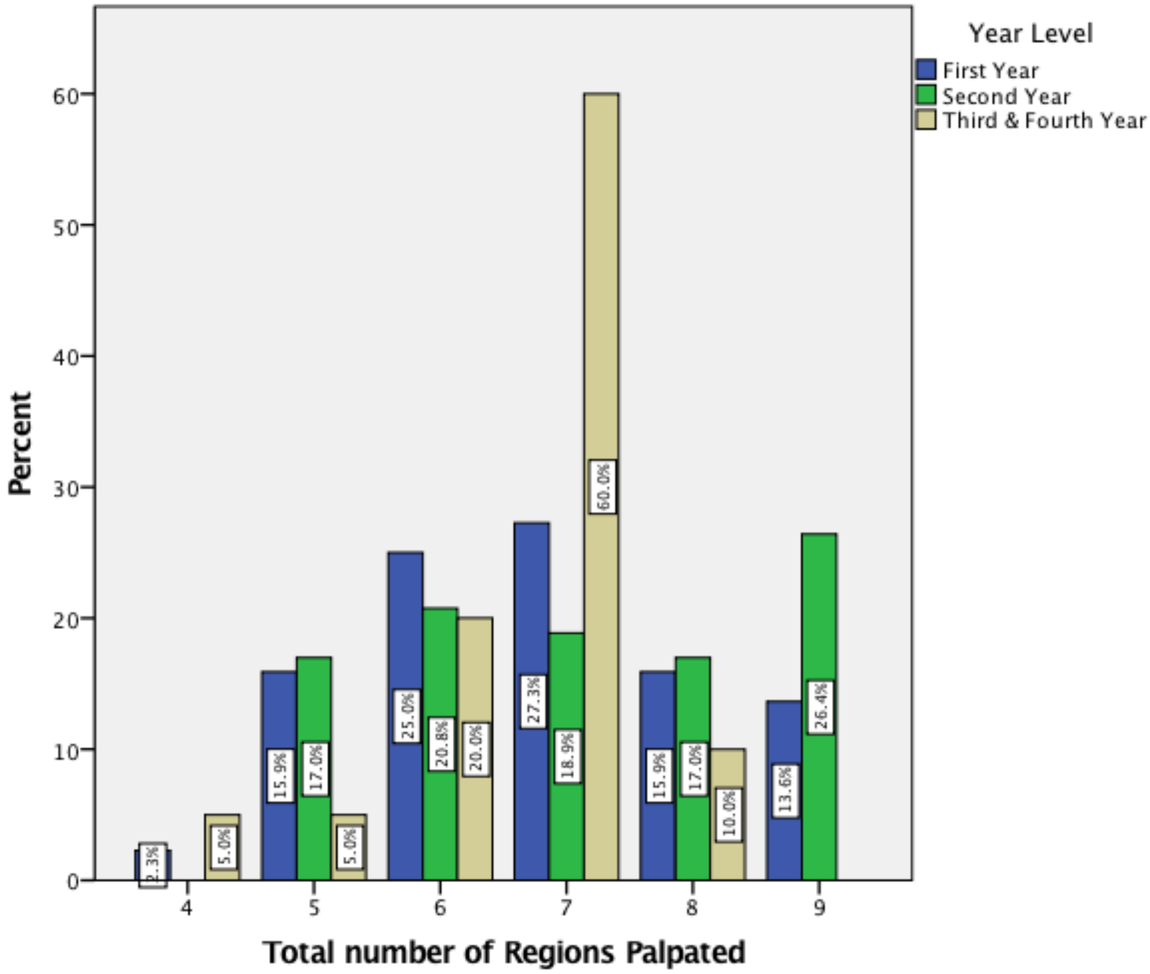


Figure 64. Total number of Regions Palpated by Student Year Level

Comparing Medical Student Year Level with the Total number of Regions Palpated in Table 30, Fisher's Exact Test was statistically significant (p=0.027) and the overall effect size of the Year Level is medium to large according to Pallant [173]. However, the smaller sample size of participants in the more experienced Third & Fourth Year Level category has an impact on this significance value.

The effect size in addition to the significance value suggests there is a relationship between the total number of regions palpated and a medical student's year level, which might be expected.

Table 30 and Figure 64 show that one Third and Fourth year student only palpated 4 regions and another only palpated 5 regions, while no Third and Fourth years palpated 9 regions. In a similar way to medical graduates (in 0), the majority (90%) of Third and Fourth years palpated 6-8 regions.

8.6.7 Results Section #3: Coverage of the Abdomen - Summary

Table 31. Summary of Total Regions Palpated significance and effect values for categorical variables

Category	Exact Sig. (2-sided)	Cramer's V
Participant Type (n = 143)	p = 0.249	0.2189 (CI: 0.134 - 0.394)
Gender (n = 143)	p = 0.628	0.166 (CI: 0.119 – 0.348)
Medical Graduate Years since Graduation (n = 26)	p = 1.000	0.175 (CI: 0.209 – 0.576)
Medical Student Year Level (n = 117)	p = 0.027	0.288 (CI: 0.237 – 0.442)

Table 31 shows the summary of all the significance values and effect sizes for coverage of categorical variables. The number of regions palpated was not statistically significant for Participant Type, Gender or Medical Graduate Years since Graduation, so the null hypothesis could not be rejected and therefore is unlikely any relationship between the total number of regions palpated and each of those categories. The only statistically significant relationship was between the total number of regions palpated and the Student Year Level where the significance value was $p = 0.027$.

Sample sizes may have had an impact on some of the results, as there was a much larger sample of medical students than medical graduates, and there were larger numbers of first and second year student participants compared to more experienced students in their later years of the degree.

Overall, participants palpated on average only 6.92 (CI: 6.70-7.13) regions out of 9, so missed on average two regions when palpating. As students are taught to cover the whole abdomen systematically, to ensure nothing is missed in diagnosis, this reveals a deficiency in the technique of both students and medical graduates.

8.7 Results Section #4: Systematism

8.7.1 Systematism of Approach

This section refers to research question 2 (ii) in 7.1.1:

2) Do participants palpate the whole abdomen in a systematic way and what forces do they apply when palpating?

> ii. When the sequence and pattern of examinations are reviewed, do results demonstrate if participants used a systematic approach?

The results in this section look at whether the participants had a systematic approach to palpation by examining the sequence order of the regions palpated, the patterns in sequence order, and whether specific regions were palpated or missed.

The first sets of data look at the first two regions palpated by each participant and if there was any relationship between the regions first palpated and participant type or gender.

The next sets of data look at the prevalence of patterns of the first three regions palpated, and if there was a greater likelihood of any three regions to be palpated first.

The final data presented in this section show which specific regions were palpated most consistently and which were most often missed. This helped to identify the gaps in current techniques and to consider any potential clinical significance to missing these areas.

8.7.2 Initial Sequence Order by Participant Type

Table 32. First and Second Region Palpated by Participant Type

Region		First Region Palpated			Second Region Palpated		
		Participant Type		Total	Participant Type		Total
		Student	Medical Graduate		Student	Medical Graduate	
1	Count	2	0	2	2	1	3
	% within Participant Type	1.7%	0.0%	1.4%	1.7%	3.8%	2.1%
2	Count	13	2	15	27	3	30
	% within Participant Type	11.1%	7.7%	10.5%	23.1%	11.5%	21.0%
3	Count	2	0	2	6	3	9
	% within Participant Type	1.7%	0.0%	1.4%	5.1%	11.5%	6.3%
4	Count	12	3	15	16	5	21
	% within Participant Type	10.3%	11.5%	10.5%	13.7%	19.2%	14.7%
5	Count	1	3	4	3	0	3
	% within Participant Type	0.9%	11.5%	2.8%	2.6%	0.0%	2.1%
6	Count	5	1	6	12	3	15
	% within Participant Type	4.3%	3.8%	4.2%	10.3%	11.5%	10.5%
7	Count	3	1	4	3	1	4
	% within Participant Type	2.6%	3.8%	2.8%	2.6%	3.8%	2.8%
8	Count	9	1	10	23	5	28
	% within Participant Type	7.7%	3.8%	7.0%	19.7%	19.2%	19.6%
9	Count	70	15	85	25	5	30
	% within Participant Type	59.8%	57.7%	59.4%	21.4%	19.2%	210%
Total	Count	117	26	143	117	26	143
	% within Participant Type	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

First Region Palpated (Student versus Medical Graduate):

Fisher's Exact Test = 7.954, Exact Sig. (2-sided) p = 0.348, Cramer's V = 0.270 (CI: 0.173 – 0.503)

Second Region Palpated (Student versus Medical Graduate):

Fisher's Exact Test = 5.280 Exact Sig. (2-sided) p = 0.701, Cramer's V = 0.178 (CI: 0.154 – 0.427)

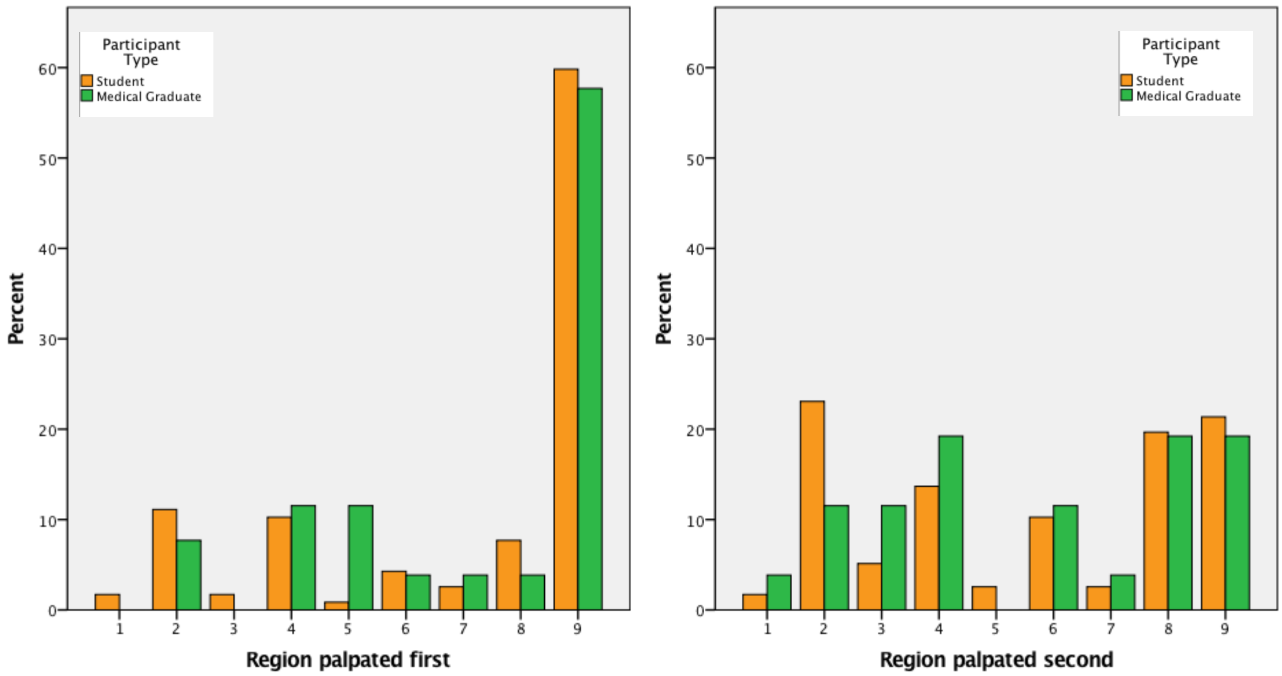


Figure 65. First and Second Region Palpated by Participant Type

Statistical comparison of the First Region Palpated and the Second Region Palpated with the Participant Type (see Table 32, Figure 65) was not significant (p = 0.348, p=0.701) so there is unlikely any relationship between the region number and if it is palpated first or second. However, the frequency count per cell for medical graduates is very small.

Figure 65 shows similarities between medical students and medical graduates and the regions they palpated first and second. Region 9 stands out as the region most commonly palpated first, with almost 60% of participants starting in that region. Another 21% of participants palpate Region 9 second, so overall >80% of participants palpate Region 9 in the first two movements within a sequence. Regions 2, 8, 4 are the next most typically pressed regions.

8.7.3 Initial Sequence Order by Gender

Table 33. First and Second Region palpated by Gender

Region		First Region Palpated			Second Region Palpated		
		Gender		Total	Gender		Total
		Male	Female		Male	Female	
1	Count	1	1	2	3	0	3
	% within Gender	1.4%	1.4%	1.4%	4.1%	0.0%	2.1%
2	Count	8	7	15	13	17	30
	% within Gender	11.0%	10.0%	10.5%	17.8%	24.3%	21.0%
3	Count	0	2	2	3	6	9
	% within Gender	0.0%	2.9%	1.4%	4.1%	8.6%	6.3%
4	Count	5	10	15	17	4	21
	% within Gender	6.8%	14.3%	10.5%	23.3%	5.7%	14.7%
5	Count	2	2	4	0	3	3
	% within Gender	2.7%	2.9%	2.8%	0.0%	4.3%	2.1%
6	Count	5	1	6	5	10	15
	% within Gender	6.8%	1.4%	4.2%	6.8%	14.3%	10.5%
7	Count	3	1	4	2	2	4
	% within Gender	4.1%	1.4%	2.8%	2.7%	2.9%	2.8%
8	Count	6	4	10	14	14	28
	% within Gender	8.2%	5.7%	7.0%	19.2%	20.0%	19.6%
9	Count	43	42	85	16	14	30
	% within Gender	58.9%	60.0%	59.4%	21.9%	20.0%	21.0%
Total	Count	73	70	143	73	70	143
	% within Gender	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

First Region Palpated (Males versus Females):

Fishers Exact Test = 7.504, Exact Sig (2-sided) $p = 0.488$, Cramer's V = 0.233 (CI: 0.198 – 0.422)

Second Region Palpated (Males versus Females):

Fisher's Exact Test = 16.785, Exact Sig (2-sided) $p = 0.020$, Cramer's V = 0.348 (CI: 0.279 – 0.512)

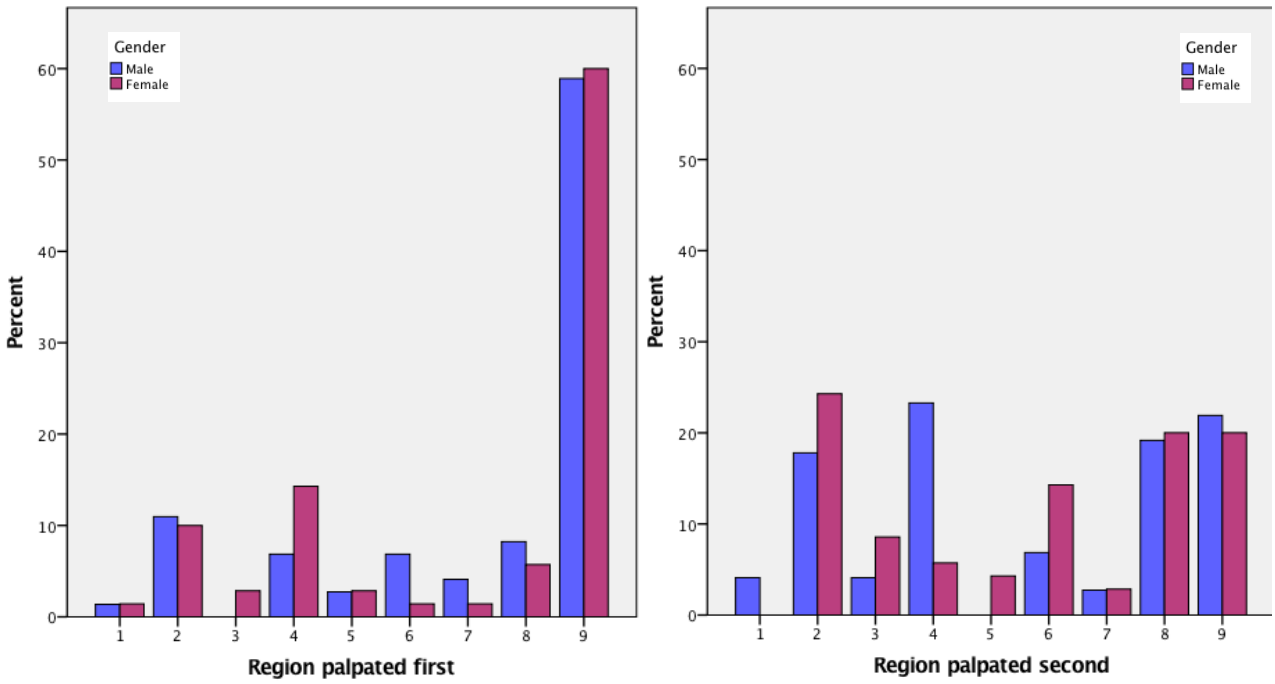


Figure 66. First and Second Regions Palpated by Gender

While the Fishers Exact Test Value for the First Region Palpated and Gender in Table 33 was not statistically significant (p = 0.488), the value for the Second Region Palpated was statistically significant (p = 0.020 < 0.05) and therefore the null hypothesis can be rejected for that case. This means that gender does have some impact on the second region palpated with a medium to large effect size (0.348 CI: 0.279-0.512). The contributing factors to this significance in Table 33 are that more females are likely to palpate Region 2, 6, or 8 second (see Figure 67), the regions closest to themselves, and males are more inclined to palpate Region 2, 4 or 8 second, in the upper half of the abdomen.

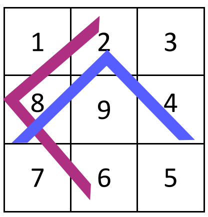


Figure 67. Regions more likely palpated second by males (blue), females (pink)

8.7.4 Initial Sequence: Student Year Level (1-4) versus region number and order

Table 34. First and Second Region Palpated by Student Year Level

Region		First Region Palpated				Second Region Palpated			
		Year Level			Total	Year Level			Total
		First Year	Second Year	Third & Fourth Year		First Year	Second Year	Third & Fourth Year	
1	Count	2	0	0	2	1	1	0	2
	% within Year Level	4.5%	0.0%	0.0%	1.70%	2.3%	1.9%	0.0%	1.70%
2	Count	4	7	2	13	11	11	5	27
	% within Year Level	9.1%	13.2%	10.0%	11.1%	25.0%	20.8%	25.0%	23.1%
3	Count	0	1	1	2	4	2	0	6
	% within Year Level	0.0%	1.9%	5.0%	1.7%	9.1%	3.8%	0.0%	5.1%
4	Count	7	5	0	12	3	9	4	16
	% within Year Level	15.9%	9.4%	0.0%	10.3%	6.8%	17.0%	20.0%	13.7%
5	Count	0	1	0	1	1	1	1	3
	% within Year Level	0.0%	1.9%	0.0%	0.9%	2.3%	1.9%	5.0%	2.6%
6	Count	1	0	4	5	5	5	2	12
	% within Year Level	2.3%	0.0%	20.0%	4.3%	11.4%	9.4%	10.0%	10.3%
7	Count	3	0	0	3	0	3	0	3
	% within Year Level	6.8%	0.0%	0.0%	2.6%	0.0%	5.7%	0.0%	2.6%
8	Count	4	4	1	9	8	12	3	23
	% within Year Level	9.1%	7.5%	5.0%	7.7%	18.2%	22.6%	15.0%	19.7%
9	Count	23	35	12	70	11	9	5	25
	% within Year Level	52.3%	66.0%	60.00	59.8%	25.0%	17.0%	25.0%	21.4%
Total	Count	44	53	20	117	44	53	20	117
	% within Year Level	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

First Region Palpated (Comparison by Year Level):

Fishers Exact Test = 23.636, Exact Sig (2-sided) p = 0.025, Cramer's V = 0.362 (CI: 0.297 – 0.516)

Second Region Palpated (Comparison by Year Level):

Fisher's Exact Test = 10.786, Exact Sig (2-sided) p = 0.837, Cramer's V = 0.221 (CI: 0.227 – 0.412)

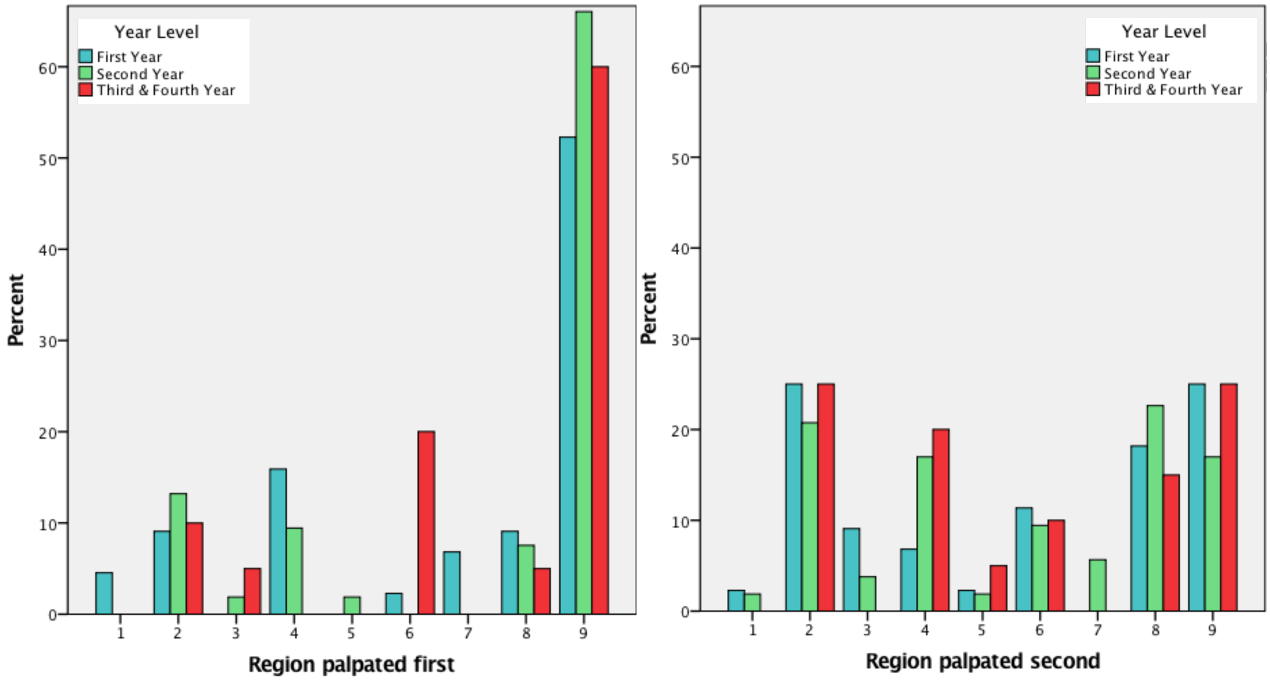


Figure 68. First and Second Region Palpated versus Year Level

Table 34 shows the first and second region palpated compared with Year Level of students. The first region palpated was statistically significantly related to year level (p = 0.025) with a medium effect size, meaning that statistically the year level influenced what region a participant started in. While again, most (60%) started in Region 9, 20% (4) of Third and Fourth year students started in Region 6.

Figure 68 shows there is similarity across year levels in the region palpated second, which is confirmed by the fact there is no statistical significance (p = 0.837) between these variables (see Table 34).

8.7.5 Patterns in first three palpated regions

To further examine the sequence of palpation for all participants, the prevalence of patterns in the first three palpated regions was examined to highlight any common approaches to the start of a palpation examination.

Table 35 shows the most common starting sequences highlighted in blue (see Appendix 10.14.1 for sequences in full), where the top six sequences start in Region 9, and Region 9 was also the most common starting region 59.4% of the time.

Table 35. Prevalence of Patterns in first three palpated regions

Sequence Pattern starting region	Number of Participants	% of Total
1	2	1.4%
1-2-9	1	0.7%
1-8-9	1	0.7%
2	15	10.5%
2-1-8	1	0.7%
2-1-9	2	1.4%
2-3-9	2	1.4%
2-4-3	1	0.7%
2-9-3	3	2.1%
2-9-4	2	1.4%
2-9-8	4	2.8%
3	2	1.4%
3-2-9	1	0.7%
3-4-9	1	0.7%
4	15	10.5%
4-3-2	1	0.7%
4-3-9	2	1.4%
4-7-8	1	0.7%
4-8-9	1	0.7%
4-9-2	5	3.5%
4-9-3	1	0.7%
4-9-6	1	0.7%
4-9-8	3	2.1%
5	4	2.8%
5-4-9	1	0.7%
5-6-9	2	1.4%
5-9-8	1	0.7%
6	6	4.2%
6-4-9	1	0.7%
6-5-9	1	0.7%
6-7-8	1	0.7%
6-8-9	1	0.7%
6-9-4	1	0.7%
6-9-8	1	0.7%
7	4	2.8%
7-6-4	1	0.7%
7-6-8	1	0.7%
7-6-9	1	0.7%
7-8-9	1	0.7%
8	10	7.0%
8-6-4	1	0.7%
8-7-9	1	0.7%
8-9-2	5	3.5%
8-9-4	2	1.4%
8-9-6	1	0.7%
9	85	59.4%
9-2-1	4	2.8%
9-2-3	10	7.0%
9-2-4	12	8.4%
9-2-8	2	1.4%
9-3-2	1	0.7%
9-3-4	3	2.1%
9-4-2	7	4.9%
9-4-3	3	2.1%
9-4-6	4	2.8%
9-4-8	3	2.1%
9-5-4	1	0.7%
9-5-6	1	0.7%
9-6-2	2	1.4%
9-6-3	1	0.7%
9-6-7	6	4.2%
9-7-6	1	0.7%
9-8-1	1	0.7%
9-8-2	13	9.1%
9-8-4	6	4.2%
9-8-5	1	0.7%
9-8-6	1	0.7%
9-8-7	2	1.4%
Grand Total	**143**	**100.0%**

Table 36 shows that within the first three regions palpated, over half the participants palpated Regions 9 and 2 (highlighted in green), which are the regions along the midline, middle and top of the abdomen.

Table 36. Regions Palpated in first three of sequence

Region	Palpated in First 3 Regions of Sequence (Count)	Palpated in First 3 Regions of Sequence (% of Total Participants)
1	10	7.0%
2	79	55.2%
3	30	21.0%
4	65	45.5%
5	8	5.6%
6	30	21.0%
7	16	11.2%
8	56	39.2%
9	135	94.4%

Table 37 shows that over half the participants (highlighted) palpated regions 9, 2, 4 and 8 within the first four palpation sequences.

Table 37. Regions Palpated in first 4 moves of sequence

Region	Palpated first in Sequence? (Count)	Palpated first in Sequence? (% of Total Participants)	Palpated in first 2 regions of Sequence? (Count)	Palpated in first 2 regions of Sequence? (% of Total Participants)	Palpated in first 3 regions of Sequence? (Count)	Palpated in first 3 regions of Sequence? (% of Total Participants)	Palpated in first 4 regions of Sequence (Count)	Palpated in first 4 regions of Sequence? (% of Total Participants)
1	2	1.4%	5	3.5%	10	7.0%	20	14.0%
2	15	10.5%	45	31.5%	79	55.2%	109	76.2%
3	2	1.4%	11	7.7%	30	21.0%	54	37.8%
4	15	10.5%	36	25.2%	65	45.5%	98	68.5%
5	4	2.8%	7	4.9%	8	5.6%	13	9.1%
6	6	4.2%	21	14.7%	30	21.0%	37	25.9%
7	4	2.8%	8	5.6%	16	11.2%	19	13.3%
8	10	7.0%	38	26.6%	56	39.2%	81	56.6%
9	85	59.4%	115	75.2%	135	94.4%	141	98.6%

Figure 69 shows the regions palpated in the first 4 moves of a sequence (as in Table 37), demonstrating that participants typically cover the top half of the abdomen in the first part of the examination but miss the edges in regions 1 and 3.

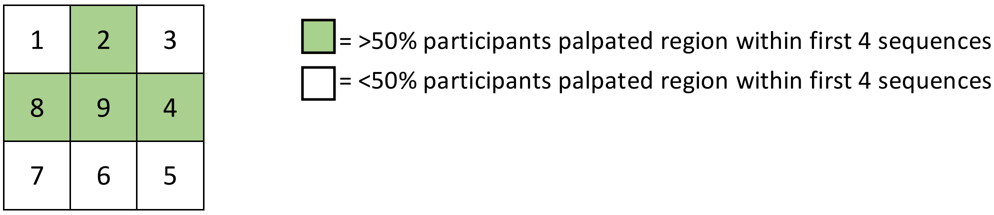


Figure 69. Regions palpated in first 4 moves of sequence

8.7.6 Region Numbers Palpated and Missed

The final data presented in this section in Table 38 show which specific regions are palpated in a region most consistently and which are most often missed. This helps to identify the gaps in current techniques and what this would mean in terms of missed clinical signs.

Table 38. Specific Regions Palpated by Participant Type

Region Palpated	Students (Count)	% Total Students (95% CL)	Medical Graduates (Count)	% Total Medical Graduates (95% CL)	Total Participants Palpated	% Total Participants Palpated (95% CL)	% Total Missed
1	65	55.6 (CI: 46.5-64.2)	14	53.8 (CI: 35.5-71.2)	79	55.2 (CI: 47.1-63.2)	44.8
2	116	99.1 (CI: 95.3-99.8)	25	96.2 (CI: 81.1-99.3)	141	98.6 (CI: 95.0-99.6)	1.4
3	105	89.7 (CI: 82.9-94.0)	22	84.6 (CI: 66.5-93.8)	127	88.8 (CI: 82.6-93.0)	11.2
4	116	99.1 (CI: 95.3-99.8)	26	100.0 (CI: 87.1-100.0)	142	99.3 (CI: 96.1-99.9)	0.7
5	51	43.6 (CI: 34.9-52.6)	13	50.0 (CI: 32.1-67.9)	64	44.8 (CI: 36.9-52.9)	55.2
6	66	56.4 (CI: 47.4-65.1)	16	61.5 (CI: 42.5-77.6)	82	57.3 (CI: 49.1-65.2)	42.7
7	65	55.6 (CI: 46.5-64.2)	10	38.5 (CI: 22.4-57.5)	75	52.4 (CI: 44.3-60.5)	47.6
8	110	94.0 (CI: 88.2-97.1)	26	100.0 (CI: 87.1-100.0)	136	95.1 (CI: 90.2-97.6)	4.9
9	117	100.0 (CI: 96.8-100.0)	26	100.0 (CI: 87.1-100.0)	143	100.0 (CI: 97.4-100)	0.0

Table 38 highlights the regions most typically palpated by students (in yellow) and medical graduates (in green) and overall (in grey) and conversely those most commonly missed (in blue). Table 38 and Figure 71 show that typically Regions 2, 3, 4, 8 and 9 are palpated (see Figure 70) most often by participants.

1	2	3
8	9	4
7	6	5

= >50% participants palpated region within first 4 sequences

= <50% participants palpated region within first 4 sequences

Figure 70. Regions commonly missed by participants

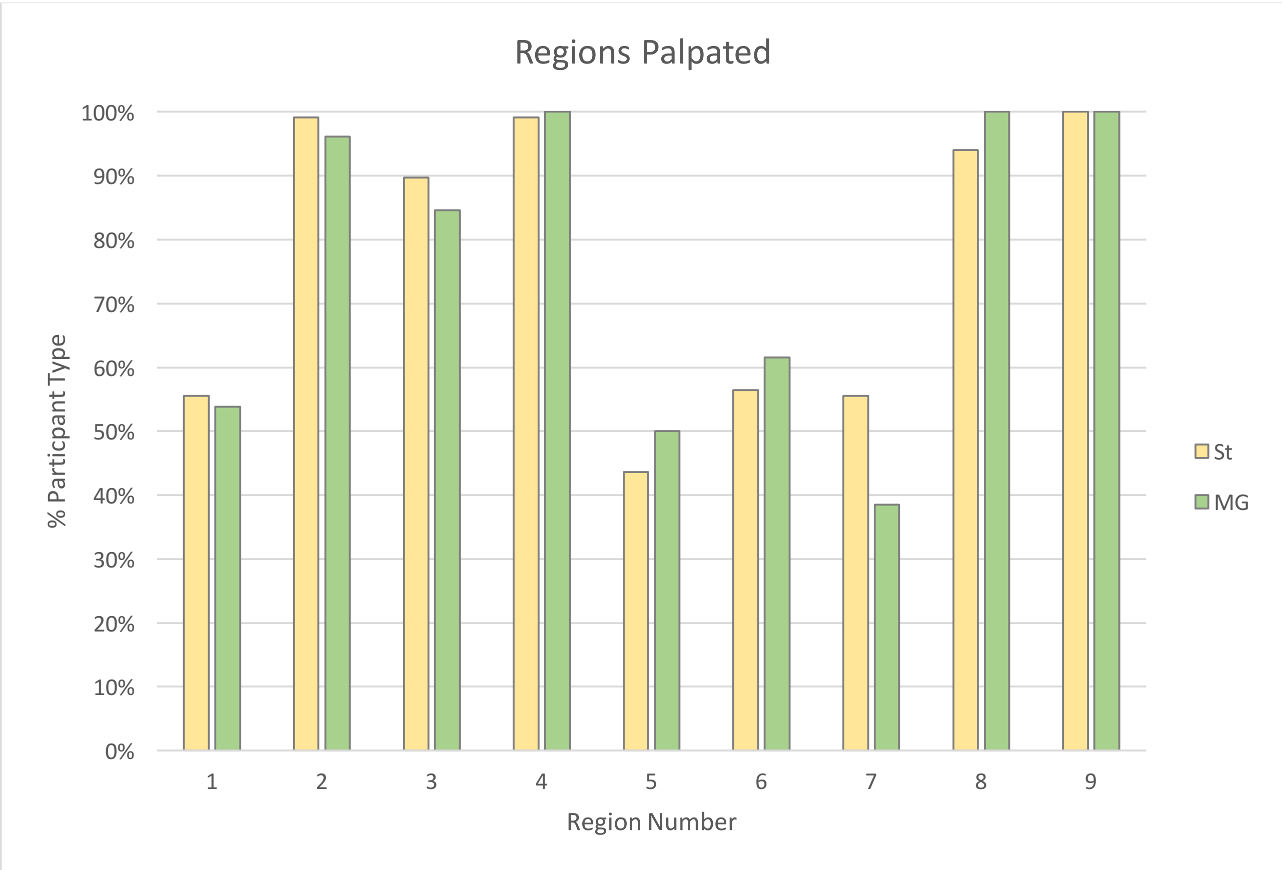


Figure 71. Specific Regions Palpated by Participant Type

Table 38 shows that Region 4, 8 and 9 are palpated by every Medical Graduate. It could be interpolated that for the whole population, Medical Graduates would always palpate across the mid-line of the abdomen in Regions 4, 8 and 9 (CI: 87-100%) shown in Figure 72a.

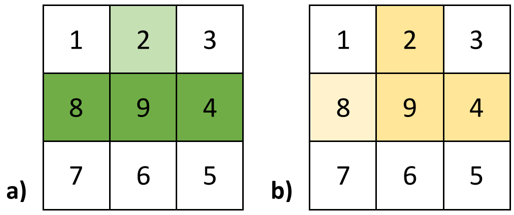


Figure 72. Shaded regions palpated at least 94% of the time by a) Medical Graduates, b) Medical Students. Darker shaded regions indicate regions palpated 99% or more of the time.

Table 38 shows that Medical Students always palpate Region 9 (100% CI: 96.8-100%), and almost always Regions 2 and 4 (99.1% CI: 95.3-99.8%), and Region 8 (94.0% CI: 88.2-97.1%) shown in Figure 72b.

Figure 72 illustrates the regions most palpated by Medical Graduates and Students as in Table 38. This shows that there are similarities in the palpation technique of Medical Graduates and Students with the same regions palpated most often by both participant types.

8.7.7 Results Section #4: Systematism - Summary

The sequence in which participants palpated regions was investigated to look at whether participants palpate the abdomen with a systematic approach and whether there were common patterns between participants. The first two regions palpated were examined for statistical relationship, and further regions in the order beyond these were not studied due to the dependence on previous regions palpated.

The first region palpated was not statistically significant for Participant Type (Table 32), or Gender (Table 33), while Medical Graduates years since graduation had too small sample size and region cell values to be able to make any assumptions for the population. Statistical analysis of Student Year Level and palpation order (Table 34) showed that the first region was related to Year Level ($p = 0.025$), where most students start in Region 9 but first years that don't start in region 9 are more likely to start in Region 4, 8, or 2, while second years are more likely to start in 2, 4 or 8 if not in 9 and Third and Fourth years were more likely to start in 6 if not 9.

Analysis of the second region palpated against the different categorical variables was significant only for Gender (see Table 33) where $p = 0.020$, and the Effect size was medium to large (0.348, CI: 0.279 – 0.512), so the null hypothesis could be rejected and some level of independence assumed between males and females and the region palpated second. The contributing factors to significance of gender and region palpated second in Table 33 and were that more females were likely to palpate Region 2, 8 or 6 second, and males were more inclined to palpate Region 4, 8 or 2 second. A possible reason for this may be that females being typically smaller than males may find it harder to lean across the abdomen to reach Region 4.

Examining the prevalence of common patterns in the first three regions (Table 35) found that region 9 was the most common starting region 59.4% of the time. The region labelled 9 was in the middle of the abdomen and clinically a likely location for an examiner to initially place their hand as they approached the patient. Regions 2, 4, and 8 were the next most commonly palpated regions in the first 3 regions to be palpated (Table 36), these are all along the midline (transverse plane) and centreline (sagittal plane) (see Figure 69). Table 37 shows that the regions participants typically covered in the first four regions of an examination sequence covered the top half of the abdomen but missed the corners (see Figure 69).

Overall Table 38 showed the most commonly missed regions were regions 1, 5, 6, and 7 that were missed over 44% of the time. That regions 5, 6 and 7 are commonly missed might be due to the intimacy of palpating regions closer to the groin. However, it is concerning that regions 1, 5, 6 and 7 are missed as often as they are palpated, as these are abdominal areas in which palpation may be of clinical relevance and could inform the diagnoses of common abdominal pathologies such as liver related conditions (Region 1), appendicitis (Region 6, 7), colon issues, Crohn's disease, hernias or problems with sigmoid colon or caecum (Regions 5-7).

These results highlight that while a systematic approach may be taught, the actual technique of students and graduates is lacking and requires further training/practise. The use of the simulator to provide feedback regarding their technique to assist in improving it, and awareness of areas missed would offer valuable information in practical training.

8.8 Results #5: Technique for diagnoses

This section refers to research question 2 (iii) and (iv) in 7.1.1:

2) Do participants palpate the whole abdomen in a systematic way and what forces do they apply when palpating?

iii. What do the data reveal about the technique of medical students versus medical graduates, the forces they applied, and the time they took to complete the examination?

iv. Were they able to detect any abnormalities (e.g. pathologies) in the simulator?

The results in this section uses Generalised Linear Mixed Model (GLMM) to statistically model the data (see 7.4.2.3) and produce estimates of the following cases, including the effects of the lesion placement on each:

- Average force of palpation peaks in each region
- Average time spent in each region
- Average count of palpation peaks in each region

8.8.1 Average Force of Peaks in Regions

8.8.1.1 Checks for normality of data

Checks for normality were undertaken with typically used statistical tools [168], and displayed using frequency histograms (see Figure 73).

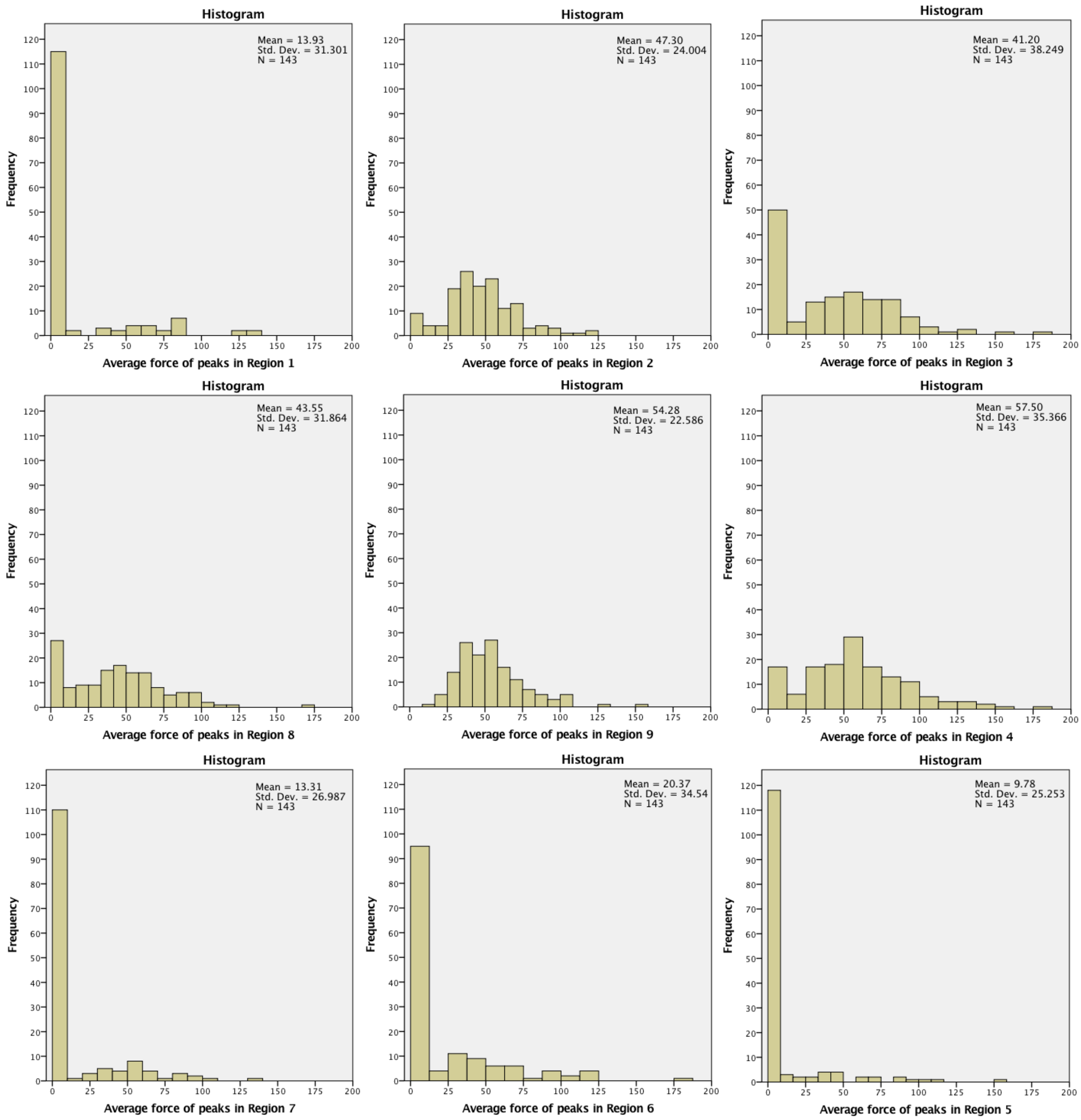


Figure 73. Histograms of F_{av_peaks} in Regions 1-9 as per 1-9 labelling of Regions in abdominal palpation simulator model

Figure 73 illustrates the highly-skewed distribution of the average force of peaks in Regions 1, 5, 6, 7 and the low frequency of palpation recorded in these regions with high frequencies of participants recording zeros (i.e. no palpation force applied in that region). This matches the data seen in Table 38, while the distribution of the data in Regions 2, 3, 4, 8 and 9 is less skewed as there is more frequency of palpation in these regions.

The GLMM model was used to estimate the average force of peaks, as it doesn't require the assumption that the dependent variable follows a normal distribution (as per other commonly used statistical models).

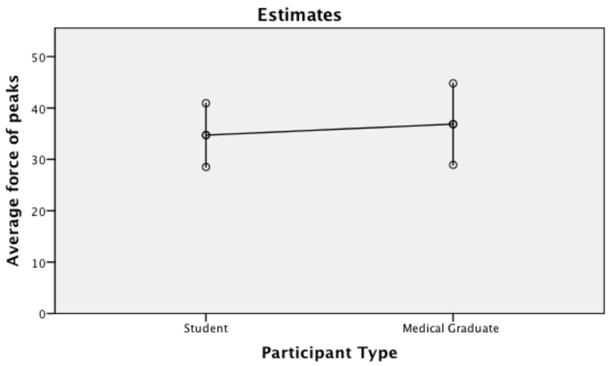
8.8.1.2 Factor Effects: Average Force Peaks per Region

To estimate the Average Force Peaks per region, the GLMM controls for within factor effects (see 7.4.2.3). Table 39 shows the Fixed Effects of the model for average force of peaks per region and that the Participant Type, Lesion Region Location and Gender are not significant. Figure 74a illustrates this for Participant Type, while Figure 74b shows how Gender has a smaller significance value than Participant Type (p = 0.54) and more likely to have effect on the average force of peaks in region estimates with males pressing slightly harder than females.

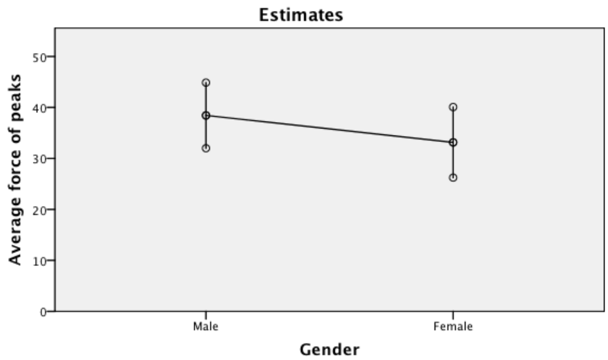
Table 39. GLMM Average force peaks per region: Fixed Effects

Source	F	df1	df2	Sig.
Corrected Model	16.158	46	1240	.000
Participant Type	.331	1	1240	.565
Lesion Region	1.841	4	1240	.119
Gender	3.718	1	1240	.054
Region	19.478	8	1240	.000

Model parameters: Probability distribution: Normal, Link function: Identity[a]



a)



b)

Figure 74. a) Effects of Participant Type on GLMM b) Effects of Gender on GLMM

Table 39 and Figure 75 show the location of the lesion is inconsequential (p = 0.464) to estimates of average force of peaks in a region, with participants applying a similar force in regions with a lesion, and more force in regions where there are none.

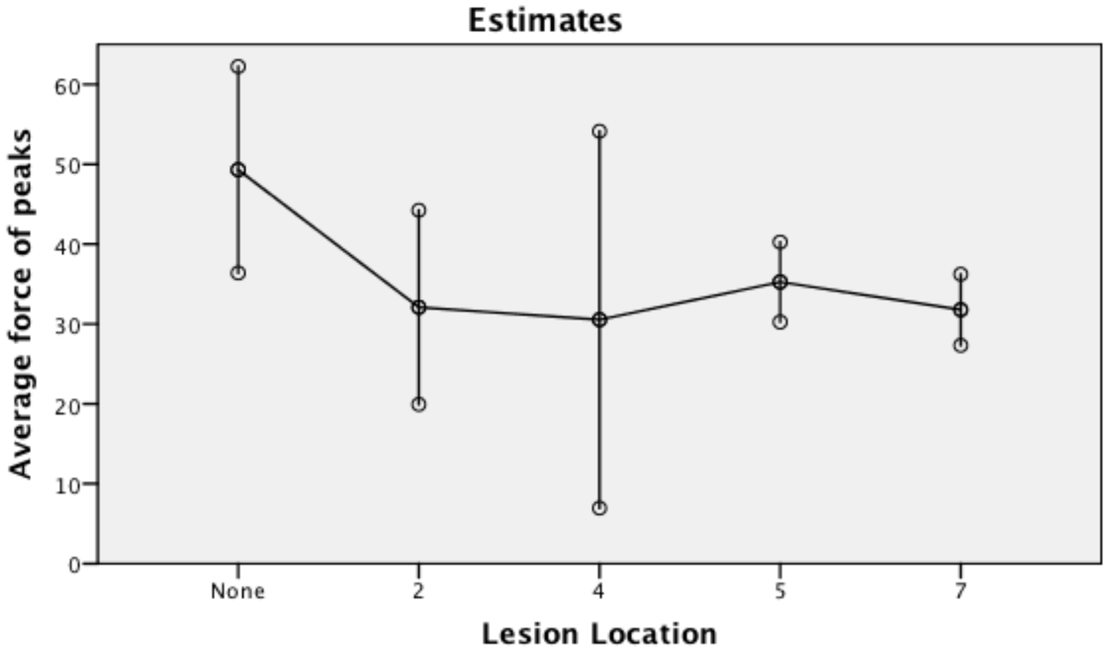


Figure 75. Effects of Lesion Location on GLMM

8.8.1.3 Average Force of Peaks in Region – Estimates

Table 40 and Figure 76 show the Estimates of the average force of peaks in each region for the full dataset using the GLMM. Confidence can be placed in the estimates from this model because the GLMM addresses and controls for the nesting and within factors (due to regions being related to the same participant), noting regions 1, 5, 6 and 7 had high frequency of zeros therefore small number of overall participants contributing to the estimates for those regions, and therefore less reliable values to interpolate for the whole dataset.

Table 40. Estimates of Average Force (N) of Peaks in Regions, full dataset

Region	Mean	Std. Error	95% Confidence Interval	
			Lower	Upper
1	19.492	6.081	7.562	31.423
2	49.212	4.334	40.710	57.714
3	45.222	6.948	31.591	58.853
4	57.667	5.883	46.124	69.209
5	11.112	5.365	.586	21.639
6	17.500	6.261	5.217	29.784
7	16.617	5.267	6.285	26.950
8	48.067	5.201	37.863	58.271
9	57.230	3.843	49.689	64.770

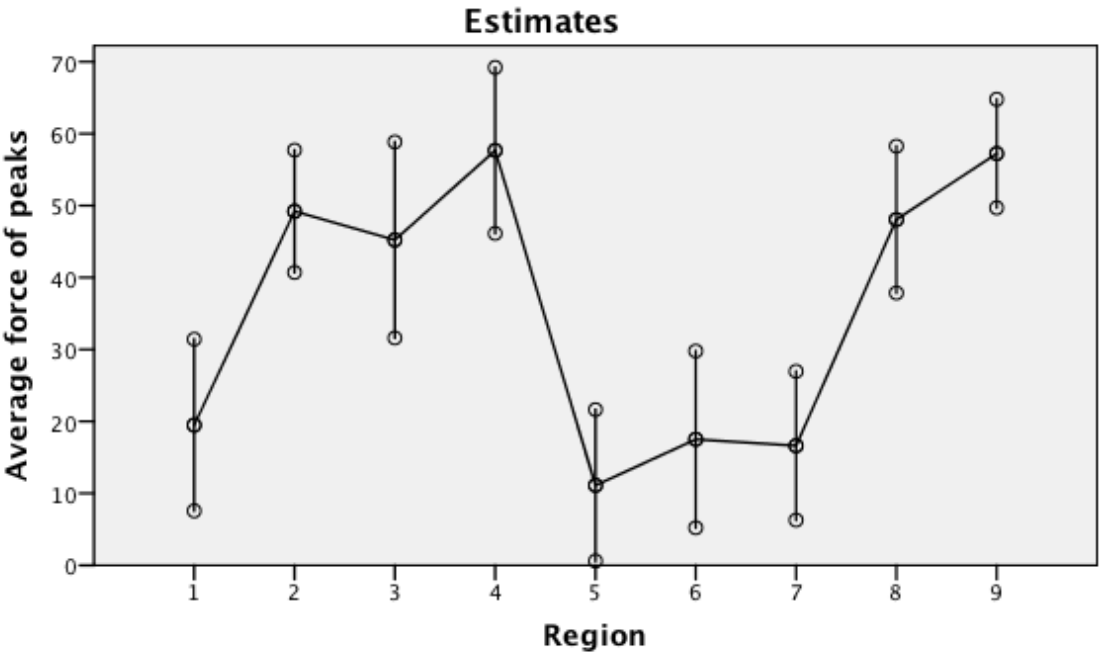


Figure 76. Estimates of Average force of peaks in Region with GLMM, full dataset

8.8.1.4 Pearson Residual for GLMM of Average Force of Peaks per Region

The data transformations of the GLMM model for the average force of peaks per region are illustrated (see Figure 77 histogram) using Pearson Residual value. The Pearson Residual demonstrates the discrepancy between the model estimates and the raw data. In this instance, the Pearson Residual approximates a normal distribution (noting some outliers), indicating that model and results for estimates of average force in regions can be trusted.

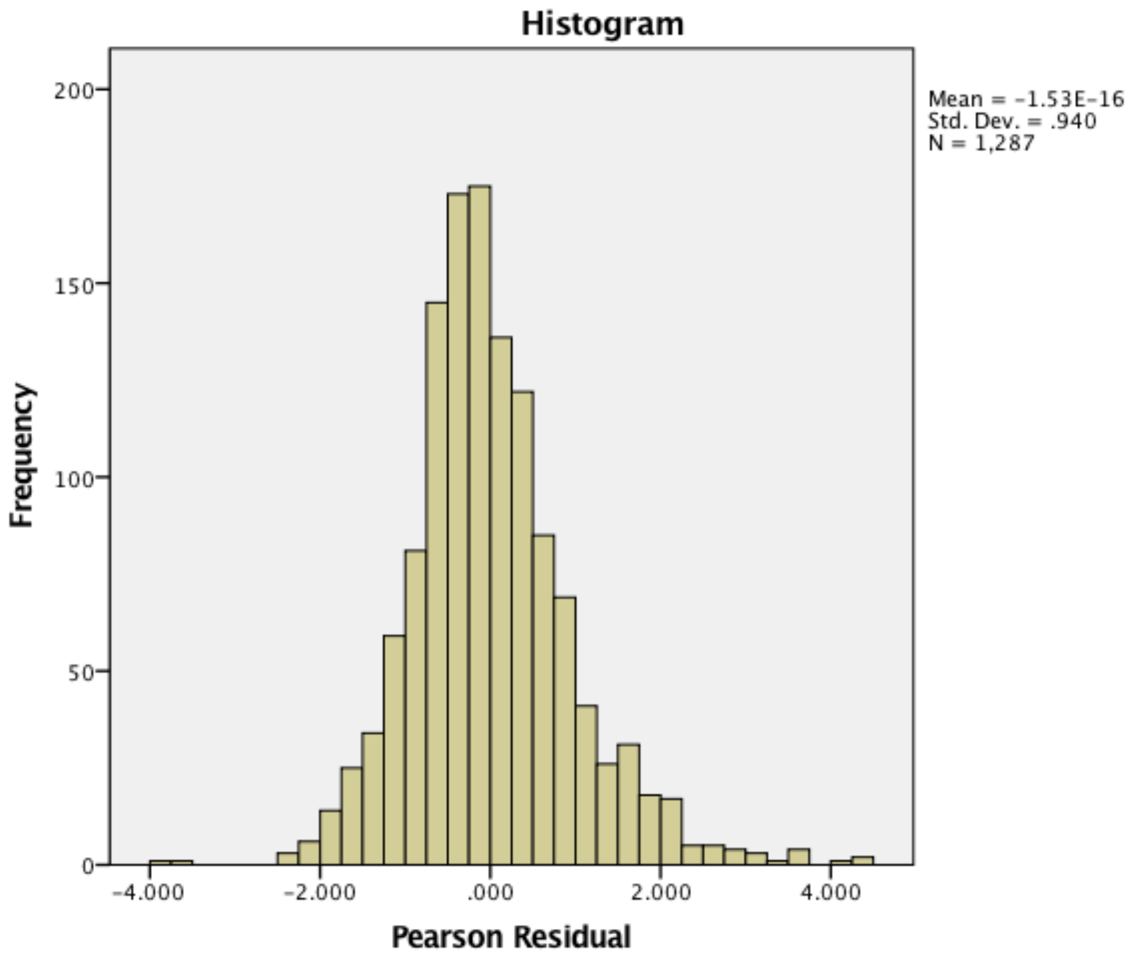


Figure 77. Pearson Residual for Average Force of Peaks per Region GLMM model

8.8.2 Count of Peaks in Each Region

8.8.2.1 Checks for Normality of data - Count of Peaks per Region

Normality checks were completed as for the previous section (see Figure 78), with similar observations in that the number of peaks in regions 1, 5, 6 and 7 had severely skewed distributions and high frequencies at zero. Regions 2, 3, 4, 8 and 9 were asymmetrically skewed, with region 9 the closest to approaching a normal distribution.

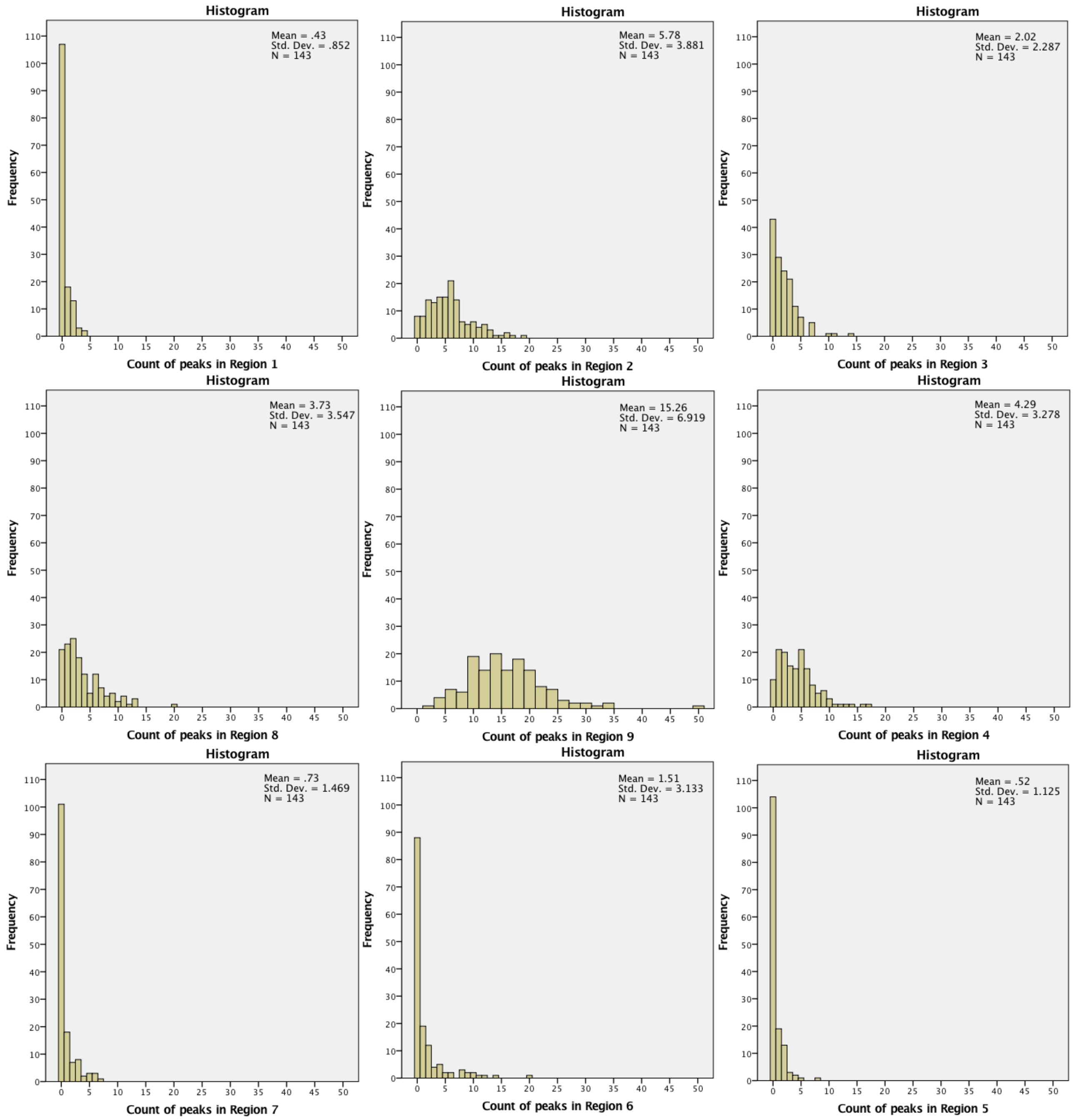


Figure 78. Frequency histograms for Count of Peaks in Regions

8.8.2.2 Within Factor Effects

Table 41. GLMM Count of peaks per region: Fixed Effects

Source	F	df1	df2	Sig.
Corrected Model	35.914	46	1240	0.000
Participant Type	0.000	1	1240	0.997
Lesion Region	1.102	4	1240	0.354
Gender	2.073	1	1240	0.150
Region	25.983	8	1240	0.000

Model Parameters: Probability distribution: Poisson, Link function: Log[a]

Table 41 shows that the effects of the Participant Type, Gender and Lesion Location factors on the count of peak estimates will be negligible as $p > 0.05$ for each variable.

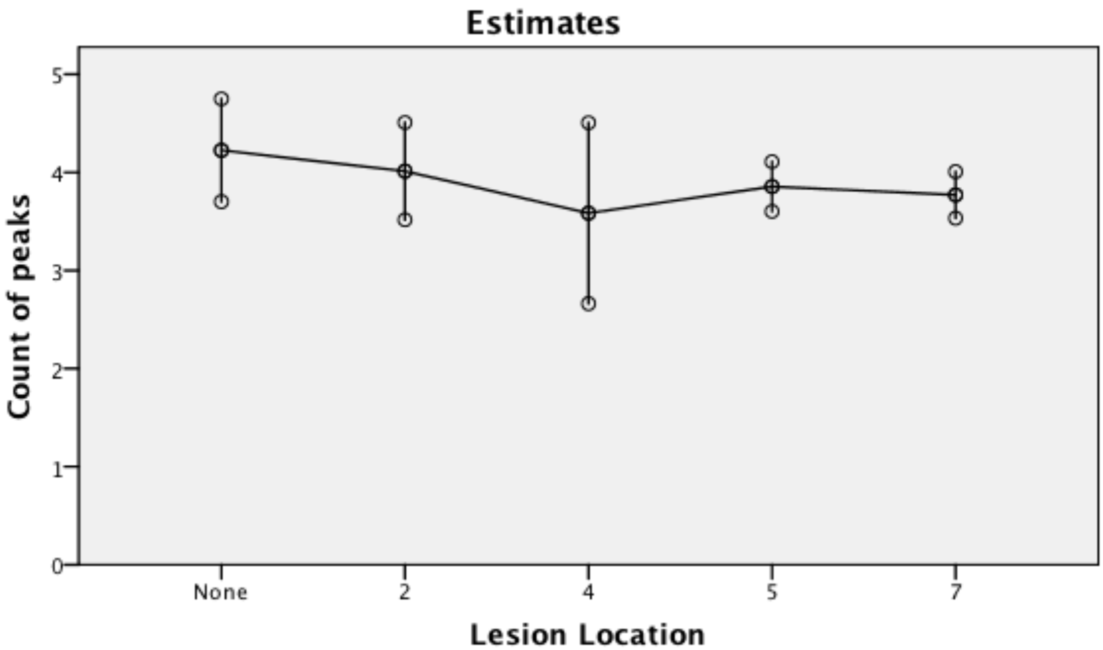


Figure 79. GLMM within factor, Count of peaks in regions, Lesion Region Location

8.8.2.3 Average Count of peaks Estimates

Table 42. GLMM Count of peaks in regions, Estimates

Region	Mean	Std. Error	95% Confidence Interval	
			Lower	Upper
1	.492	.143	.278	0.868
2	5.854	.733	4.578	7.485
3	1.542	.499	.817	2.911
4	3.865	.709	2.697	5.540
5	.101	2.597	0.000	∞
6	.237	5.414	0.000	∞
7	.150	3.770	0.000	∞
8	3.760	.646	2.684	5.267
9	14.068	1.263	11.795	16.778

8.8.2.4 Pearson Residual for GLMM of Average Count of Peaks

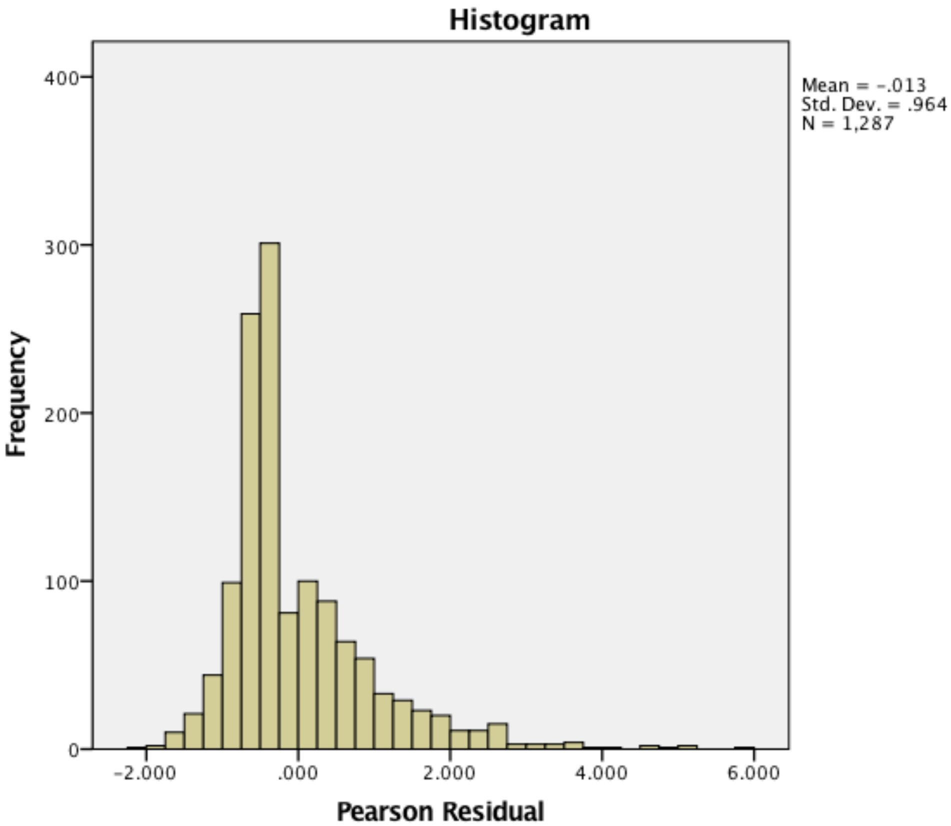


Figure 80. Pearson Residual of GLMM Count of peaks in regions

Table 42 shows the GLMM Estimates of the mean Count of Peaks in each region. The low frequency counts of peaks in regions 1, 5, 6, 7 impact the confidence of estimates for those regions as there are few data contributing to the estimates. The histogram of the Pearson Residual in Figure 80 shows that it is not a perfectly normal-shaped distribution, however the model provides a sufficient estimation of the counts per region for the regions 2, 3, 4, 8, 9 for the purposes of the estimate.

8.8.3 Time in Regions – GLMM model

8.8.3.1 Checks for Normality of data - Time in Regions

Normality checks were completed as for previous sections, with similar outcomes, whereby the time in regions 1, 5, 6 and 7 had severely skewed distributions with high frequencies at zero. Regions 2, 3, 4, 8 and 9 were also asymmetrically skewed, with region 9 having a histogram the closest to approaching a normal distribution.

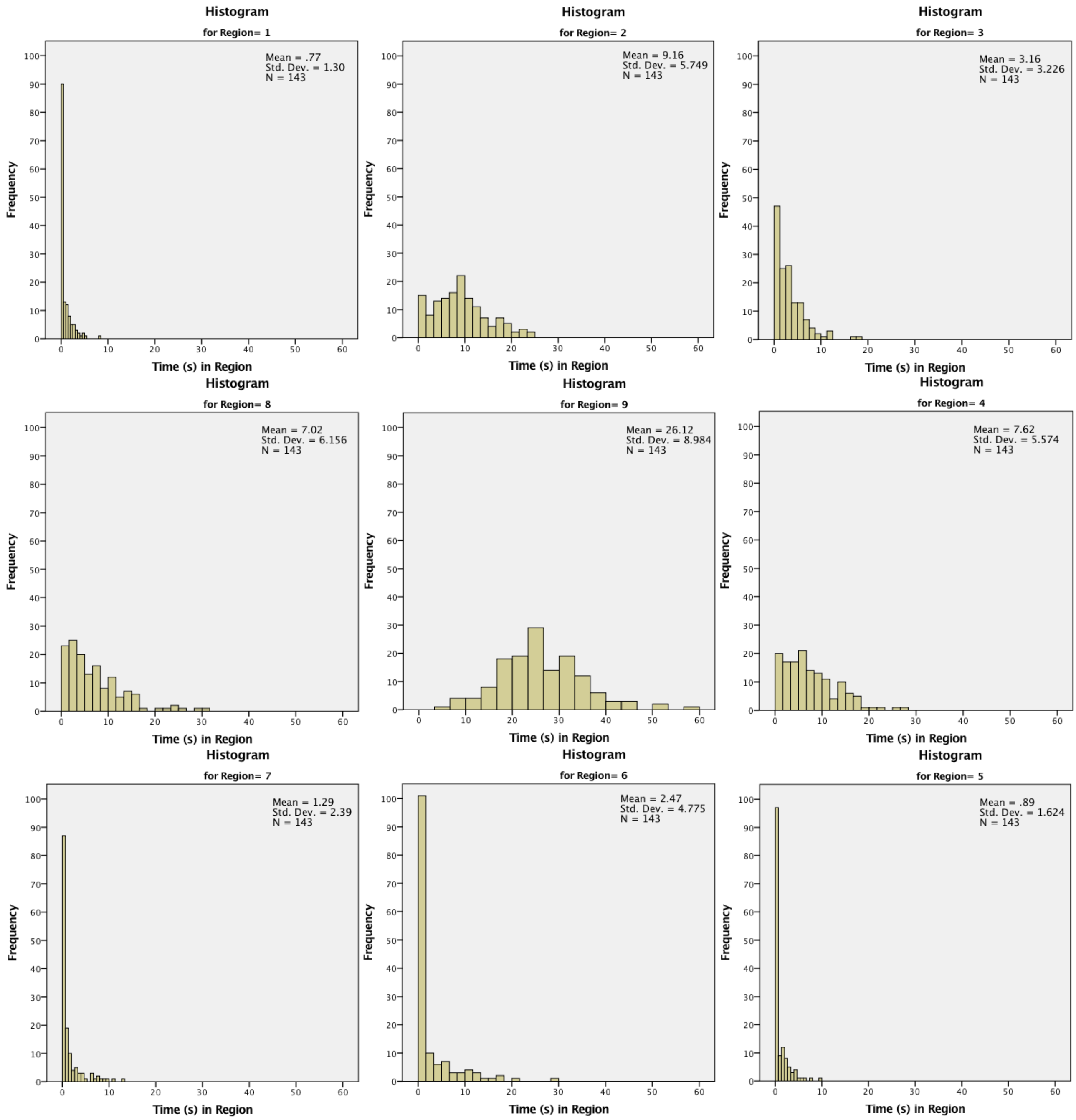


Figure 81. Frequency histograms for time spent in regions

8.8.3.2 Within Factor Effects

Table 43. GLMM Time in Regions: Fixed Effects

Source	F	df1	df2	Sig.
Corrected Model	123.147	46	1272	0.000
Participant Type	0.062	1	1272	0.804
Lesion Region	1.472	4	1272	0.208
Gender	3.396	1	1272	0.066
Region	214.238	8	1272	0.000

Model Parameters: Probability distribution: Normal, Link function: Identity[a]

Table 43 shows that for GLMM Estimates of Time in Regions, the factors participant type (p=0.804) and region location of lesion (p=0.208) are unlikely to have an effect on the time spent palpating in a region. While Gender is also not statistically significant (p=0.066), it is more likely to have an effect on the time spent in regions than the other factors. Figure 82 shows the effect of Gender on Time in Regions with females spending marginally more time than males in regions.

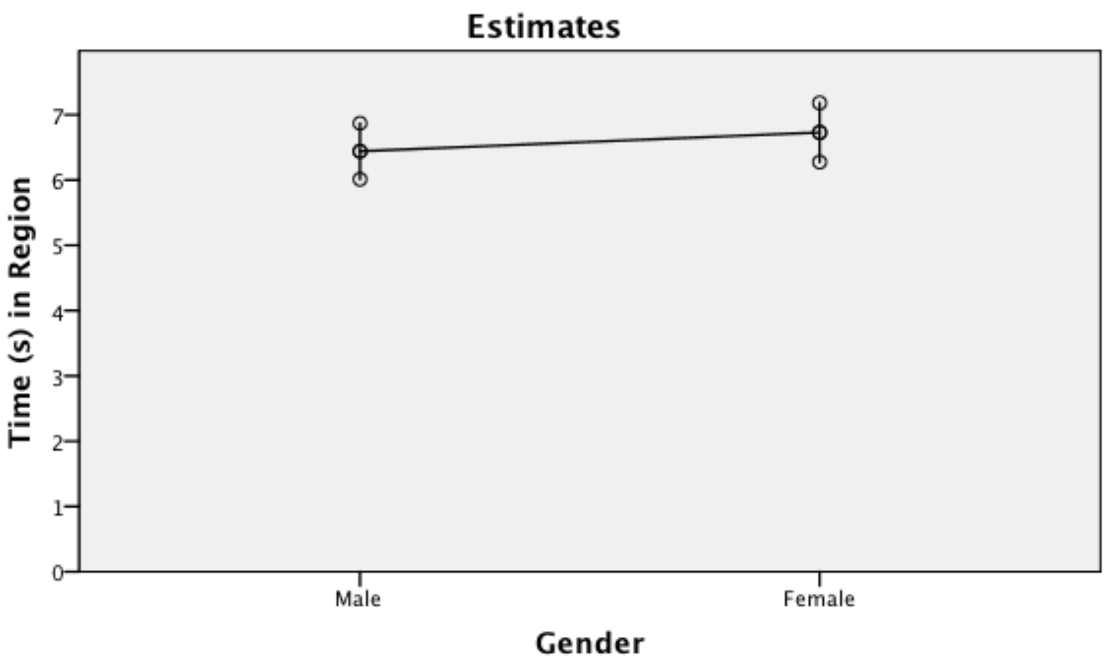


Figure 82. GLMM Estimates within factor, Time in Regions, Gender

Figure 83 shows effect of lesion location on GLMM estimates negligible (p=0.208), with time spent within the region when the lesion was in Region 4 approximately 1 second less than none or other locations, though with a larger standard deviation.

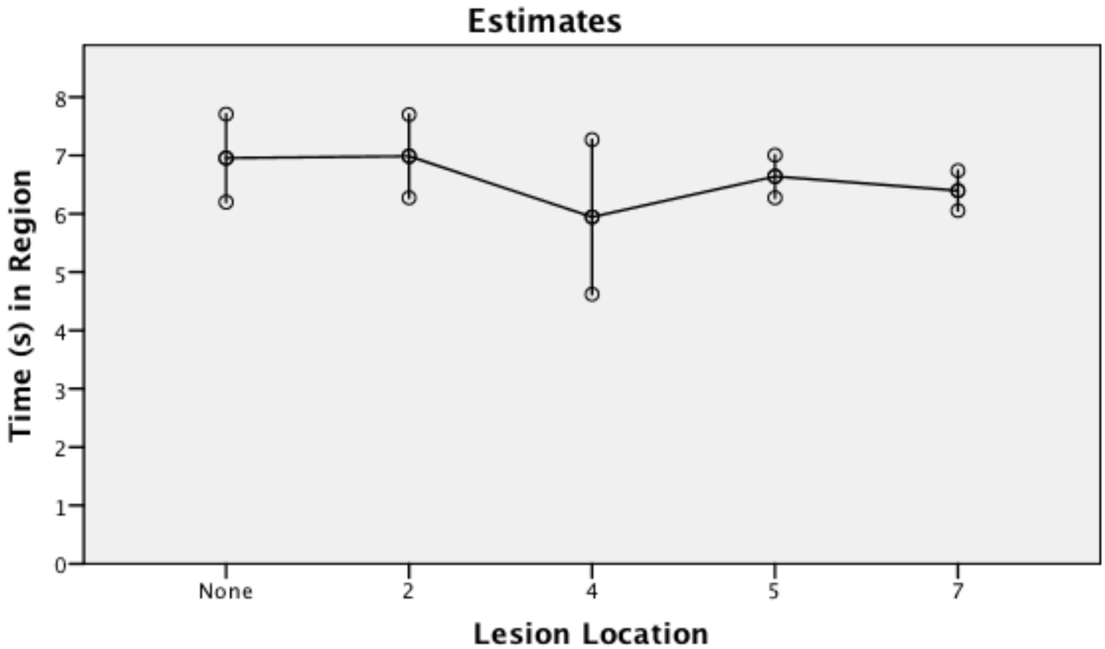


Figure 83. GLMM Estimates within factor, Time in Regions, Lesion Region Location

8.8.3.3 GLMM Estimates of Average Time in Regions

Table 44. GLMM Estimates Time in Regions

			95% Confidence Interval	
Region	Mean	Std. Error	Lower	Upper
1	.823	.192	.447	1.199
2	9.240	.506	8.246	10.233
3	3.228	.312	2.616	3.840
4	7.719	.489	6.760	8.678
5	.961	.205	.559	1.364
6	2.534	.425	1.700	3.369
7	1.353	.249	.864	1.842
8	7.087	.532	6.042	8.131
9	26.314	.775	24.794	27.833

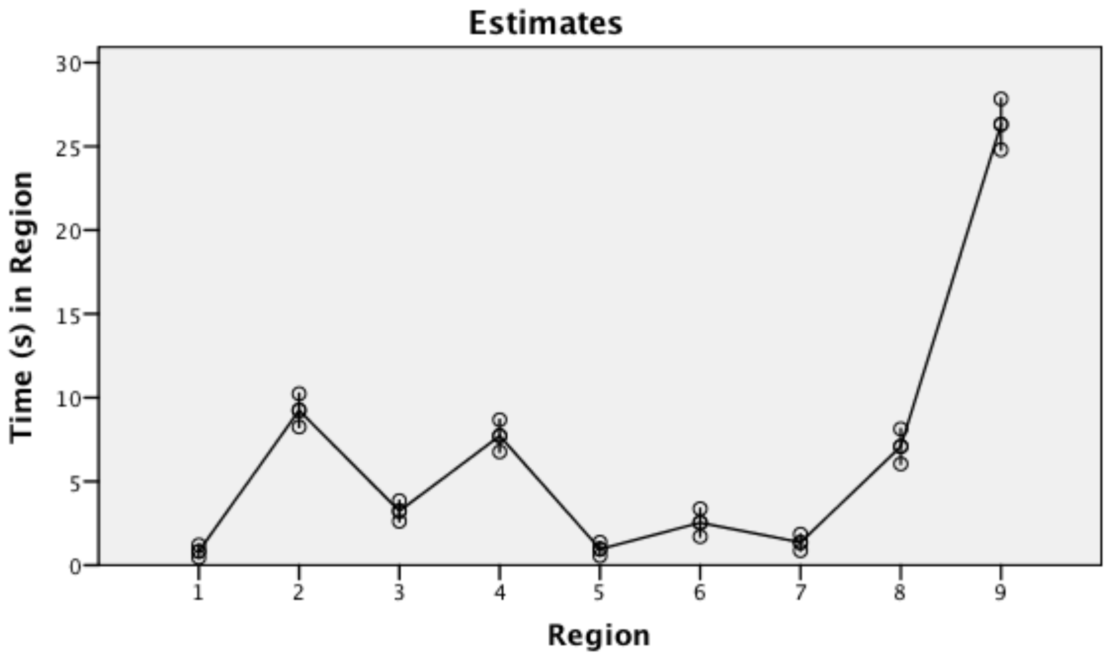


Figure 84. GLMM Estimates Time in Regions

Table 44 and Figure 84 show the estimates of average time spent palpating each region, with notably participants spending most time in Region 9 (middle of abdomen), next most time in regions 2, 4 and 8 and minimal time in regions 1, 5, 6 and 7, as evidenced by the frequency histograms.

8.8.3.4 Pearson Residual for GLMM of Time in Regions

The distribution of Pearson's Residual of the GLMM transformation in Figure 85 was still positively skewed, but a closer approximation to a normal distribution than before the GLMM was applied.

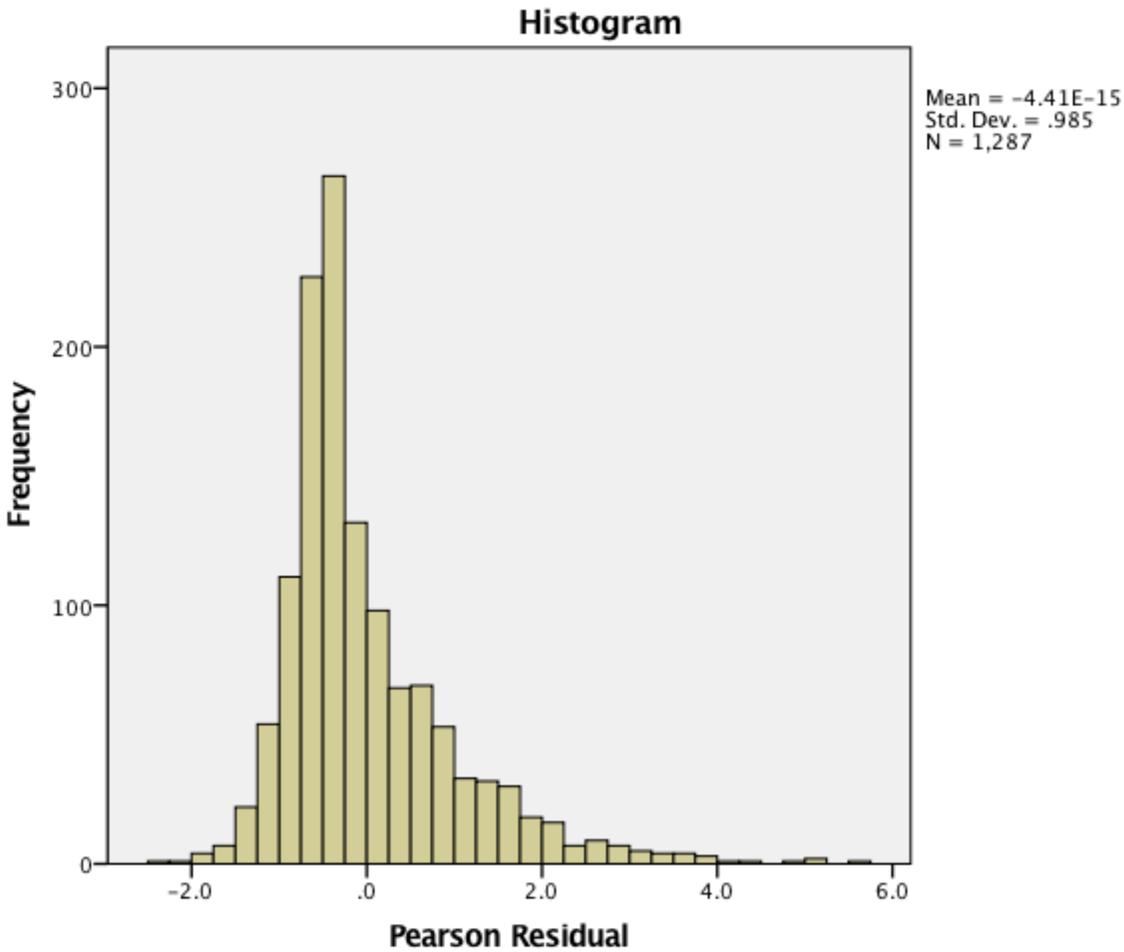


Figure 85. Time in Regions GLMM Pearson Residual Histogram

8.8.4 Results Section #5: Technique - Summary

The technique of participants was investigated to determine if they had an appropriate procedure for abdominal diagnosis. For each region the average forces, number of peaks, and time spent was analysed to determine the mean values and if there was any statistically significant difference when there was a lesion.

Since the nine regions for each dataset were all related to the same subject (the abdominal palpation simulator), the Generalised Linear Mixed Model (GLMM) was used to statistically model the categorical data (refer to 7.4.2.3). A summary of the estimate of the means per region for each of the categorical variables from the GLMM is shown in Table 45. This shows the range of mean forces in individual regions were from 12.2N (CI: 5.0-19.4) to 59.9N (CI: 52.4-67.5).

Table 45 shows that generally participants did not palpate Regions 1, 5, 6, and 7 with two or less peaks in these regions, and fewer than 2.5 seconds spent palpating in these regions. Region 3 also had a small overall amount of time spent and peaks palpated during an examination by students (but higher frequency in histogram).

Table 45. Summary of GLMM means per region for force, count of peaks, time

Region Number	Mean Force (N)	Mean Count Peaks (rounded to nearest whole count)	Mean Time in Regions (s)
1	19.5 (CI: 7.6-31.4)	0 (CI: 0 - 1)	0.82 (CI: 0.45 - 1.2)
2	49.2 (CI: 40.7-57.7)	6 (CI: 5 - 7)	9.2 (CI: 8.2 - 10.2)
3	45.2 (CI: 31.6-58.9)	2 (CI: 0 - 3)	3.2 (CI: 2.6 - 3.8)
4	57.7 (CI: 46.1-69.2)	4 (CI: 3 - 6)	7.7 (CI: 6.8 - 8.7)
5	11.1 (CI: 0.6-21.6)	0 (CI: 0 - ∞)	0.96 (CI: 0.56 - 1.4)
6	17.5 (CI: 5.2-29.8)	0 (CI: 0 - ∞)	2.5 (CI: 1.7 - 3.4)
7	16.6 (CI: 6.3-27.0)	0 (CI: 0 - ∞)	1.4 (CI: 0.86 - 1.8)
8	48.1 (CI: 37.9-58.3)	4 (CI: 3 - 5)	7.1 (CI: 6.0 - 8.1)
9	57.2 (CI: 29.7-64.8)	14 (CI: 12 - 17)	26.3 (CI: 24.8 - 27.8)

In Table 45 we can see that the mean force in each Regions 2, 3, 4, 8, 9 ranges from 45.2N (CI: 31.6-58.9) to 57.7N (CI: 46.1-69.2). This does not model the light and deep palpation, as will be discussed in section 8.9, however provides an understanding of the average forces participants apply during palpation, which has not previously been determined in the literature. The table also shows that participants spend the most time in region 9, which was the central umbilical region. This would suggest that instead of moving sequentially around the abdomen, as was expected by the investigator, they use the middle as the reference point from which to examine the other points of the abdomen. Clinically this is understandable, as students are taught not to remove their hand from the patient during the examination, to avoid guarding by the patient.

The data also show that the technique used by participants is somewhat inconsistent, as there is a disproportionate amount of time spent in region 9, less in regions 2, 4, 8 and minimal or no time spent in the others, which means little confidence can be had in the values for regions 1, 5, 6, 7. This is concerning as all regions have some relevance for diagnosis of different abdominal pathologies, and the clinical scenario given was intended to require a thorough examination.

The presence of a lesion on the parameters was negligible for average force of peaks and the count of peaks in a region, with marginally less time spent in a region with a lesion, but a larger standard deviation.

The data presented in this section highlight the inadequacies of the technique of participants, and that the use of a simulator can reveal areas of technique that need addressing and provide a useful method of feedback to users for learning.

8.9 Results # 6: Peak Force and Force Bands

This section refers to research question 2iii in 7.1.1:

2) Do participants palpate the whole abdomen in a systematic way and what forces to they apply when palpating?
   iii. What do the data reveal about the technique of medical students versus medical graduates, the forces they applied, and the time they took to complete the examination?

The results in this section cover the palpation peak forces and group the palpation peaks into force bands to examine from the data the force patterns of participants, and whether the forces can be categorised as light or deep palpation.

8.9.1 Overall palpation peak forces

Table 46 presents a summary of the palpation peaks' force data, including maximum peak force, the mean force of peaks, the median force of peaks, and the duration of a palpation examination by participants, and the total number of regions palpated per participant.

Table 46. Summary of Force data for all Participants

	Student				**MG**			
	Mean	**95% CI**	**Std Dev**	**S.E.**	**Mean**	**95% CI**	**Std Dev**	**S.E.**
Max Peak Force, Fp_max (N)	103.5	97.0-109.9	35.3	3.3	108.6	92.4-124.7	40.0	7.8
Mean Peak Force (N)	51.6	48.1-55.1	19.0	1.8	55.1	45.5-64.8	23.9	4.7
Median Peak Force (N)	49.4	45.2-53.7	23.2	2.1	56.2	45.7-66.8	26.0	5.1
Total Palp Duration (s)	59.5	56.5-62.5	16.5	1.5	53.2	46.0-60.4	17.7	3.5
Total number of regions palpated	6.9	6.7-7.2	1.3	0.12	6.9	6.4-7.3	1.1	0.22

Table 46 shows that the mean maximum peak force for both students and medical graduates was approximately double the mean and median peak forces. The mean total number of regions palpated was consistent across Participant Types at 6.9.

8.9.2 Palpation Force Bands - Individual Patterns

There was a lot of variability in the techniques used by participants to apply palpation forces. As detailed in 7.4.1.4, the force data were categorised into five groups, or “force bands” based on 20% increments of the maximum peak palpation force (100%). The idea of this ‘banding’ was to investigate whether participants use distinct “light” and “deep” forces when they palpate.

Figure 86 illustrates the force bands and an example of a participant (St29) performing light palpation for the first 50 seconds and deep palpation after that. For this participant, the majority of peaks occurred in the 20-40% force band of maximum palpation force. Figure 87 shows a similar pattern from another participant (St54). In contrast, Figure 88 shows a participant (St12) who applied little variation in palpation force. As a result, most peaks appear in the 60-100% maximum palpation force range. Figure 89 illustrates a participant (St43) who applied force more consistently across all force bands.

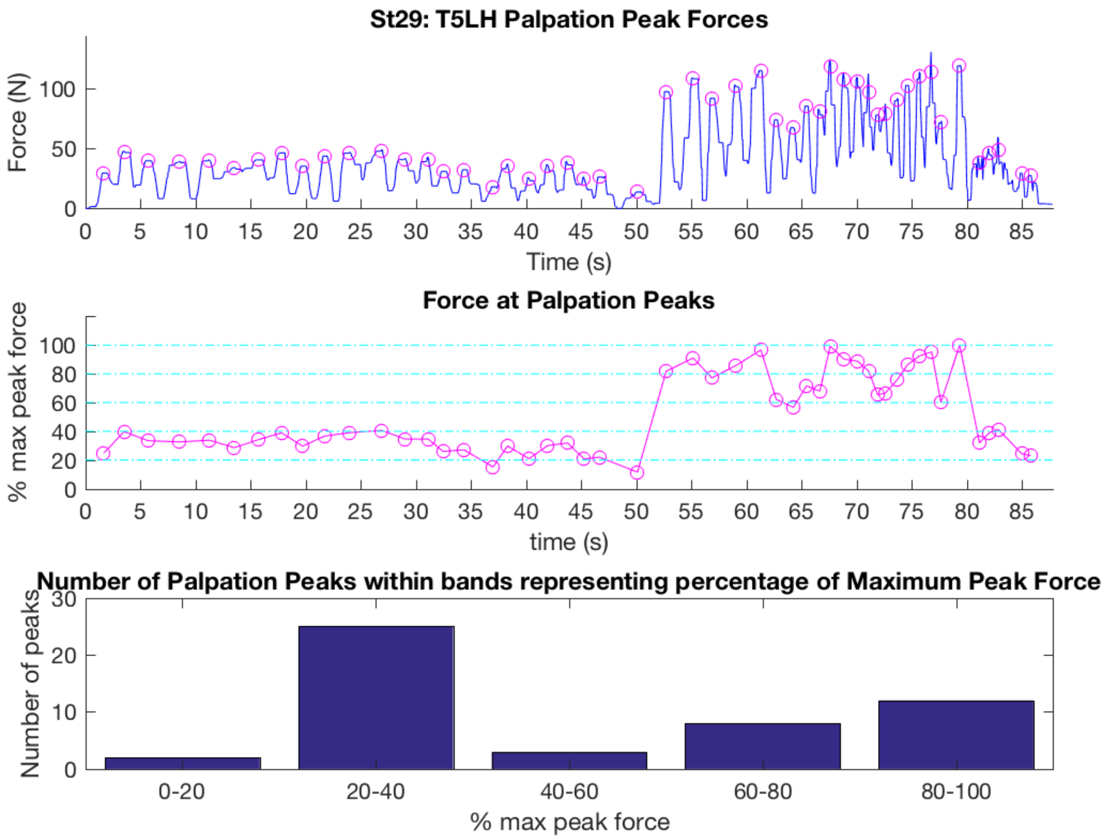


Figure 86. St29 Palpation Peak Forces, and peaks per force band.

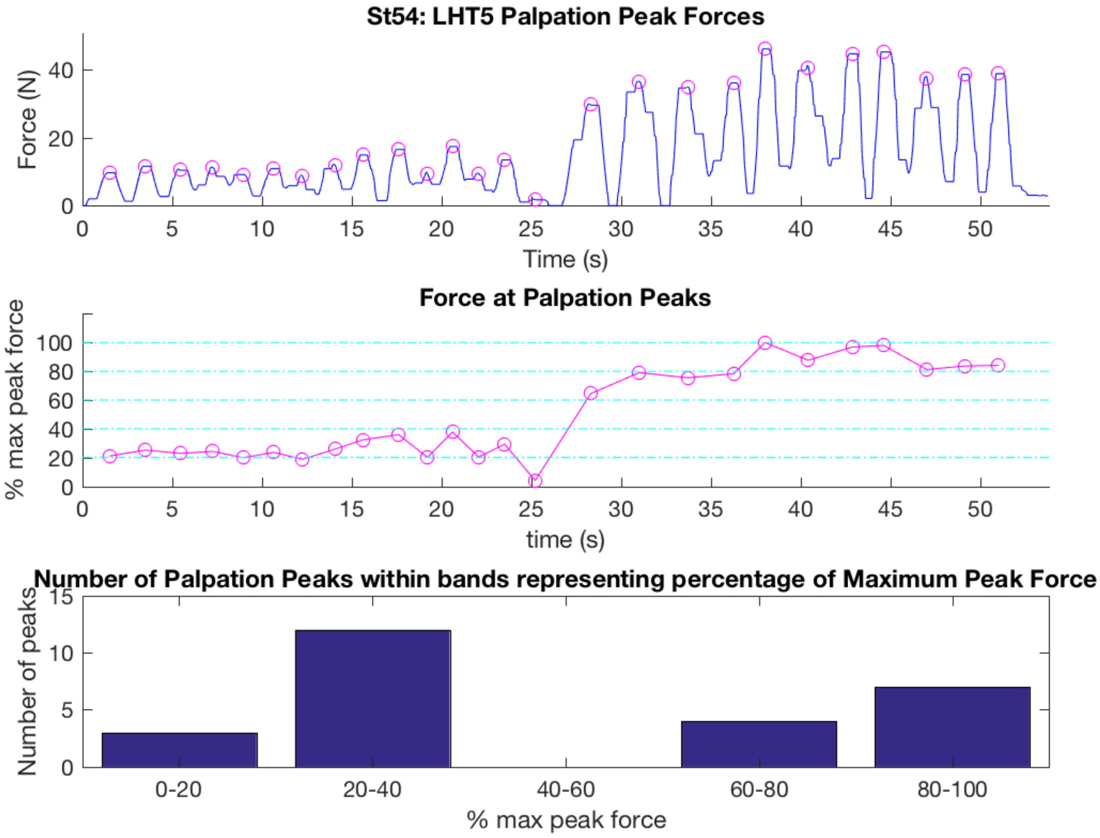


Figure 87. St54 force of palpation peaks and count of peaks in bands

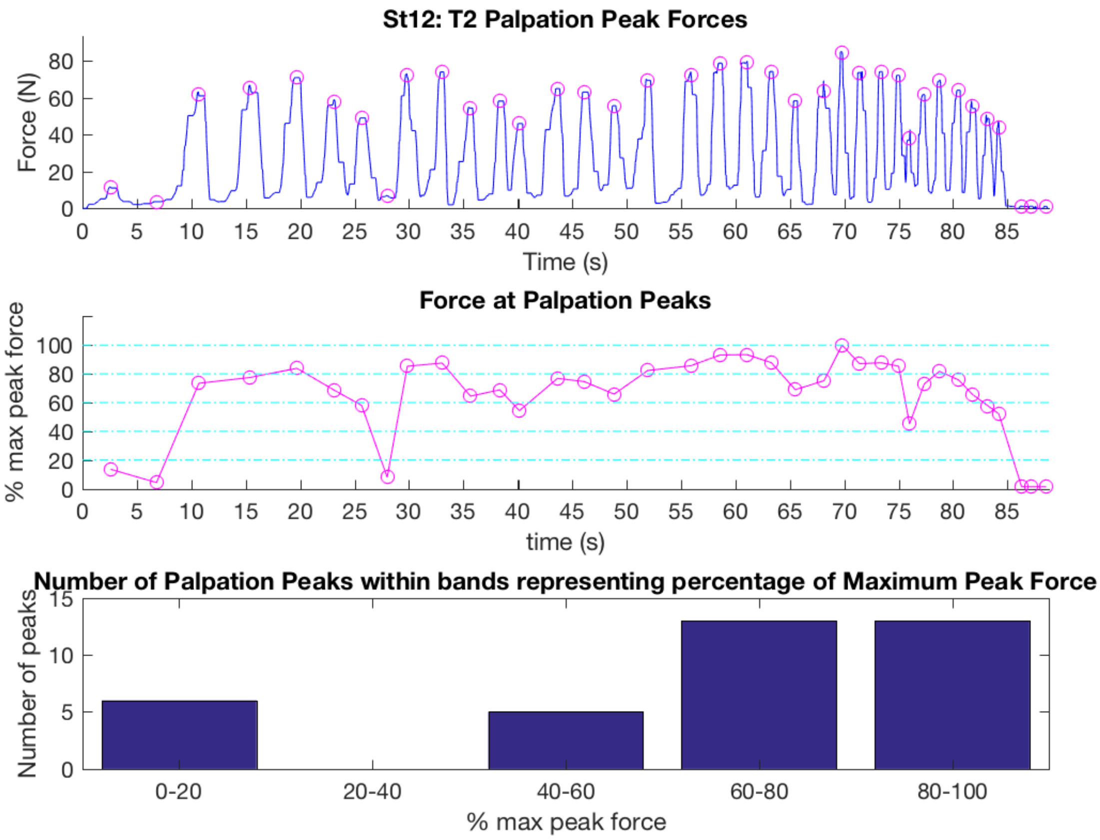


Figure 88. St12 Force at palpation peaks and force band data

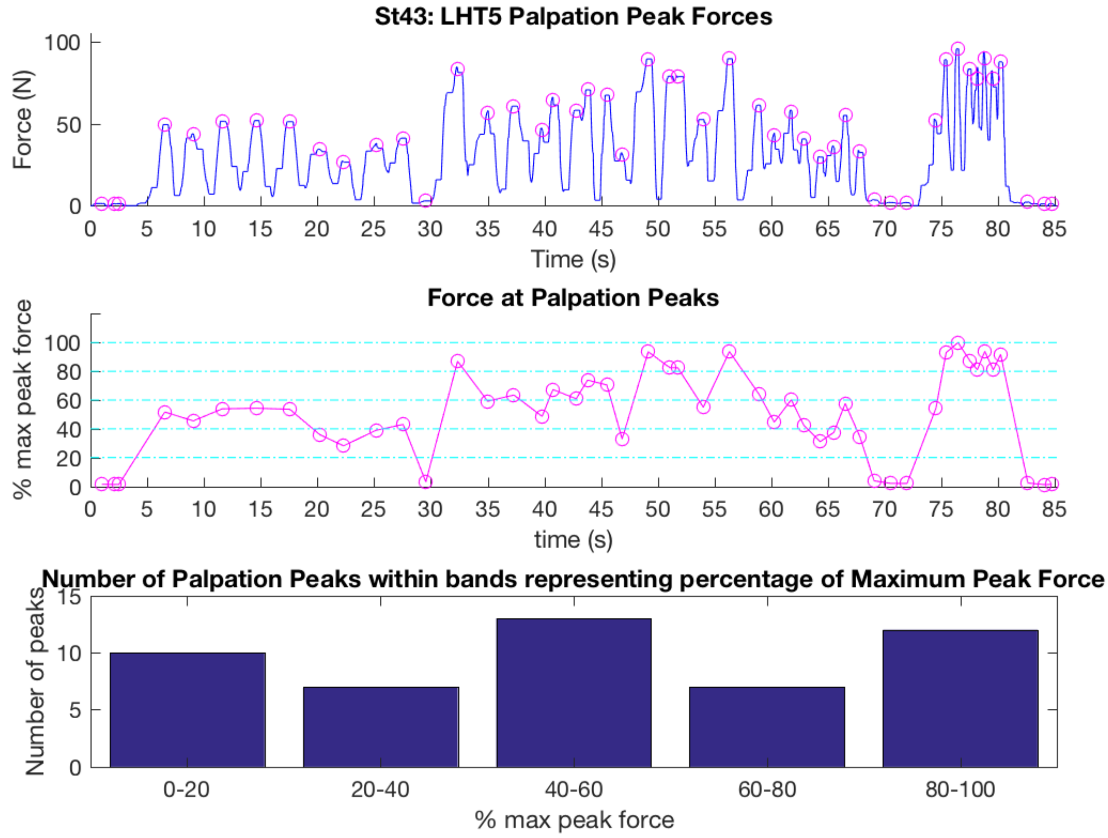


Figure 89. St43 Force at palpation peaks and force band data

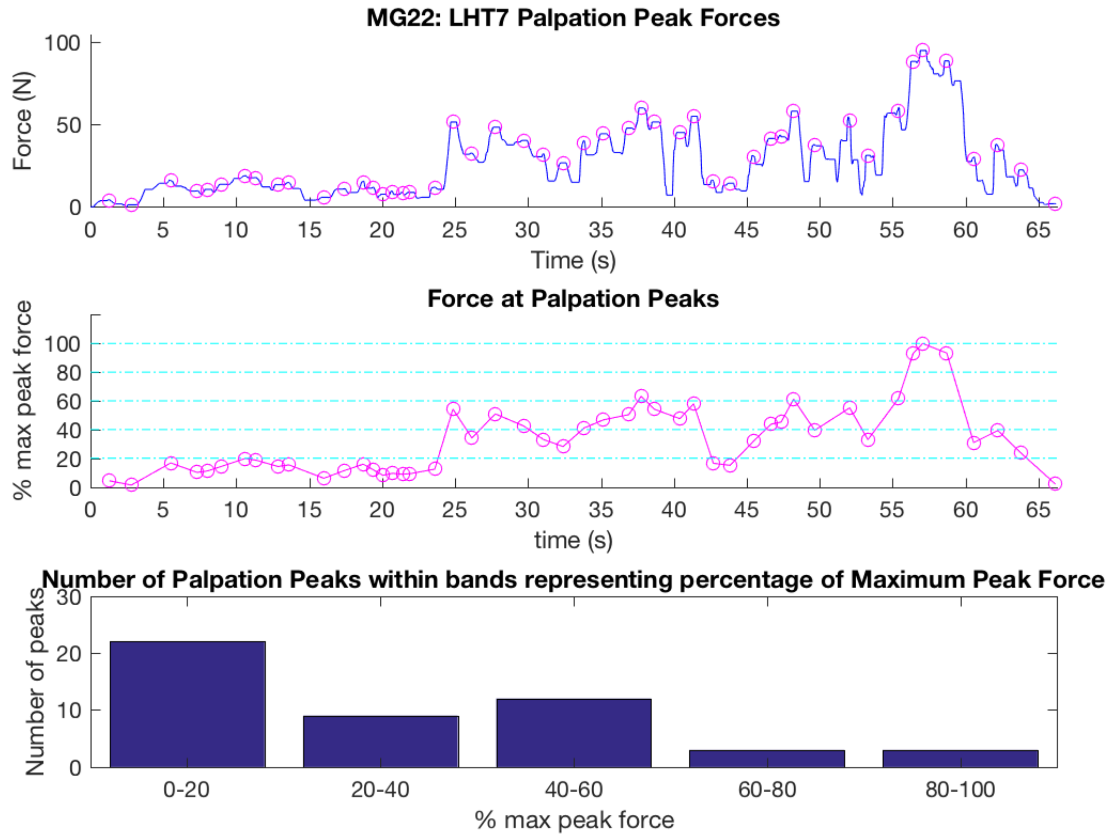


Figure 90. Medical Graduate 22, Palpation Peak forces, peaks per force band

The technique taught to medical students is to use a “light” force to first survey the area and find any areas of interest or rigidity and guarding, then followed by a “deeper” palpation force to identify and characterise any lesions or masses and areas of interest. This light then deep technique is illustrated well by Student 29 (in Figure 86) where for the first 50 seconds the student uses a light palpation, under 40% of the maximum peak force, followed by deeper forces above 40% maximum peak force. Figure 90 shows a medical graduate (MG22) with a similar technique, who spent more time (approximately 2/3 of the examination from 23 seconds to the end) deeply palpating but used fewer palpation peaks.

Both medical students and medical graduates however had quite varied technique and perhaps different understandings of light and deep palpation, or different perceptions of the magnitude of palpation force they were applying.

In contrast to Student 29 (Figure 86) and Medical Graduate 22 (Figure 90), were Student 12 (see Figure 91) and Medical Graduate 17 (see Figure 92), who palpated in the upper force bands for the whole examination, and had little variation in the forces applied or no distinct “light” and “deep” palpation.

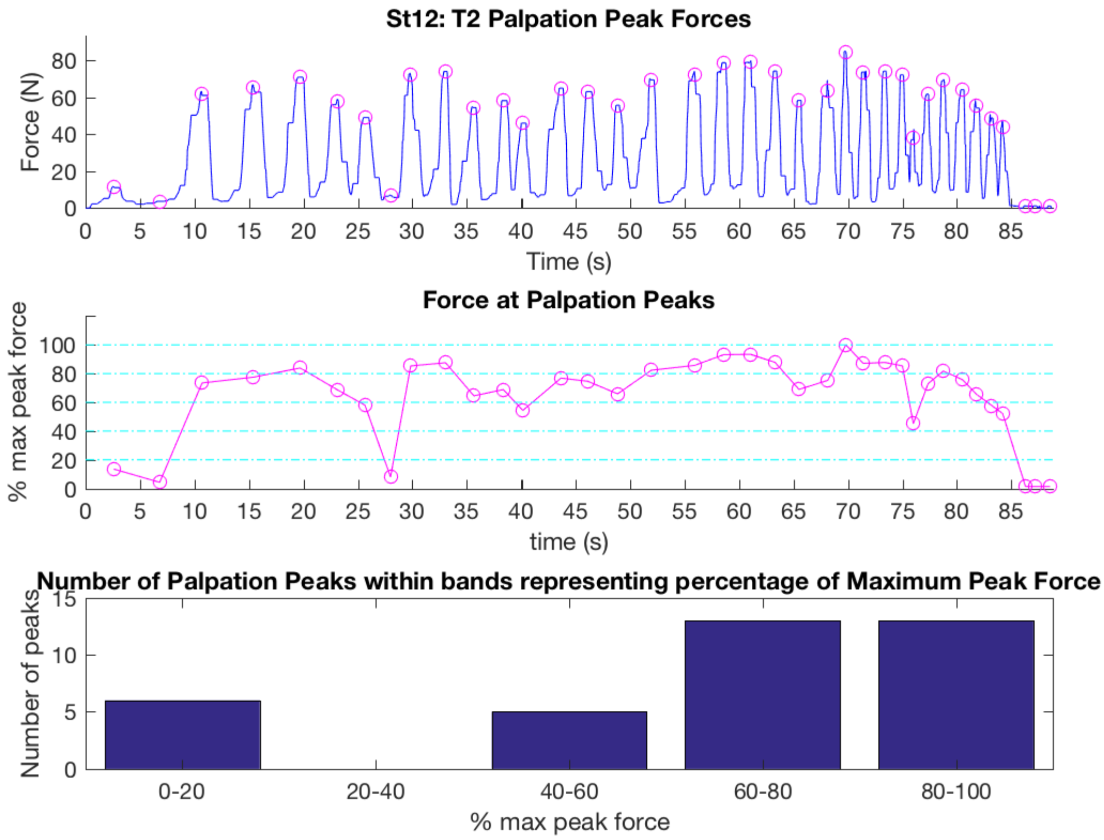


Figure 91. Student 12 Force at palpation peaks and force band data

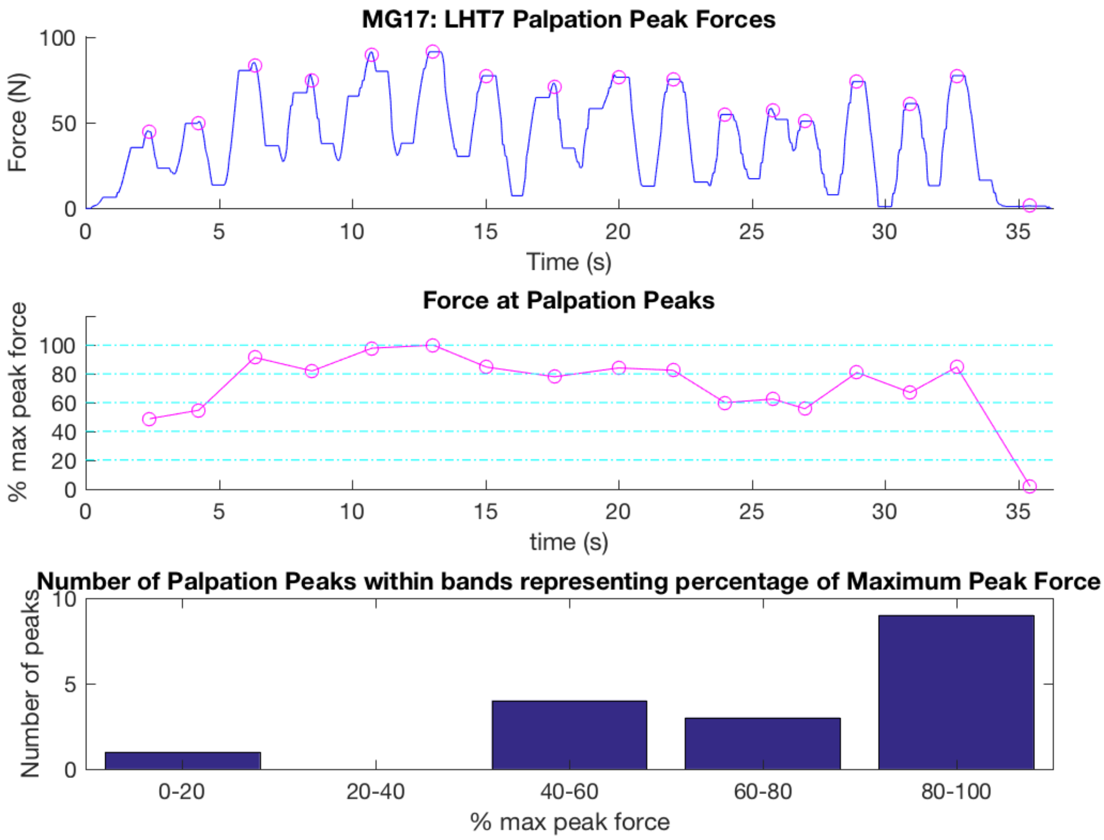


Figure 92. Medical Graduate 17 Force and palpation peaks and force band data

Student 43 (see Figure 93) illustrates a participant that spent time more consistently across all force bands, with what they probably intended as light palpation the first 30 seconds, deeper palpation from 30 to 70 seconds and the last part of the palpation (70-85 seconds) may have been targeting a specific area of interest where the palpation peaks are closer and force in the uppermost band applied.

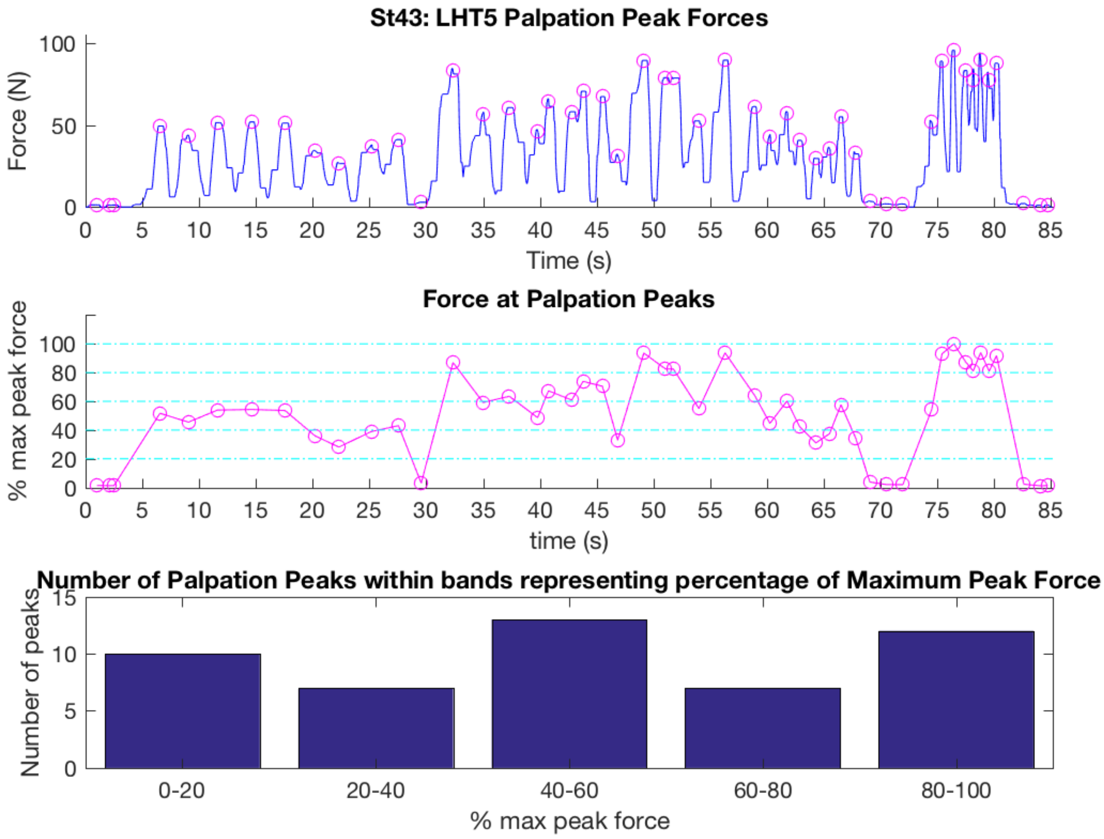


Figure 93. Student 43 Force at palpation peaks and force band data

Medical Graduate 1 (see Figure 94), has a similar technique to Student 43 (Figure 89), with time spent more evenly in each force band, and the first 24 seconds light palpation, followed by deeper palpation, and a small targeted burst at the end.

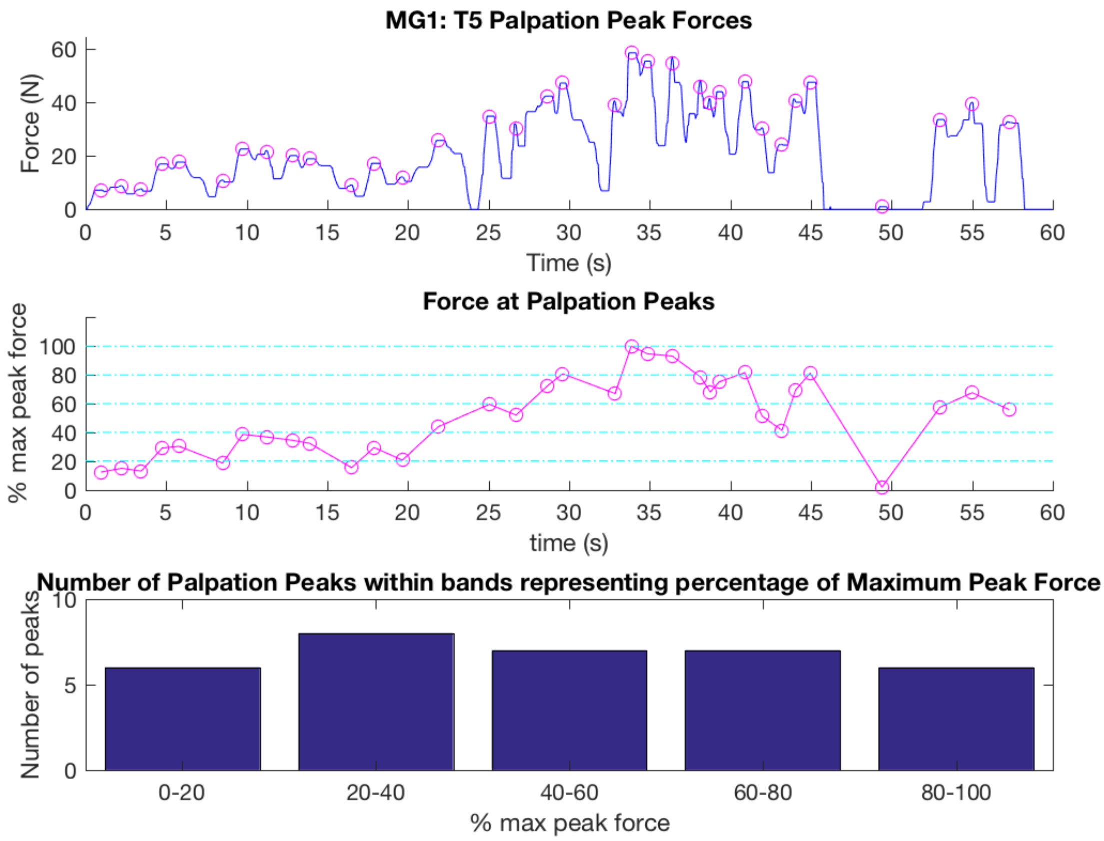


Figure 94. Medical Graduate 1, Force at palpation peaks and force bands

Student 5 (Figure 95) illustrates a participant with an extreme difference in their forces applied with quite light touch initially, and much greater palpation force in comparison for the second half of the examination, but with most of their palpation peaks in the lowest force band.

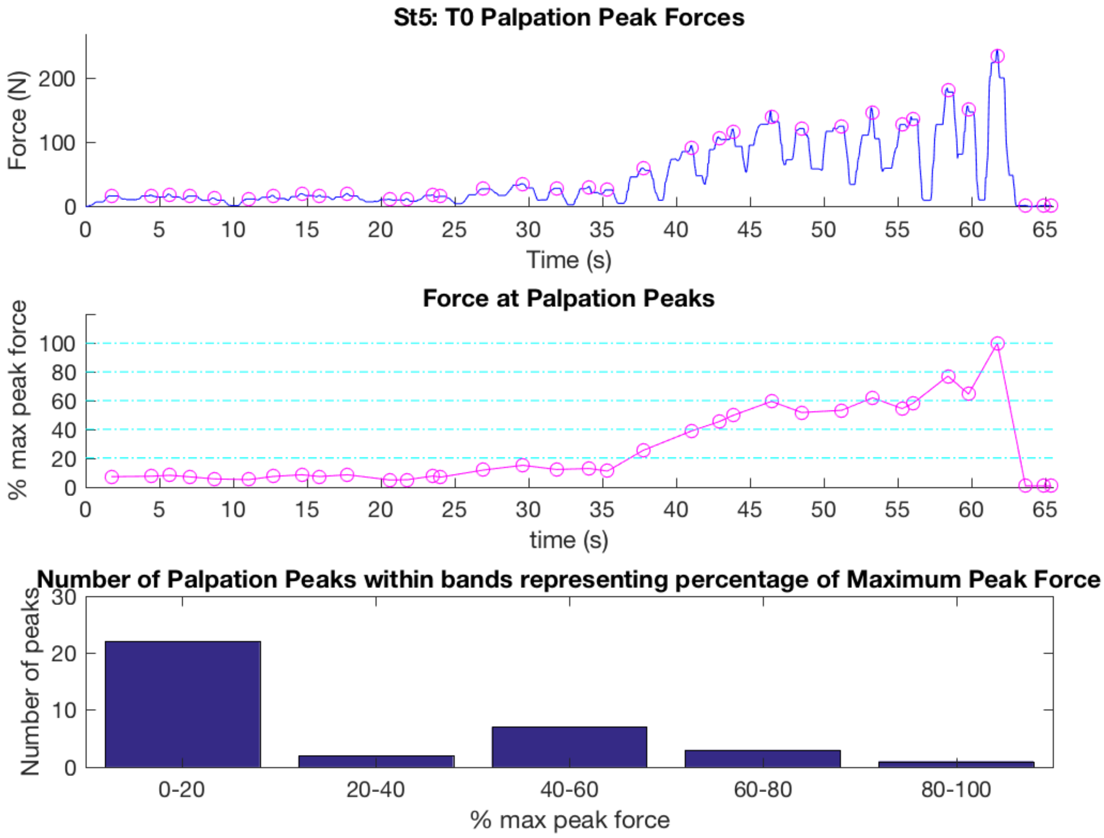


Figure 95. Student 5 force of palpation peaks and count of peaks in bands

Another variation of technique is shown in Figure 96 by Medical Graduate 19, with graduated force in a more cyclical pattern, rather than the taught light palpation for the first part of the examination then deep palpation for the second part.

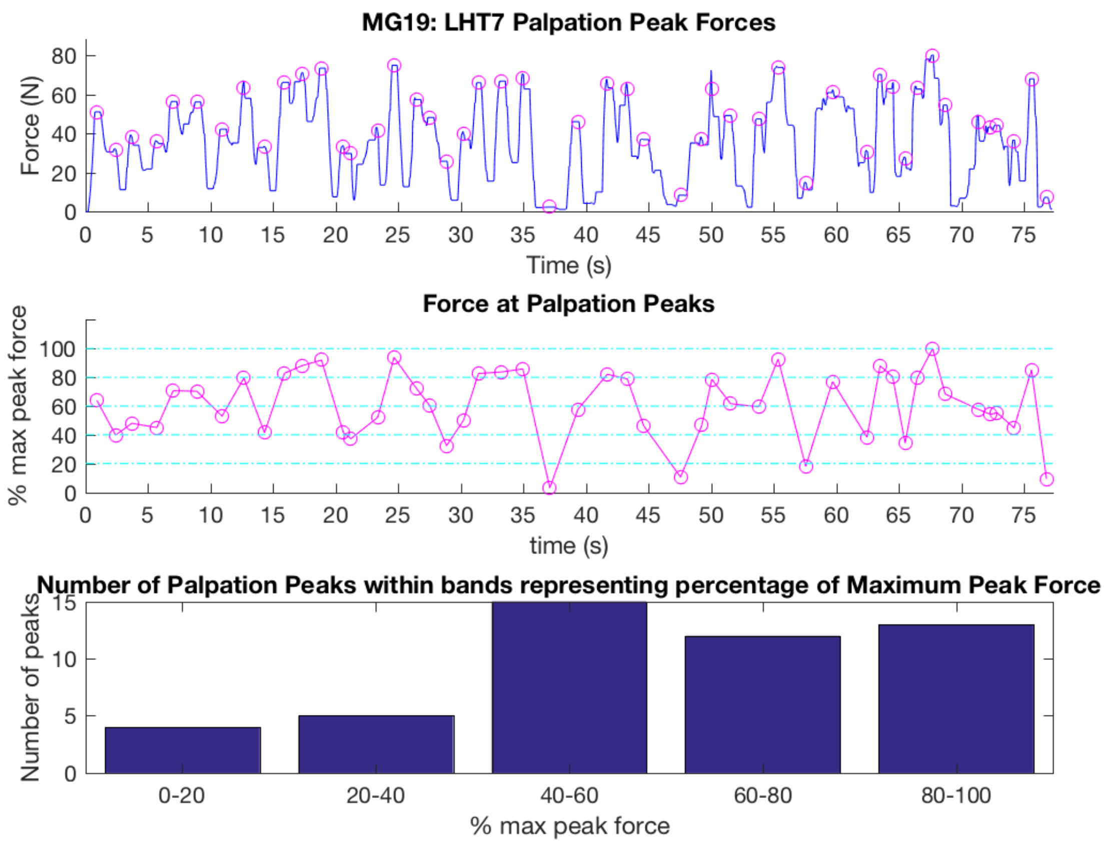


Figure 96. Medical Graduate 19. Force of palpation peaks and count of peaks in force bands.

All the variations in the applied forces technique as illustrated, made it difficult to draw any conclusions or assumptions about light and deep palpation from the shape of the waveforms.

8.9.3 Palpation Force Bands - by Participant Type

Table 47 and Figure 97 present the mean number of palpation peaks counted in each of the force ranges, i.e. the count of peaks with values 0-20% of the maximum force, palpation peaks counted with values 20-40% of the maximum force, and so on for 40-60%, 60-80% and 80-100% of the maximum force.

Table 47. Average number of palpation peaks in each force band, and t-test comparison of Student and MG mean values

	Student (n=118)			MG (n=26)			T-test
Count of peaks corresponding to:	**Mean**	**Std Dev**	**S.E.**	**Average**	**Std Dev**	**S.E.**	**p-value**
Fp_max 0-20%	5.49	4.81	0.45	5.19	5.08	1.00	0.776
Fp_max 20-40%	7.78	5.73	0.53	7.50	4.71	0.92	0.280
Fp_max 40-60%	8.25	5.18	0.48	8.96	5.11	1.00	0.527
Fp_max 60-80	7.22	4.13	0.38	7.00	3.42	0.67	0.800
Fp_max 80-100	5.80	3.33	0.31	4.88	3.25	0.64	0.202

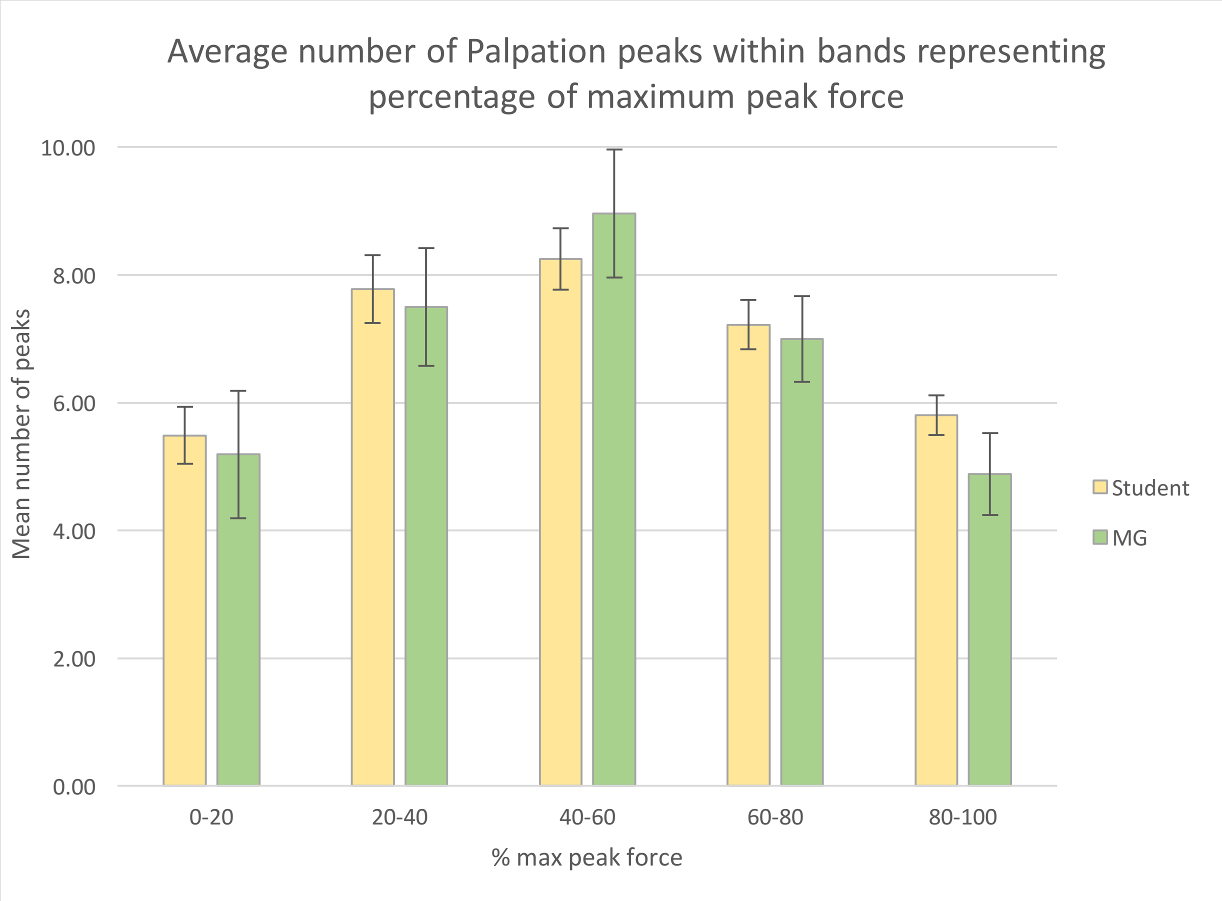


Figure 97 Mean count of palpation peaks within force bands

The independent two-tailed t-test of comparing mean force band values of students and medical graduates (see Table 47) was not statistically significant ($p<0.05$) for any of the force band brackets.

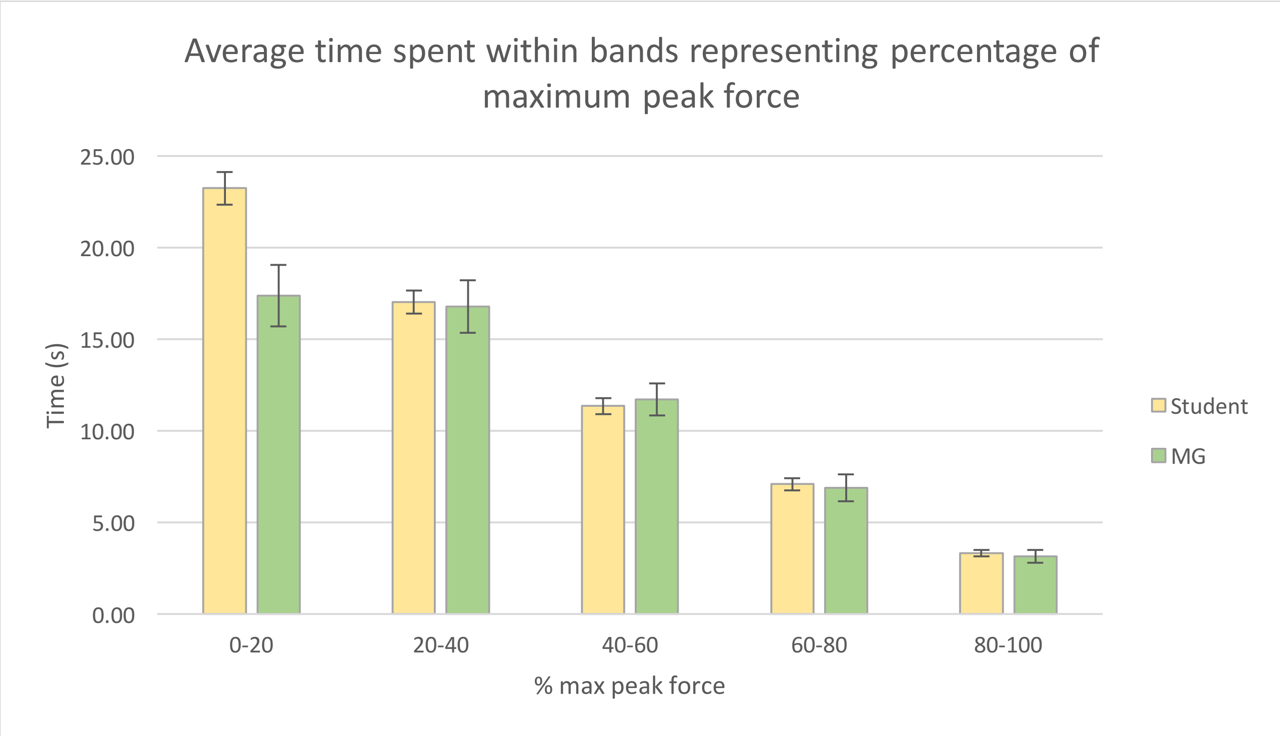


Figure 98. Average time spent in each force band

The duration (time in seconds) of palpation examination within each force band is shown in Table 48 and Figure 98.

Table 48. Time (in seconds) spent in each force band

	Student (n = 118)			MG (n = 26)			T-test
Duration of time spent in force bands:	**Mean**	**Std Dev**	**S.E.**	**Average**	**Std Dev**	**S.E.**	**p-value**
Fp_max 0-20%	23.25	9.66	0.89	17.39	8.61	1.69	0.005
Fp_max 20-40%	17.04	6.95	0.64	16.79	7.37	1.44	0.870
Fp_max 40-60%	11.36	4.86	0.45	11.73	4.51	0.89	0.723
Fp_max 60-80	7.10	3.54	0.33	6.90	3.72	0.73	0.797
Fp_max 80-100	3.34	1.98	0.18	3.15	1.76	0.34	0.652

Independent two-tailed t-test values for duration of time spent in force bands versus participant type was only significant in the 0-20% maximum force range (p=0.005), where students are more likely to spend a greater amount of time palpating than medical graduates. This is likely as they are still learning and take more time getting oriented with the patient and examination than the more experienced clinicians.

Examination of Figure 97 and Figure 98 show that while more time is spent (on average) by participants palpating in the 0-40% force (Figure 98) range, the number of peaks within that time period is not increased accordingly (Figure 97). From observation of the Plot 1 figures (such as Figure 51 earlier in the chapter) and the idea of "clusters" for light palpation (as described in 5.3), this indicates that participants use a slower palpation technique in the 0-40% "light" palpation force bands, which could be because it is more controlled, hence done more slowly. When participants apply larger forces in the 40-100% of maximum peak force ("deep" palpation), palpation tends to become more rapid with "bounces/oscillations" (as described in 5.3). This kind of technique is nicely illustrated by St29 in Figure 86. While not all participants used the same technique, time spent per palpation for each force band was, when averaged over all participants, higher at lower forces, as Figure 99 illustrates.

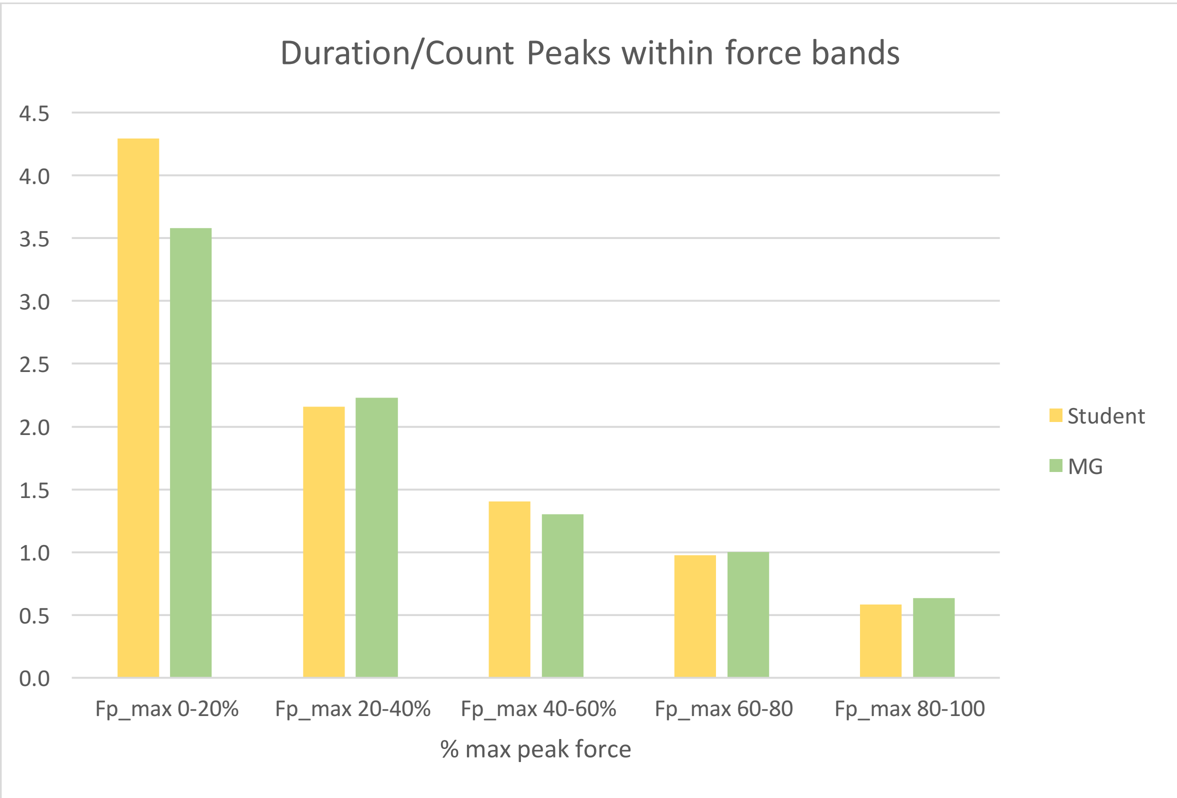


Figure 99. Ratio of Duration within force band to Count of Peaks within force band

8.9.4 Results Section #6: Peak Force and Force Bands - Summary

From Table 46 we can see that the mean maximum palpation peak force for students is 103.5 N (CI: 97.0-109.9 N), and medical graduates is 108.6 N (CI: 92.4-124.7N). The mean total palpation examination duration for students is 59.5s (CI: 56.5-62.5) and medical graduates is 53.02s (CI: 46.0-60.4). The mean and median forces were approximately 50% of the value of maximum peak palpation force and both participant types on average palpated 6.9 out of 9 regions.

The mean number of palpation peaks in each force band is presented in Table 47. This table shows that there is no statistical significance between the technique of Medical Students and Medical Graduates overall, except for the time spent in 0-20% of maximum force, and the mean count of peaks in each force band of the same order for both types of participants.

The variation of palpation peaks per force band and inconsistency of the order of force application suggests a large gap in technique both for medical students and medical graduates.

A simulator such as this one, would be of assistance to help with education and self-awareness of both the magnitude of forces applied, how they are applied sequentially throughout the examination, and in training students to know what application of “light” and “deep” palpation “feels-like”.

8.10 Evaluation and Testing of the Abdominal Palpation Simulator - Summary

The trial was designed to evaluate the abdominal palpation simulator and answer the questions:

1) Does the AbSim prototype sufficiently simulate an average male abdomen?
2) Do participants palpate the whole abdomen in a systematic way and what forces do they apply when palpating?

Participants in general found the simulator to be sufficiently realistic for the purposes of teaching and training in abdominal palpation. Areas in which they would like to see improvements on the prototype included the skin texture and thickness, less resistance when palpating, and additional features to enable more interaction with the patient.

The trial showed that participants do not palpate the whole abdominal area, and often miss the upper corners and lower regions of the abdomen. A simulator such as AbSIM would assist students practise and receive feedback regarding their coverage of the abdomen.

Results revealed participants also do not necessarily have a systematic technique, however they generally start in the middle of the abdomen and cover the middle sagittal line of the abdomen. There was however little difference in technique whether there was a lesion or not.

Observation of the force data showed there was not consistent patterns of light and deep palpation amongst participants, however the mean palpation force was generally 50% of the maximum peak palpation force for both medical students and graduates.

AbSIM could be a useful educational tool that provides quantitative feedback to students about their abdominal coverage, sequence and systematism of palpation technique, forces applied, and identification of lesions. It would enable them to immediately playback their palpation examination, and receive feedback to learn by assessing the information recorded in conjunction with an educator, and improve confidence and ability without harm or discomfort to patients.

CHAPTER 9. Thesis Summary and Recommendations

9.1 Summary of Contributions

The title of this thesis is: The development and evaluation of a sensor-enabled abdominal palpation simulator.

The thesis detailed the construction of an abdominal palpation simulator using low-cost materials to produce a prototype modelled on a real person. The prototype was trialled by student and graduate participants to determine if it was a sufficiently realistic tool to learn the technique of abdominal palpation.

The outcomes of the research were:

- the development of a novel prototype sensor-enabled abdominal palpation simulator as detailed in CHAPTER 6;
- the evaluation of the abdominal palpation simulator by surveying the participants and identifying the abdominal palpation techniques of medical students and medical graduates using the custom made abdominal simulation prototype as detailed in CHAPTER 7 and CHAPTER 8;
- a better understanding of the forces applied when examiners palpate the abdomen, for light and deep palpation (see CHAPTER 5 and 8.9) and of the discernible differences due to experience or gender as detailed in CHAPTER 7 and CHAPTER 8;
- the determination that the abdominal palpation simulator was sufficiently realistic and could assist in teaching the skill of abdominal palpation by providing data to students about their technique, the forces they apply and the abdominal area they cover during an examination.

Palpation techniques of the medical students and medical graduates were assessed using the custom made abdominal palpation simulation prototype to reveal:

- the total number of regions palpated ranged from 4 to 9 out of a possible 9, showing a skill deficiency in the coverage of the abdomen by participants,
- the order in which regions were palpated by participants varied, which in itself may not be

problematic, but since the coverage of the abdomen was incomplete in many cases, this suggests a more systematic approach to palpation might be indicated,

- the forces applied by participants was wide-ranging, with large variations in the manner and method of forces magnitudes applied,
- the total time taken by participants for the palpation examination varied, with medical students taking more time to palpate with lighter force than the more experienced medical graduates.

Light and Deep Palpation

The studies conducted in CHAPTER 5, CHAPTER 7 and CHAPTER 8 provide quantitative data to better understand the forces applied for light and deep palpation. There have been very few other studies in the literature that consider abdominal palpation forces, and none that has considered the different requirements for light and deep palpation. The abdominal palpation simulator extends simple methods for palpation force measurement described in the literature (e.g the blood pressure cuff method by Shafer [125] and the upside-down kitchen scale by Patkin [126] (described in 3.5.2)), by recording the forces applied across the 9-regions of the abdomen instead of recording the force at single points on the abdomen.

The Lumps and Bumps Box [132], Honglian Abdominal Palpation Manikin [133], Limbs and Things Abdominal Examination trainer [134], and Abe the Tummy Dummy [135](see 3.5.3) are all existing abdominal palpation simulators that provide the ability to practise and repeat abdominal palpation. The AbSIM prototype developed for this thesis has the added benefits of providing feedback regarding which of the 9-regions the trainee is palpating, to enable them to improve their technique. The SmarTummy [138] was divided into 100 regions with “inflatables” (balloons) that provides scenarios and feedback to the user. However, from the images of this model, the area of the “Tummy” concentrates on the upper half of the torso. The full torso of the AbSIM model developed in this thesis, encourages participants to consider the complete coverage of the whole abdominal area, and has highlighted that the lower abdominal area is often missed in abdominal palpation.

The palpation forces recorded (in CHAPTER 5 and CHAPTER 8) were much larger than that recorded by Laufer and colleagues [127] (see 3.5.2.4) for the Breast Examination Simulator, however the different contexts for palpation would account for some of this difference. Forces for abdominal palpation would likely be larger (especially for deep palpation) than the forces applied during a clinical breast exam and the more delicate breast tissue. The magnitude of the force measured by Patkin [126] for slight tenderness was approximately two-thirds of the mean medical graduate force recorded using the AbSIM, however Patkin was measuring the point of tenderness in pre- and post-surgical patients with abdominal conditions.

The HHDCP study (in CHAPTER 5) intentionally looked at light and deep palpation forces and clinician examiners were specifically asked to palpate with light and deep palpation forces, both in sequence and in the one region to simplify the analyses of the applied forces. The clinicians' perceptions of light and deep palpation were interesting, noting a small cohort of five. Some had marked differences between light and deep applied forces when deep repetitive palpation was performed immediately after light repetitive palpation in a single region. When they palpated the abdomen in a sequence, light (full 9-region) sequence then deep sequence, the forces were of similar magnitude for light and deep palpation. These perceptions may have been due to the differences in technique of applying light and deep forces, or because more attention was paid to palpating "lightly" and "deeply" when in a repetitive pattern. It highlights that clinicians may not be aware of their own techniques.

Light and deep palpation were more difficult to identify from the larger prototype trial (in CHAPTER 7, CHAPTER 8), since participants were only given a simple clinical scenario to direct the examination, rather than being specifically asked to palpate with both light and deep forces. Participants in the trial palpated with very varied forces and patterns, with some not displaying any evidence of using both light and deep palpation, and others using extreme differences. This emphasises the need for training in light and deep palpation.

Experience and Gender Factors

There were some discernible palpation technique differences between genders. Males palpated with slightly more force than females, which may be due to typical strength differences between males and females. The order in which regions were palpated by participants also varied slightly between genders. Females tended to palpate the regions closest to themselves first, while males palpated the upper top regions of the abdomen first. This may be due to physical reach as females are often smaller than males with shorter arms. Another consideration would be that there may be potential gender differences in the way in which clinicians establish rapport with the patient, before beginning a thorough examination.

There were some noticeable differences in palpation due to experience, with students improving in coverage with year level. While there were some differences between medical students and medical graduates, there were fewer than expected with many of the statistics showing no significance between the two groups. This may have been due to the much smaller sample of medical graduates compared with students, or that the majority were from an anaesthetic background dealing more commonly with airways, anaesthetic drug delivery and monitoring patient vital signs in an operating theatre environment, and less often required to undertake abdominal examination.

Issenberg [41] noted that “most medical students and practitioners have little regular access to professional feedback with opportunities for repetition and correction of errors.” The results from the studies in CHAPTER 5, CHAPTER 7 and CHAPTER 8, provide evidence that there are noticeable gaps in the abdominal palpation skills of both medical students and those practicing clinicians who have graduated from medical school, and that these can be quantitatively measured using the abdominal palpation simulator. This can then be used to develop appropriate training modules with feedback for trainees.

In the literature, some simulation validation studies (mentioned in 3.4) stated difficulties in establishing a control group for the studies [102] (cited in [98]), as that group of participants would be penalised, since the simulation groups performed so much better. The study in this thesis (reported in CHAPTER 7 and CHAPTER 8) also did not have a control group, but instead utilised medical student participants from different year levels within the medical school program at Flinders University, and a sample of medical graduates to provide a method for comparison of skill levels.

Role of AbSIM in Abdominal Palpation Training

This thesis implies that there is a role for an abdominal palpation simulator in training medical students. The AbSIM simulator is well suited to assist in teaching the skill of abdominal palpation, by providing immediate feedback to students and their educators about their technique in order to improve and modify their technique, repeat their practise and improve in competence. Feedback regarding coverage of the regions palpated provides awareness to participants of the areas they miss; data regarding the magnitude of forces they apply may help in developing the sense of touch and feel that is such a subjective technique to teach, and may help to further quantify typical palpation forces and inform benchmarking of force metrics for evidence-based clinical practise; data regarding palpation patterns, how systematic, and the procedure used (rapid or slow, light or deep), may lead to improved technique, and also provide data for further research into best practice and the patterns or technique that should be applied in specific clinical scenarios and pathologies.

A quote from Levine et al in 2012 [59] states that: "To date, there is a small body of convincing evidence that simulator training improves healthcare education, practice, and patient safety, but Gaba argues, '… no industry in which human lives depend on skilled performance has waited for unequivocal proof of the benefits of simulation before embracing it.'" The literature currently has relatively few clinically-based reports regarding the transfer of specific skills from the simulation training environment into clinical practice [52], but despite the lack of evidence, it is increasingly being used for training. The research presented in this thesis provides a method to quantify the effectiveness of abdominal palpation training.

It is also difficult to find quantitative information or research in the literature regarding the procedure of how to perform an abdominal palpation. On the validity of diagnostic pathways Gans [3] said "Most studies have analysed the combination of medical history, physical examination, and laboratory parameters, and not the separate elements." And while the technique of light and deep palpation covering all quadrants or regions in a systematic fashion is instructed in most clinical skills textbooks, there is little information regarding how this procedure was determined or any clinical studies supporting or assessing the technique and its clinical value. Regarding abdominal clinical diagnosis, Gans reported that currently "the diagnostic accuracy of medical history and physical examination is insufficient to reach a correct diagnosis." The outcomes of the studies presented in this thesis suggest that examiners are not consistently systematic, they do not cover all the regions and there are large variations in the forces applied during palpation. This is true not only for medical students, but for medical graduates which suggests that current training is insufficient.

There is limited time within a medical degree course to learn all required skills due to the volume of work to be learnt. A study by Remmen [104] et al showed that clinical skills laboratory training prior to clerkships had a substantial beneficial effect on training outcomes. The AbSIM simulator provides a method to support and make the most of the time-limited opportunities in the crowded medical school curriculum (see 2.4.1), to enable students to learn and receive immediate feedback regarding their abdominal palpation skills in Year 1 and 2, to be more proficient before transitioning to clinical practice in Years 3 and 4.

The traditional "learn by doing" preferred training style (as discussed in 3.4.1) can be facilitated by the use of the abdominal palpation simulator, instead of the apprenticeship model of over 20 years ago. The use of AbSIM for training in abdominal palpation addresses common concerns regarding patient safety by providing a tool sufficiently realistic to learn the technique of abdominal palpation. It provides the opportunity for students to practise, where patient access is limited due to shorter-stay care in hospitals and less contact available with patients.

That the most common reason for a visit to an Emergency Department is related to abdominal pain [1, 2, 11, 12, 177, 178] (see 2.2) suggests that medical professionals should be trained appropriately in abdominal examination to assist in quick and accurate diagnosis of patients. A tool that provides quantitative information about palpation, such as AbSIM, could help to not only provide feedback with regards to technique and forces, but provide a means to further quantify palpation forces and inform best clinical practice.

While this research has shown that coverage, systematism, force patterns, and applied force are all variable, the questions that arise are: Does it even matter if a clinician palpates the whole abdomen in an examination? Does it matter if they are systematic? Does the force they apply and the pattern in which they apply it matter? Does it even matter if there is variability between examiners? AbSIM provides a tool to be able to answer some of those questions.

The consequences of missed regions mean that diagnosis of pathologies in those abdominal areas could be missed. If no abnormality or suspected pathology is identified, then it is possible there would be no further referral for blood tests or imaging. While it may not be as critical to be systematic in an examination, the benefit of a systematic approach would help to avoid missing regions. Methods of force application may also be important, with different speeds and duration of palpation used to determine different conditions.

9.2 Recommendations for future development

Limitations still exist with the abdominal palpation simulator prototype in its current form. As evidenced by the comments received from the participants who trialled the simulator, the skin and foam elements would benefit from further development, and the addition of some patient feedback would assist in the realism of the scenarios. The forces recorded in some cases were extreme, and it is unlikely that such forces would be tolerated by a real patient. This is thought to be due to the limitation of the model firmness, as many of the participants did comment that they thought they had to palpate harder than usual, or because the simulator did not provide any patient feedback to participants to indicate that the applied force was too hard either verbally (i.e. “ouch!”) or by facial expressions indicating extreme discomfort or pain. The simulator provides data regarding the magnitude of the force applied, but does not currently provide students with an indication of what are expected palpation pressure ranges. Inclusion of this feedback would enable students to independently correct their technique. Another limitation is that the model developed was of an average male, and for a female model there would be other gynaecological and obstetric implications that were beyond the scope of this research.

Recommendations for future development include: improving physical elements of the simulator based on feedback in the clinical trial, a mechanism to provide patient interaction, simulation of a wider range of clinical conditions, multiple interchangeable abdomens for simulating different body types/ages/genders/sizes/skin colours, multiple modes and options to facilitate training and assessment of skills, software guidance on applied pressures, interactive GUI with modelling and recognition of underlying organs and abnormalities. A controlled randomised trial is required to determine how well the use of the simulator improves the initial procedural skills of students, and a longitudinal study to follow students to see how they retain the skills over time. Further research is needed to determine best practice for light and deep palpation forces, coverage and systematism techniques, and patterns of palpating. These are discussed below.

Physical features

The main physical features that require further development, that were highlighted in comments from the clinical trial, are the “feel” and firmness of the abdomen, and the texture and thickness of the skin and ability to slide across the underlying abdominal structures. Other abdominal features that could be added include a head, the ability to ballot kidneys, patient breathing, and the ability to practise other elements of an abdominal examination including percussion, and auscultation. Other feedback from the trials requested the addition of more patient feedback and interaction that would provide further realism to the training scenarios. Features that could be included to address this could include verbal responses from the patient with either audio recordings or a speaker/microphone scenario run by the clinical educator or facial responses on a screen. Patient responses could be either pre-programmed responses for specific scenarios, or triggered i.e. if a force threshold was exceeded. The addition of physical responses, i.e. guarding or rigidity, on application to an area with tenderness or abnormalities would also add to the realism of the simulation experience.

Pathologies

The future inclusion of a wider range of clinical conditions, scenarios and pathologies to the simulator would enhance its use within the curriculum to enable simulation of pathologies not normally experienced by students. Standard inclusions could include: liver, spleen, kidneys, gallbladder, with lump lesions and other abnormalities such as appendicitis, aortic aneurysms and even incorporation of a breast palpation model. Consideration of the work and theories by Klatzky and Lederman [179, 180], with regards to touch and object recognition, could inform further understanding in the palpation design of these areas. The ability for the software to recognise the location of a lesion or abnormality, and provide feedback as to whether the applied pressure should differ would also be very beneficial to guide learners.

Aesthetics/Realism

Generally, most training manikins look the same, small in size, slim build and pale pink in colour. The fact that AbSIM looked different, being larger and with an olive skin colour, received mixed feedback comments from students. Multiple interchangeable abdominal skin colours and abdominal shapes/sizes, would provide students with more familiarity with a diversity of presentations of the abdomen. Recent work in fabrication of high fidelity anatomically accurate models by artists such as George Petrou from Artificial Bits [181], in models such as a breast simulator [182] and robotic rectum from his portfolio, or Trauma FX ® with realistic manikins called SIMBODIES [183], could be explored to consider how this might be implemented.

Modes of Interaction and Learning Theory

Different training mode options to facilitate both training and assessment of skills is another area for development consideration. Various modes and levels of difficulty for users to select include: tutorial, individual practise, self-directed learning, assessment, review. An instructional GUI could prompt the user to perform a particular task or start a scenario and guide them through it, depending on the mode chosen. A GUI to visually display the depth of force on a cross-section of abdomen, or to view in real-time a graphical display of the 3D position of examiner's hands would enhance the benefit of these modes. The best use of personal and commercial device types available commonly, such as tablets or phones, for running simulations and scenarios needs to be explored for this application.

The body of knowledge around educational theories of learning and the application of adult learning principles in medical education (including social cognitive theory, reflective practise, transformative learning, self-directed learning, experiential learning, situated learning, learning in communities of practise) [184, 185] and their implications will aid in the future design of modes within the simulator. Future design of patient-focused simulation scenarios [45] aiming for seamless integration of the simulator and consideration of this in conjunction with cognitive load theory [186] should enhance usefulness of the simulator and improve the quality of reflective practise for learners.

Evidence-based practise

Further research with regards to the measurable performance indicators for abdominal palpation, and development of evidence-based criteria and recommendations of technique parameters are needed. This research has analysed the metrics of coverage, systematism, patterns, light and deep forces from a small recorded data sample. However further research is required to determine if these are suitable quantitative parameters, and what performance metrics ought to be set to enable evidence-based training of the technique and incorporation of the parameters into a revised training simulator. This should be done using a controlled randomised trial (RCT) and method similar to Van Herzeele [187] whereby training was provided to students, who then treated a series of identical pathologies for which a simulator recorded performance data instantly and objectively, and the performance was rated by an experienced interventionalist on first and last procedure to compare. This RCT method would show if there is immediate improvement of procedural skills, and provide rated performance data for setting performance metrics and benchmarks. A further longitudinal study to follow students over time would then identify if the simulator training has improved their long-term procedural skills performance, and if they perform better than or consistent with current training methods. Outcomes are thought to provide opportunity for a full assessment and recommendation on improving clinical outcomes through training.

9.3 Conclusion

An educational tool was developed to provide an objective method to support the teaching of abdominal palpation techniques. The simulator was in the form of a physical model (see Figure 100) to simulate a male abdomen with a rigid force platform to record the location and magnitude of applied force on the surface of the abdomen.

A trial of the abdominal simulator found it to be sufficiently realistic for students to learn the technique and provide a suitable simulated experience for learners to practise and develop abdominal palpation skills.

Figure 100. AbSIM Abdominal Palpation Simulator

CHAPTER 10. Appendices

Appendix A. Chapter 5 HHDCP Supplementary Information

10.1 Ethics Documents

Government of South Australia

REPATRIATION GENERAL HOSPITAL
Daws Road, Daw Park SA 5041
Ph: (08) 8276 9666 Fax: (08) 8277 9401
www.rgh.sa.gov.au

Monday, 18th February 2008

Ms L. Burrow
School of Informatics and Engineering
Flinders University
BEDFORD PARK SA 5042

Dear Lynne

RE: How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique. RGH protocol number: 75/07

Thank you for your response to Committee concerns in the letter dated 17th December 2007, received on 24th January 2008, and attention to adding details to the information sheet for the above study. Your reply to concerns raised at the meeting of 21st November 2007 was reviewed by the committee and ethical approval to proceed was granted.

I have enclosed the following documents:
1. Approved Participant Information Sheet: Subject
2. Approved Participant Consent Form: Subject
3. Approved Participant Information Sheet: Clinician
4. Approved Participant Consent Form: Clinician

Ethical approval is given initially for a period of one year, and it is requested that an annual report be forwarded to the Committee by January 2009 or upon completion of the study. The form is found on S drive in the Ethics folder. As a condition of ethical approval you should report immediately anything which might affect ethical acceptance of the protocol, including adverse events, protocol changes, and unforeseen events which may affect continued ethical acceptability. *The Committee is to be notified when the study is complete or discontinued.*

In addition the Committee wishes to remind you that it is your responsibility to maintain the security of the information you obtain and to notify the Committee immediately any breaches occur.

The Repatriation General Hospital Research and Ethics Committee operates according to ICH/GCP and the NHMRC *'National Statement on Ethical Conduct in Research Involving Humans'* (March 2007).

This study has been given the reference number **75/07**. This number should be quoted in all further correspondence with the Committee. I can be contacted on [redacted] if you require any further help or information.

Yours sincerely

[redacted]

Executive Officer
Research and Ethics Committee
Telephone: [redacted]

Medical research at RGH is supported by Foundation Daw Park Incorporated • Donations of $2 and over are tax deductible
ABN 20 975 207 143

0-4019
/06

Flinders University · Repatriation General Hospital Daw Park · Flinders Medical Centre · Government of South Australia, Southern Adelaide Health Service

APPROVED [redacted]
DATE 18-2-08

PARTICIPANT INFORMATION SHEET: SUBJECT

How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique

(Looking at and measuring the ways different doctors press on the belly during a normal examination)

This is a research project, and you do not have to be involved. If you do not wish to participate, your medical care will not be affected in any way.

You are invited to take part in a study exploring the measurement of forces applied to the abdomen during a routine (regularly performed) abdominal (belly) examination. This study may provide data essential to the development of a new abdominal examination training simulator that will assist in training medical students to perform this technique.

If you choose to participate, you will need to lie on an examination table with your abdomen exposed. Experienced clinicians will each examine your abdomen with their hands. The location of the pressure they apply will be measured by markers attached to both their hands and your abdomen. The amount of pressure will be measured by force plates that are beneath the legs of the table. A video recording of the examination will be performed to help the investigators compare the data from the markers to a visual record of the procedure. This video will not show your face.

Five clinicians will each perform the same examination tasks lasting no more than a total of one hour per clinician. During this time we will ask the clinicians to repeat some measurements. This will help us to measure any changes in the pressure applied for each different time.

You may experience mild discomfort when force is applied to the abdomen, however this is the same as would usually occur during an abdominal examination. There are no direct benefits to you associated with this study, but participating will add to medical knowledge.

Although there are no known risks involved in taking part in this study, if you, as a participant of this research, suffer injury, compensation may, at the discretion of the Department of Health, be paid without litigation. However, compensation is not automatic and you may have to take legal action in order to receive payment.

As a participant in this study, you should advise the study doctor of any other studies in which you are participating. In the event that you need elective or emergency or other medical care, you should inform the doctor looking after you that you are participating in this study.

Your participation in the study is entirely voluntary and you have the right to withdraw at any time. If you decide not to participate in this study or if you withdraw, you may do this freely without prejudice to any treatment at Flinders Medical Centre or the Repatriation Hospital.

There is no financial or other benefit received by the doctor and/or research team for enrolling you in this study other than usual salary or stipend and costs associated with facility and equipment hire. The purpose is purely for data collection for the chief investigator's study towards a PhD.

All records containing personal information will remain confidential and no information which could lead to idenfication of any individual will be released. Your identity will not be disclosed in the event of any publication arising from this study. To comply with Government rules and guidelines, your medical records must be allowed to be viewed by representatives of the sponsoring company, the Research and Ethics Committee or other regulatory bodies for the purposes of auditing, in association with this study.

Should you require further details about the project, either before, during or after the study, you may contact Chief Investigator Lynne Burrow on [redacted] (office hours) or email [redacted] or Principal supervisor A/Prof Karen Reynolds ([redacted]).

This study has been reviewed by the Flinders Clinical Research Ethics Committee (FCREC) and the Research and Ethics Committee at the Repatriation General Hospital, Daw Park. If you wish to discuss the study with someone not directly involved, in particular in relation to matters concerning policies, information about the conduct of the study, your rights as a participant, or should you wish to make a confidential complaint, you may contact:

The Executive Officer FCREC, Flinders Medical Centre [redacted] ***or*** [redacted]

Janet Bennett, Executive Officer of Research and Ethics Committee, Repatriation General Hospital, [redacted]

Flinders UNIVERSITY

FLINDERS MEDICAL CENTRE

Government of South Australia
Southern Adelaide Health Service

REPATRIATION GENERAL HOSPITAL DAW PARK

CONSENT TO PARTICIPATION IN RESEARCH STUDY: SUBJECT

I, ... request and give consent to my
(first or given names) (last name)

involvement in the research project: **"How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique"**

I acknowledge the nature, purpose and contemplated effects of the research project, especially as far as they affect me, have been fully explained to my satisfaction by **Lynne Burrow** and my consent is given voluntarily.

I acknowledge that the detail(s) of the following has/have been explained to me, including indications of risks; any discomfort involved; anticipation of length of time; and the frequency with which they will be performed:

1. Examination of the Abdomen ....

2. Collection of force, position and video data ....

- I have understood and am satisfied with the explanations that I have been given and hereby consent to the participation in the above study.
- I understand that the results of these studies may be published, but my identity will be kept confidential.
- I have been provided with a written information sheet and have read and understood what is required.
- I understand that my involvement in this research project may not be of any direct benefit to me and that I may withdraw my consent at any stage without affecting my rights or the responsibilities of the researchers in any respect.
- I understand that representatives from the Hospital Research and Ethics Committee may need to access my medical records for information related to the study for the purpose of audit. I authorise access to my medical record for this purpose.
- I declare that I am over the age of 18 years.
- I acknowledge that I have been informed that should I receive an injury as a result of taking part in this study, I may need to start legal action to determine whether I should be paid.

Signature of Research Participant : .... Date: ....

Signature of Witness: .... Date: ....

Printed Name of Witness: ....

I, ... have described to ....
the research project and nature and effects of procedure(s) involved. In my opinion he/she understands the explanation and has freely given his/her consent.

Signature: .... Date: ....

Status in Project: ....

Flinders UNIVERSITY

FLINDERS MEDICAL CENTRE

Government of South Australia
Southern Adelaide Health Service

REPATRIATION GENERAL HOSPITAL DAW PARK

RESEARCH AND ETHICS COMMITTEE [redacted] 18-2-08

PARTICIPANT INFORMATION SHEET: CLINICIAN

How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique

This is a research project, and you do not have to be involved. Whether you take part or not, your relationship with the university and hospitals will not be affected in any way.

You are invited to take part in a study exploring the measurement of forces applied to the abdomen during a routine abdominal examination.

This study may provide data essential to the development of a new abdominal examination training simulator that will assist in training medical students to perform this technique.

If you choose to participate, you will need to perform a routine abdominal examination on a volunteer subject. The location of the applied force will be measured by markers attached to your hands and to the subject's abdomen. The amount of force will be measured by force plates that are beneath the legs of the table.

During the examination you will be asked to return to repeat the examination and perform specific parts of the examination as per directions from the investigator. Between each repeat examination you will be asked some brief interview questions related to the examination performed. The total time requirement will be no more than one hour.

A video recording of the examination will be performed to help the investigators compare the data from the sensors to a visual record of the procedure. This video will show the abdominal area of the subject. You will be asked to describe the areas/régions you are feeling for the video.

There are no direct benefits to you associated with this study, but participating will add to medical knowledge.

Although there are no known risks involved in taking part in this study, if you, as a participant of this research, suffer injury, compensation may, at the discretion of the Department of Health, be paid without litigation. However, compensation is not automatic and you may have to take legal action in order to receive payment.

Your participation in the study is entirely voluntary and you have the right to withdraw at any time.

There is no financial or other benefit received by the doctor and/or research team for enrolling you in this study other than usual salary or stipend and costs associated with facility and equipment hire. The purpose is purely for data collection for the chief investigator's study towards a PhD.

All records containing personal information will remain confidential and no information which could lead to idenfication of any individual will be released. Your identity will not be disclosed in the event of any publication arising from this study. To comply with Government rules and guidelines, your medical records must be allowed to be viewed by representatives of the sponsoring company, the Research and Ethics Committee or other regulatory bodies for the purposes of auditing, in association with this study.

Should you require further details about the project, either before, during or after the study, you may contact Chief Investigator Lynne Burrow on [redacted] (office hours) or email [redacted] or Principal supervisor A/Prof Karen Reynolds [redacted].

This study has been reviewed by the Flinders Clinical Research Ethics Committee (FCREC) and the Research and Ethics Committee at the Repatriation General Hospital, Daw Park. If you wish to discuss the study with someone not directly involved, in particular in relation to matters concerning policies, information about the conduct of the study, your rights as a participant, or should you wish to make a confidential complaint, you may contact:

The Executive Officer FCREC, Flinders Medical Centre [redacted] ***or*** [redacted]

Janet Bennett, Executive Officer of Research and Ethics Committee, Repatriation General Hospital, [redacted]

Flinders UNIVERSITY

FLINDERS MEDICAL CENTRE

Government of South Australia

Southern Adelaide Health Service

REPATRIATION GENERAL HOSPITAL DAW PARK

18-2-08

CONSENT TO PARTICIPATION IN RESEARCH STUDY: CLINICIAN

I, ... request and give consent to my
(first or given names) (last name)

involvement in the research project: **"How hard do clinicians press? A study to observe and quantify experienced clinicians' abdominal examination technique"**

I acknowledge the nature, purpose and contemplated effects of the research project, especially as far as they affect me, have been fully explained to my satisfaction by **Lynne Burrow** and my consent is given voluntarily.

I acknowledge that the detail(s) of the following has/have been explained to me, including indications of risks; any discomfort involved; anticipation of length of time; and the frequency with which they will be performed:

1. Examination of the Abdomen ....

2. Collection of force, position and video data ....

- I have understood and am satisfied with the explanations that I have been given and hereby consent to the participation in the above study.
- I understand that the results of these studies may be published, but my identity will be kept confidential.
- I have been provided with a written information sheet and have read and understood what is required.
- I understand that my involvement in this research project may not be of any direct benefit to me and that I may withdraw my consent at any stage without affecting my rights or the responsibilities of the researchers in any respect.
- I understand that representatives from the Hospital Research and Ethics Committee may need to access my medical records for information related to the study for the purpose of audit. I authorise access to my medical record for this purpose.
- I declare that I am over the age of 18 years.
- I acknowledge that I have been informed that should I receive an injury as a result of taking part in this study, I may need to start legal action to determine whether I should be paid.

Signature of Research Participant : .... Date: ....

Signature of Witness: .... Date: ....

Printed Name of Witness: ....

I, ... have described to .... the research project and nature and effects of procedure(s) involved. In my opinion he/she understands the explanation and has freely given his/her consent.

Signature: .... Date: ....

Status in Project: ....

10.2 Study Checklist

	Clinician Particulars
Date	
Time	
Clinician No	
Position *(ie Consultant, Specialist, Registrar, Research Fellow)*	
Name	
Medical School attended	
Years since graduation	
Speciality Field	
Height (cm)	
Weight (kg)	
Gender	
Information Sheet given	
Consent form signed	
4 markers on table	
8 markers on participant abdomen	
4 markers on clinician hand	
Part 1: *Ask clinician to perform a palpation examination as per their usual method (giving verbal cues as to the areas they are applying force)*	
Q1.1: Do you initially examine a patient's abdomen the same way every time?	
Q1.2: Why/Why not?	
Q1.3: Why did you use the sequence just performed today to examine the abdomen?	
Part 2: *Ask clinician to perform a palpation examination, examining the regions in the set order lightly, then again deeply.*	
1st repeat	
2nd repeat	
Q2: If this was not the sequence you normally use to examine the abdomen:	
Q2.1: How was it different?	
Q2.2: Do you think it is more/less effective?	
Q2.3: Why/Why Not?	
Part 3: a) *Ask clinician to perform "light palpation" in one region.*	
1st repeat	
2nd repeat	
3rd repeat	
b) *Ask clinician to perform "deep palpation" in same region.*	
1st repeat	
2nd repeat	
3rd repeat	
Q3.1: Do you think you were consistent in the amount of force applied?	
Q3.2: In a clinical setting do you think you are consistent?	
Q3.3: Why/why not?	

10.3 Analysis Methods

10.3.1 Maxima and minima

Slope=dy/dx=f'(x)=0

Must change from + to – at max points

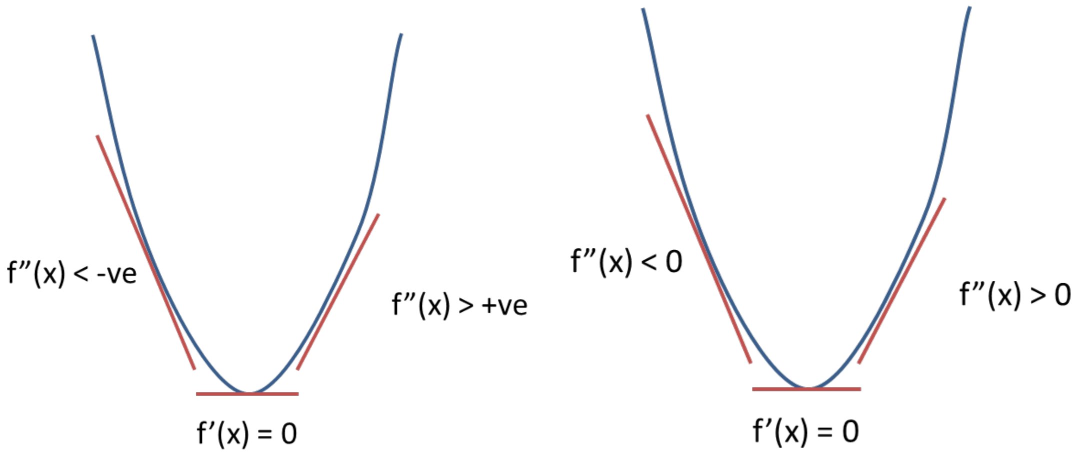
Must change from – to + at min points

f(x) is a maximum if f'(x)=0 and f''(x)= a negative number

f(x) is a minimum if f'(x)=0 and f''(x)= a positive number

Therefore

1) Find f'(x)
2) Find x values (critical values) for which f(x)=0
3) Find f''(x)
4) Substitute x values (from point 2) into f''(x) and
    a. if negative => max point
    b. if positive => min point



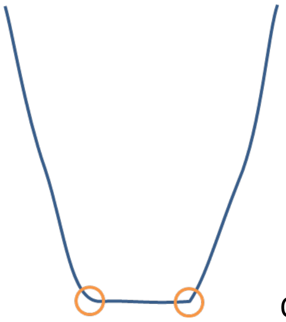
If dy/dx =0 and if $d^2y/dx^2 > 0$ => min

If dy/dx =0 and if $d^2y/dx^2 < 0$ => max

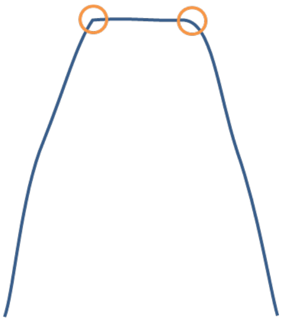
APPENDICES

Consider

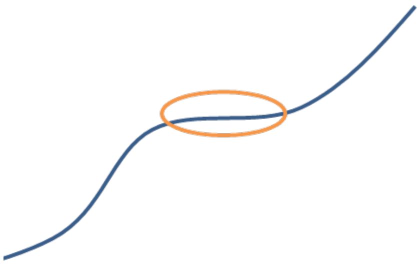
- Flat sections
    - Record start & end of flat sections critical points i.e.



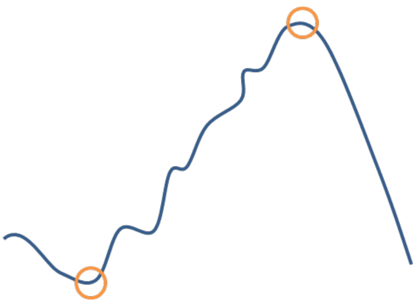
OR



- Inflexions
    - Disregard from critical point list i.e.



- Sensitivity
    - Only include min & max points i.e.



Sensitivity ξ

A local min at a if f(a)<=f(x) when |x-a|< ξ

Global min is at a if f(a)<=f(x) for all x

10.3.2 Duration of Palpation

Definitions and Assumptions:

For a **single palpation**, i.e. application and removal of force in a single action:

- Application of force is considered to be "removed" once the force drops below the "lower threshold".
- For a **"palpation"** to be considered an individual palpation, the applied force must be greater than the "upper threshold" at some point in its "duration".

Duration of a single palpation shall be from application of force (ie from 0N) to either:

- Removal of force (i.e. applied force removed and force goes back to 0N) or
- Where removal of force has been significant enough to suggest clinician had removed most of the force before beginning next palpation ie minimum critical point below the lower threshold.

Total duration = the total time of a particular task or sequence i.e. One Light Palpation Sequence, One Deep Palpation Sequence

- ***Peak force*** = the largest force reached in the "duration"

- ***Light Palpation force*** = the average force between application and removal of force for light palpation sections

- ***Deep palpation force*** = the average force between application and removal of force for deep palpation segments

Assumptions:

Light Palpation lower threshold: 30% maximum light palpation force

Light Palpation upper threshold: 70% maximum light palpation force

Deep Palpation lower threshold: 25% maximum deep palpation force

Deep Palpation upper threshold: 50% maximum deep palpation force

10.4 Part 2 Data

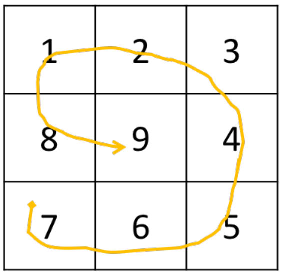


Figure 101. Specified sequence of palpation, set order = 7-6-5-4-3-2-1-8-9

Table 49. Part 2 - Light Palpation Specified Sequence Participant Summary Data

Clinician ID	Light Sequence Repeat	Light Sequence performed (Specified sequence: 7-6-5-4-3-2-1-8-9)	Total Duration (s)	Average Individual Palpation Duration (s)	Mean Force (N)
	LS#1	7-6-5-5-4-3-3-2-1-8-7	18.79	1.71	35.24
	LS#2	7-6-5-4-3-3-2-1-8-7-7	19.53	1.78	38.35
Clin1	LS#3	7-6-5-4-3-3-2-1-8-7	16.23	1.62	40.53
	Average		**18.18**	**1.70**	**37.96**
	Std. Dev		**1.73**	**0.28**	**5.91**
	LS#1	7-7-6-6-5-4-3-3-2-1-8-7-6-4-2-9	27.44	1.71	37.67
	LS#2	7-6-5-4-4-4-3-3-2-2-1-8-7-4-9-9	26.48	1.65	39.25
Clin2	LS#3	7-6-5-4-4-4-3-3-2-2-1-8-7-4-9-9	25.81	1.61	41.29
	Average		**26.57**	**1.66**	**39.41**
	Std. Dev		**0.82**	**0.65**	**5.49**
	LS#1	6-5-4-3-2-1-8-9	16.14	2.31	32.02
	LS#2	7-6-5-4-3-2-1-8-9	26.36	2.93	40.23
Clin3	LS#3	7-6-5-4-3-2-1-8-9	22.81	2.07	35.68
	Average		**21.77**	**2.42**	**36.25**
	Std. Dev		**5.19**	**0.83**	**7.50**
	LS#1	6-5-4-4-3-3-2-1-8-8-7-7	13.76	1.15	16.34
	LS#2	7-6-5-5-4-3-3-2-2-1-1-8-7	15.20	1.17	12.75
Clin4	LS#3	7-6-5-5-4-4-3-2-1-8-7-7	14.99	1.25	13.32
	Average		**14.65**	**1.19**	**14.10**
	Std. Dev		**0.78**	**0.39**	**4.35**
	LS#1	7-6-5-4-3-2-1-9	17.86	1.49	21.78
	LS#2	7-6-5-4-3-1-8-9	13.77	1.25	21.70
Clin5	LS#3	7-6-5-4-3-1-8-9	16.78	1.53	20.98
	Average		**16.14**	**1.42**	**21.50**
	Std. Dev		**2.12**	**0.97**	**4.62**

Table 50. Deep Palpation Specified Sequence Participant Summary Data

Clinician ID	Deep Sequence Repeat	Deep Sequence performed (Specified sequence: 7-6-5-4-3-2-1-8-9)	Total Duration (s)	Average Individual Palpation Duration (s)	Mean Force (N)
Clin1	DS#1	5-4-3-2-1-8-7-7-6	27.85	3.09	74.62
	DS#2	7-6-5-4-3-2-1-8-7-9-4	25.14	2.51	70.50
	DS#3	7-6-5-4-3-3 (spleen)-2(liver)-1-8	31.87	3.24	74.79
	Average		**28.29**	**3.03**	**75.58**
	Std. Dev		**3.38**	**1.44**	**8.94**
Clin2	DS#1	6-5-5-5-4-4-3-2-1-8-7-6	21.20	1.77	38.10
	DS#2	7-6-5-4-4-2-1-8-7-5-9-6	23.73	1.98	44.33
	DS#3	7-6-5-4-3-2-2-1-8-7-6-5-9-4	25.04	1.79	42.80
	Average		**23.32**	**1.84**	**41.80**
	Std. Dev		**1.95**	**0.44**	**5.45**
Clin3	DS#1	7-6-5-4-3-2-1-8-9	28.34	3.15	39.41
	DS#2	7-6-5-4-3-2-1-8-9	25.25	2.81	32.50
	DS#3	7-6-5-4-3-2-1-8-(9)	24.11	3.01	40.15
	Average		**25.90**	**2.99**	**37.25**
	Std. Dev		**2.19**	**0.46**	**4.74**
Clin4	DS#1	7-6-5-4-4-3-2-1-8	24.59	2.73	31.24
	DS#2	7-6-5-4-3-3-2-1-8	27.40	2.74	33.12
	DS#3	7-6-5-4-4-3-2-1-8-7-(6)	27.90	2.79	41.22
	Average		**26.63**	**2.75**	**35.33**
	Std. Dev		**1.79**	**0.42**	**7.00**
Clin5	DS#1	(7)-6-5-4-3-2-1-8-9	20.52	2.56	30.75
	DS#2	7-6-5-4-3-2-1-8-9	22.14	2.21	26.22
	DS#3	7-6-5-4-3-2-1-8-9	20.36	2.04	26.45
	Average		**21.01**	**2.25**	**27.59**
	Std. Dev		**0.99**	**1.10**	**5.46**

10.5 Part 2 Graphs

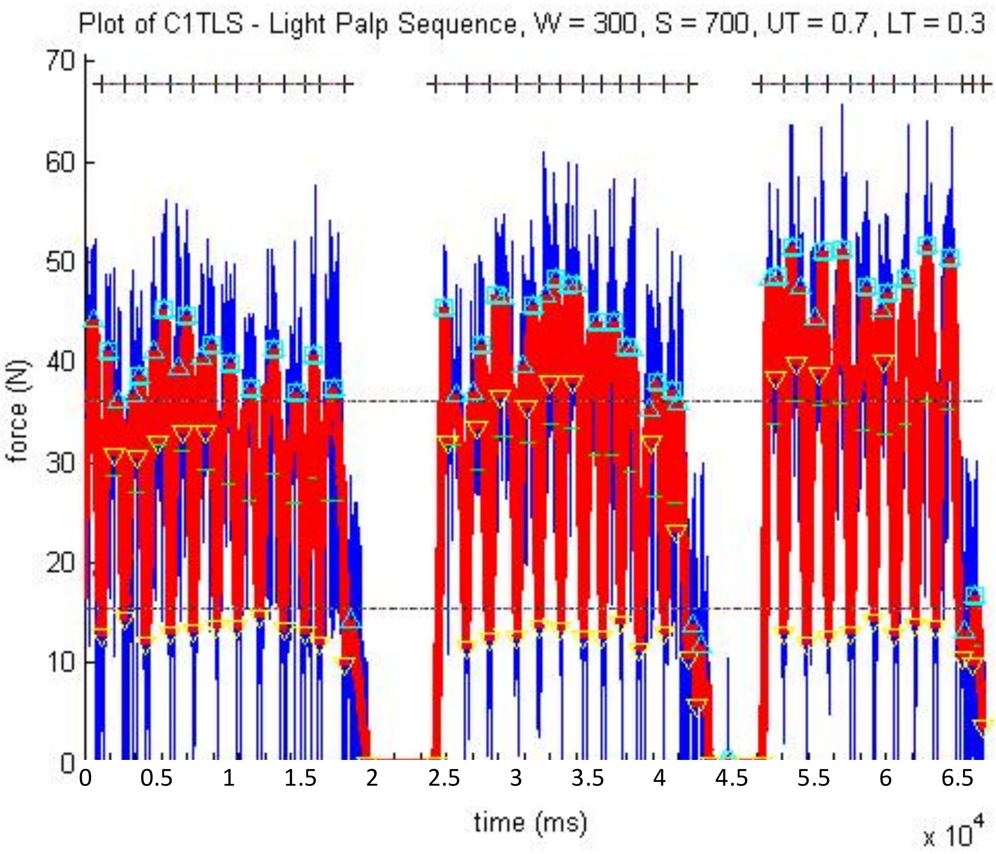


Figure 102. Clin1 Light Palpation Sequences

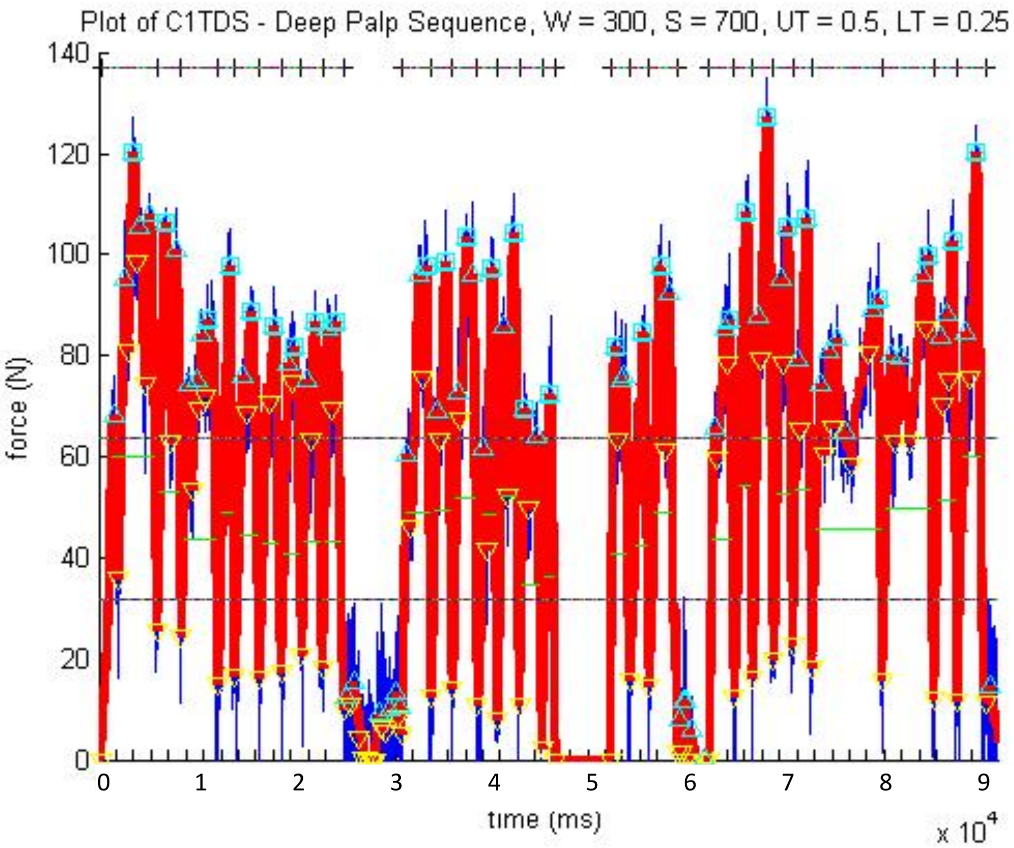


Figure 103. Clin1 Deep Palpation Sequences

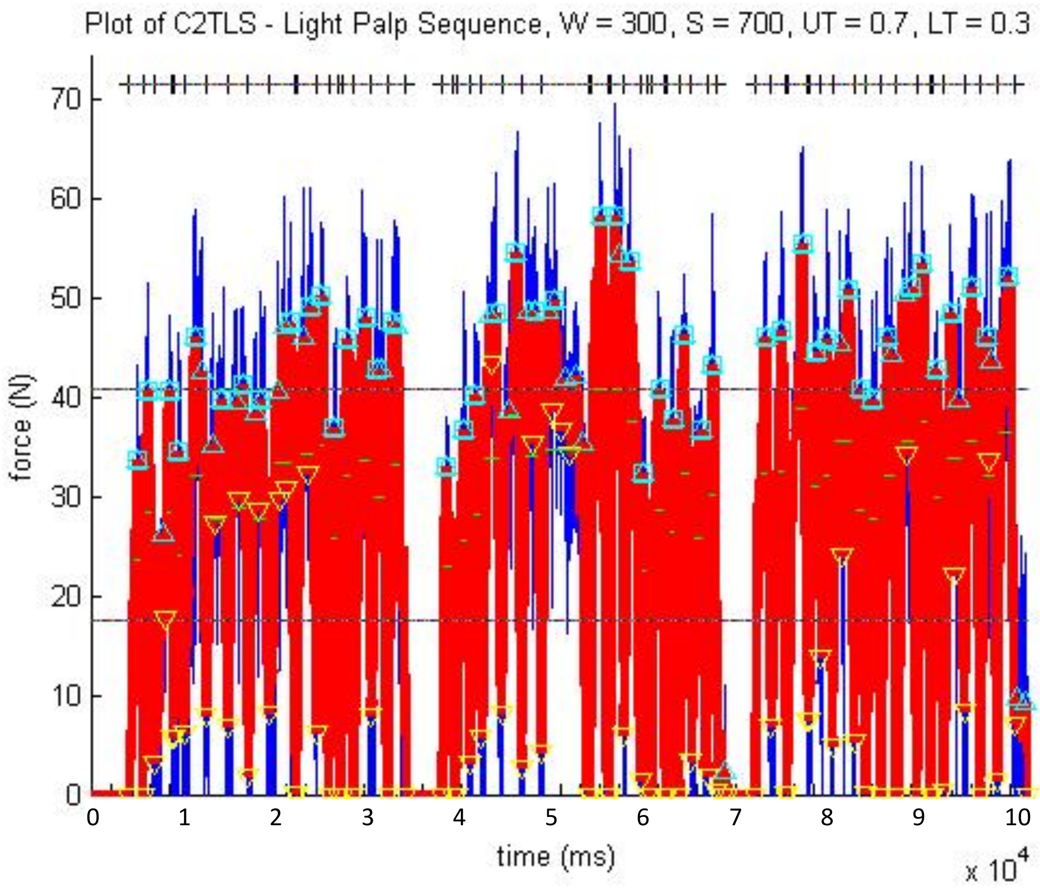


Figure 104. Clin2 Light Palpation Sequences

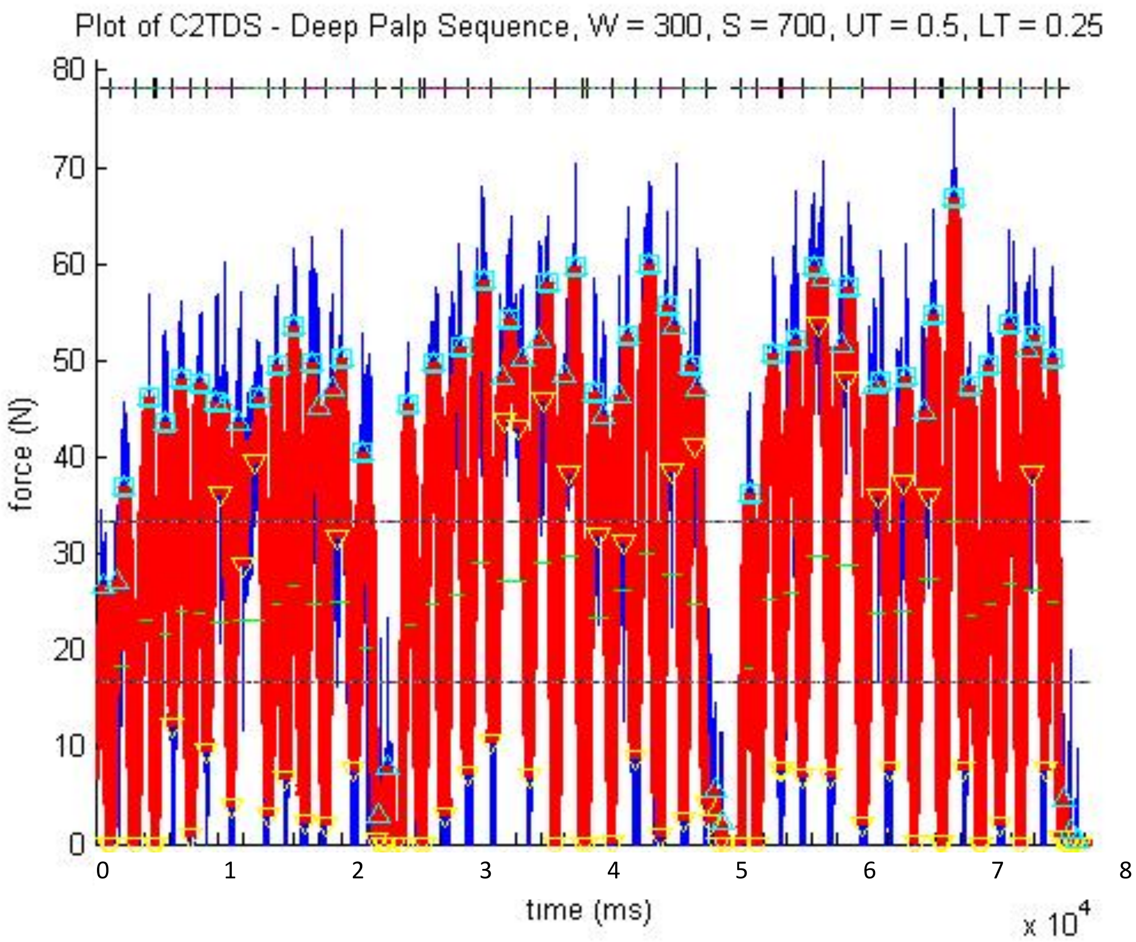


Figure 105. Clin2 Deep Palpation Sequences

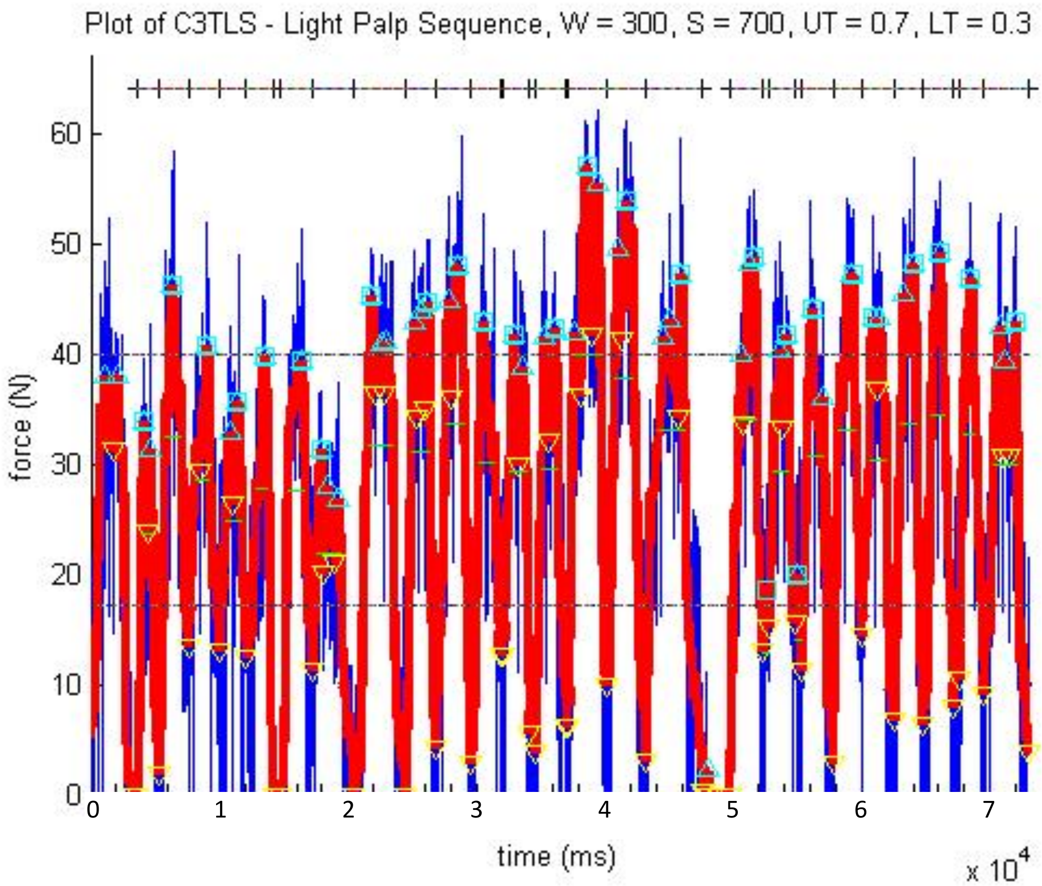


Figure 106. Clin3 Light Palpation Sequences

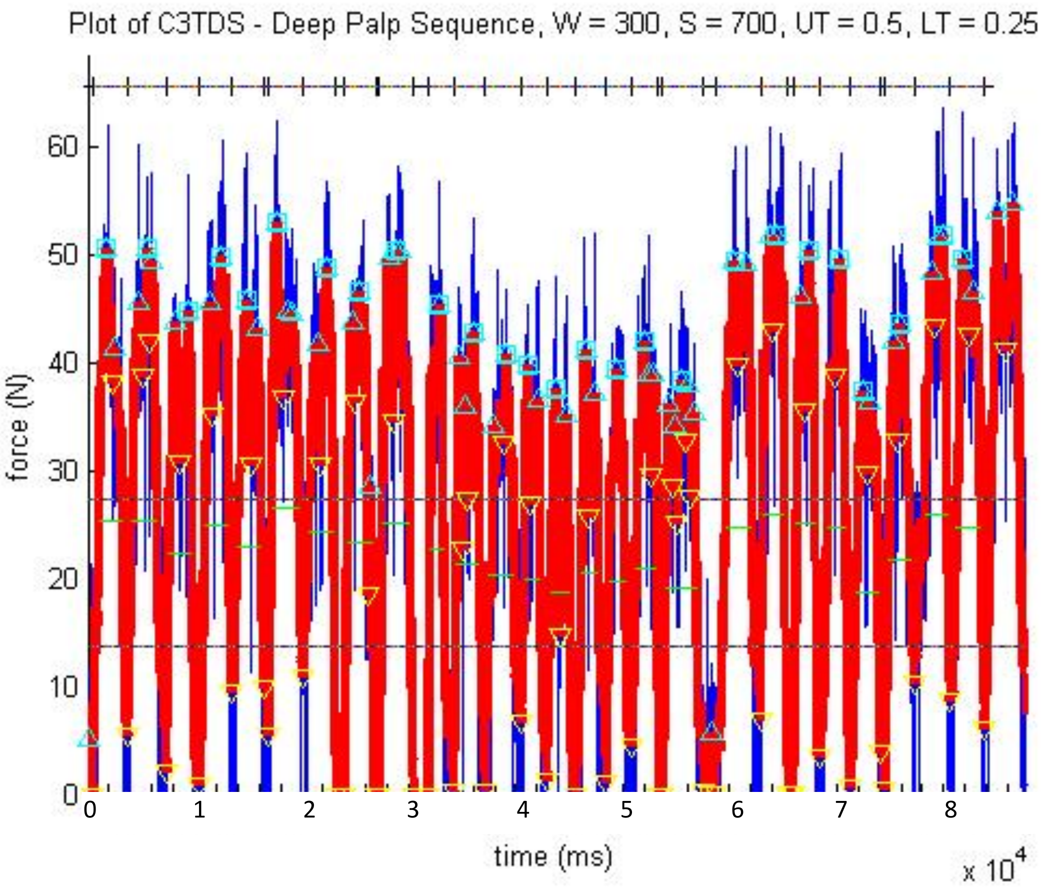


Figure 107. Clin3 Deep Palpation Sequences

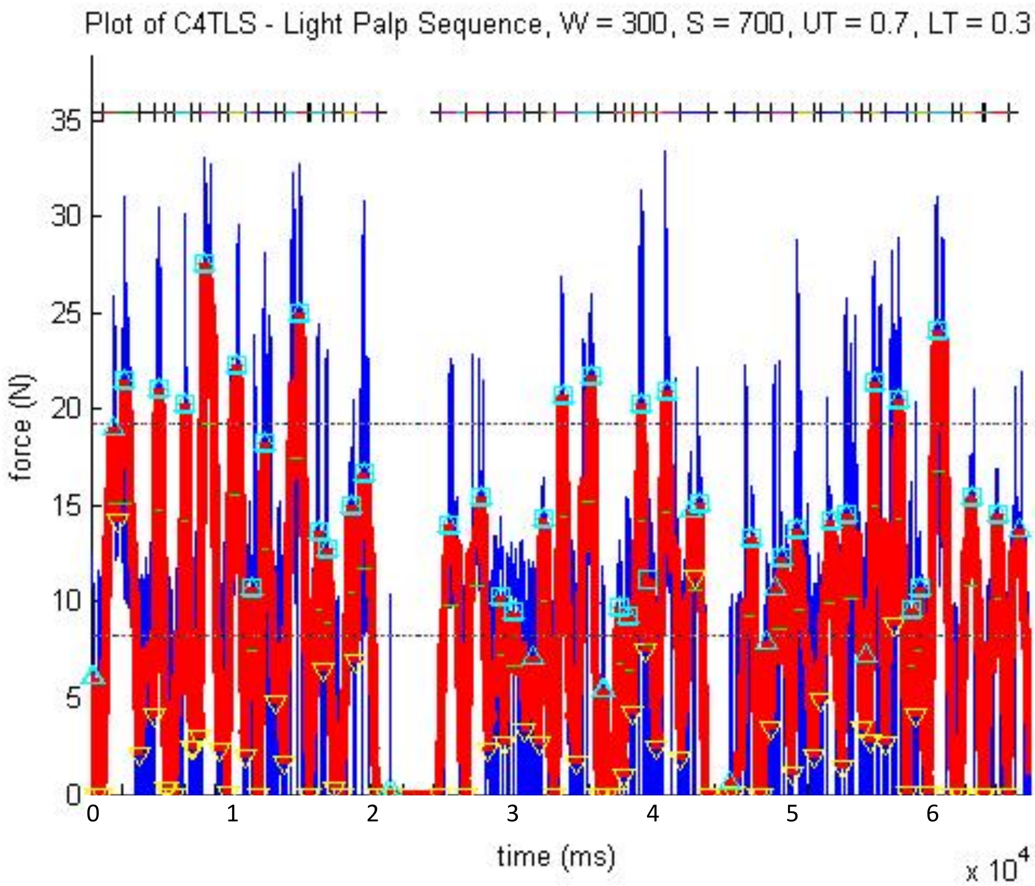


Figure 108. Clin4 Light Palpation Sequences

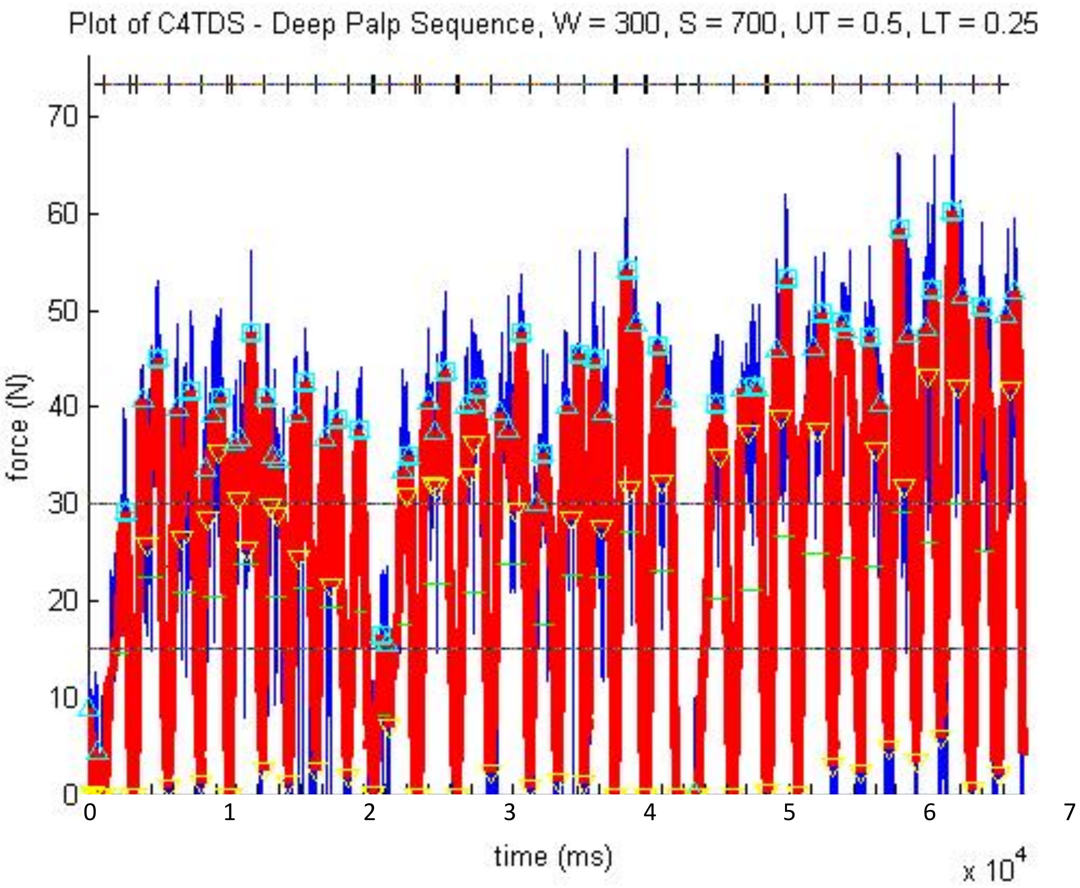


Figure 109. Clin4 Deep Palpation Sequences

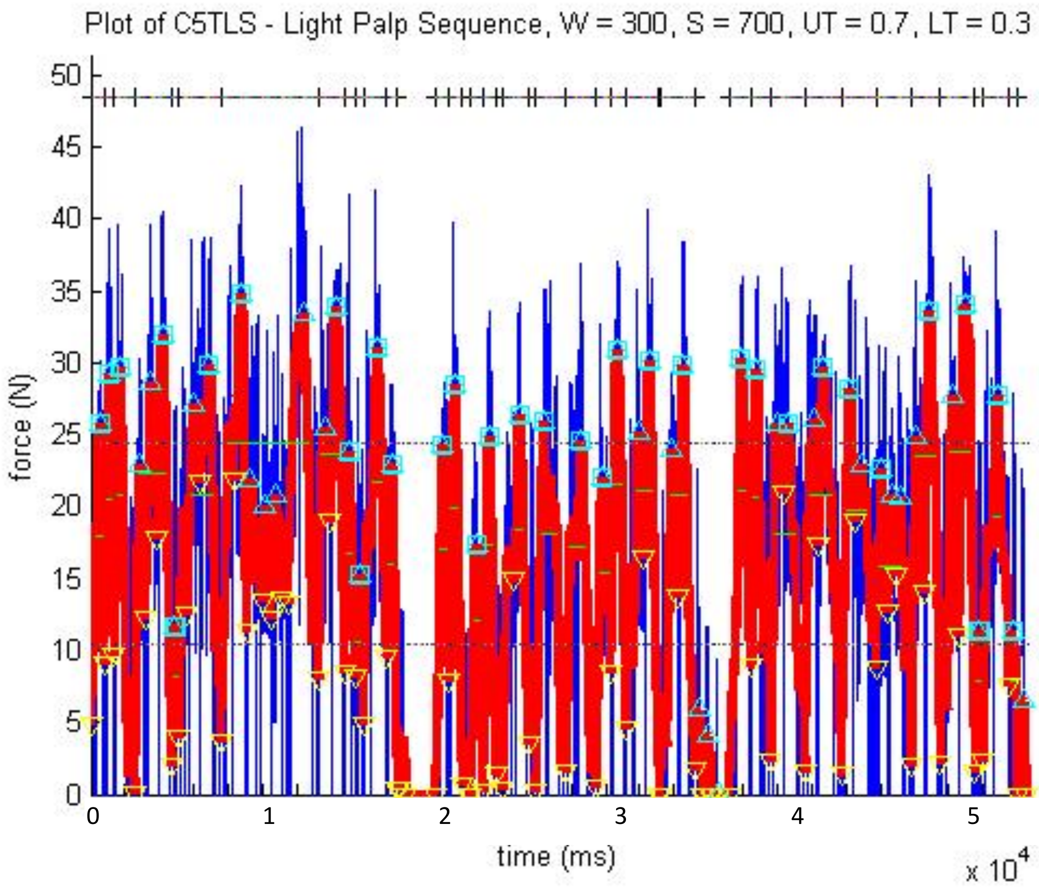


Figure 110. Clin5 Light Palpation Sequences

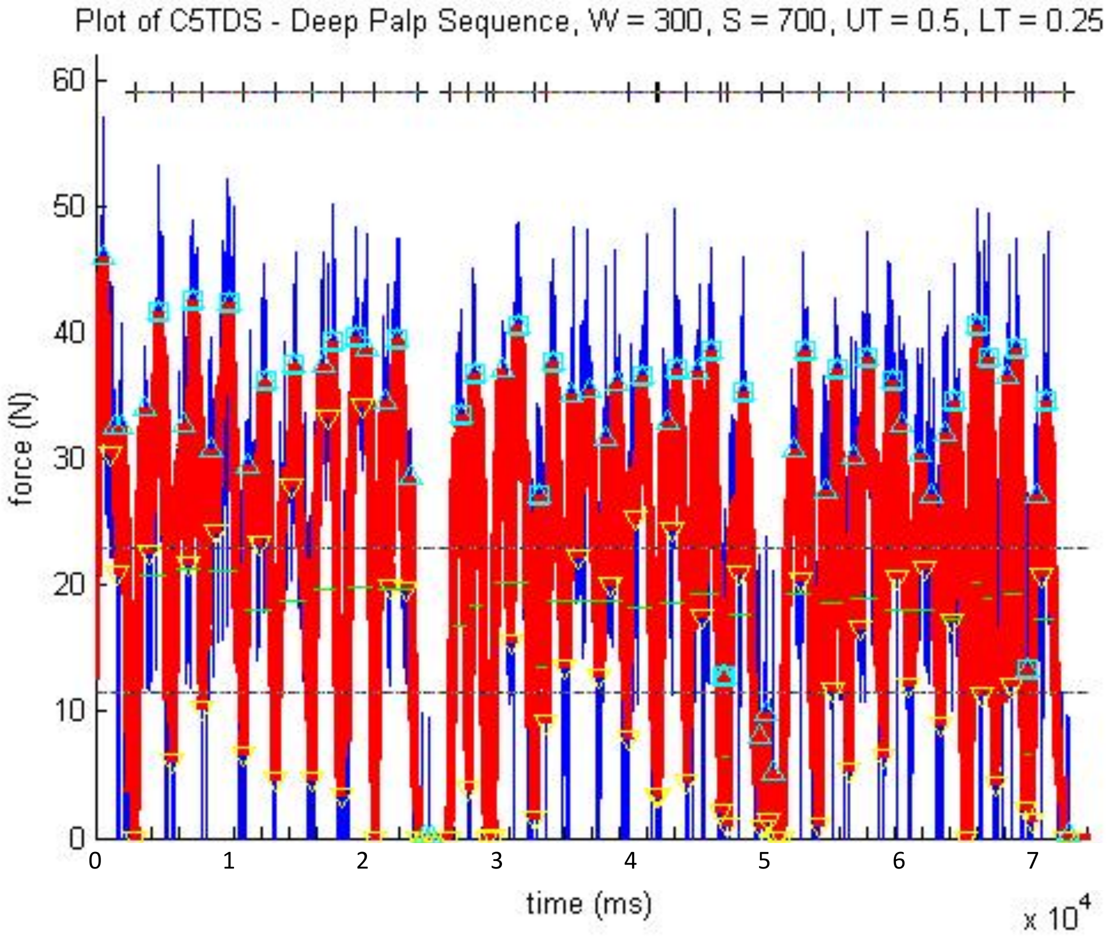


Figure 111. Clin5 Deep Palpation Sequences

10.6 Part 3: Graphs

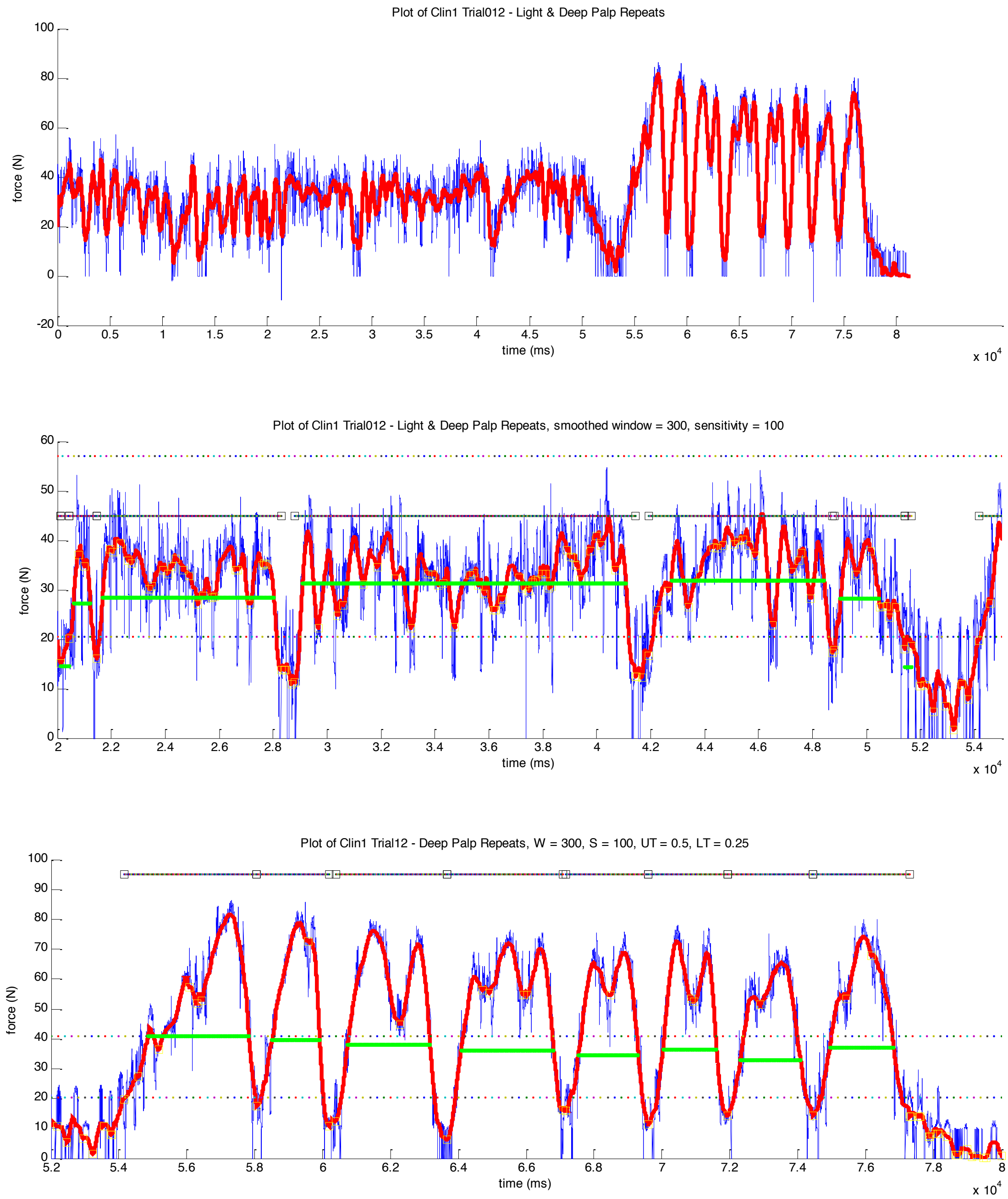


Figure 112. Clin1, Top: Light and Deep Palpation Repeats, Middle: Light Palpation Section of examination Bottom: Deep Palpation section of examination

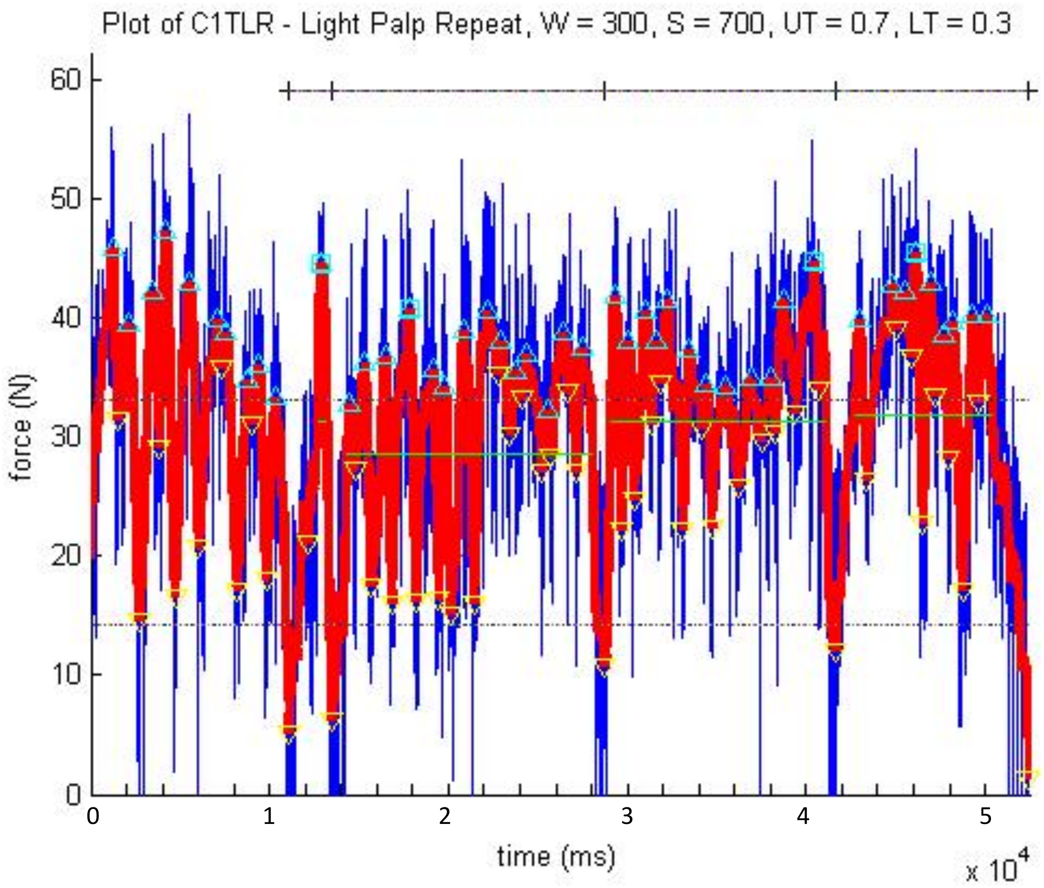


Figure 113. Clin1 Light Palpation Repeats

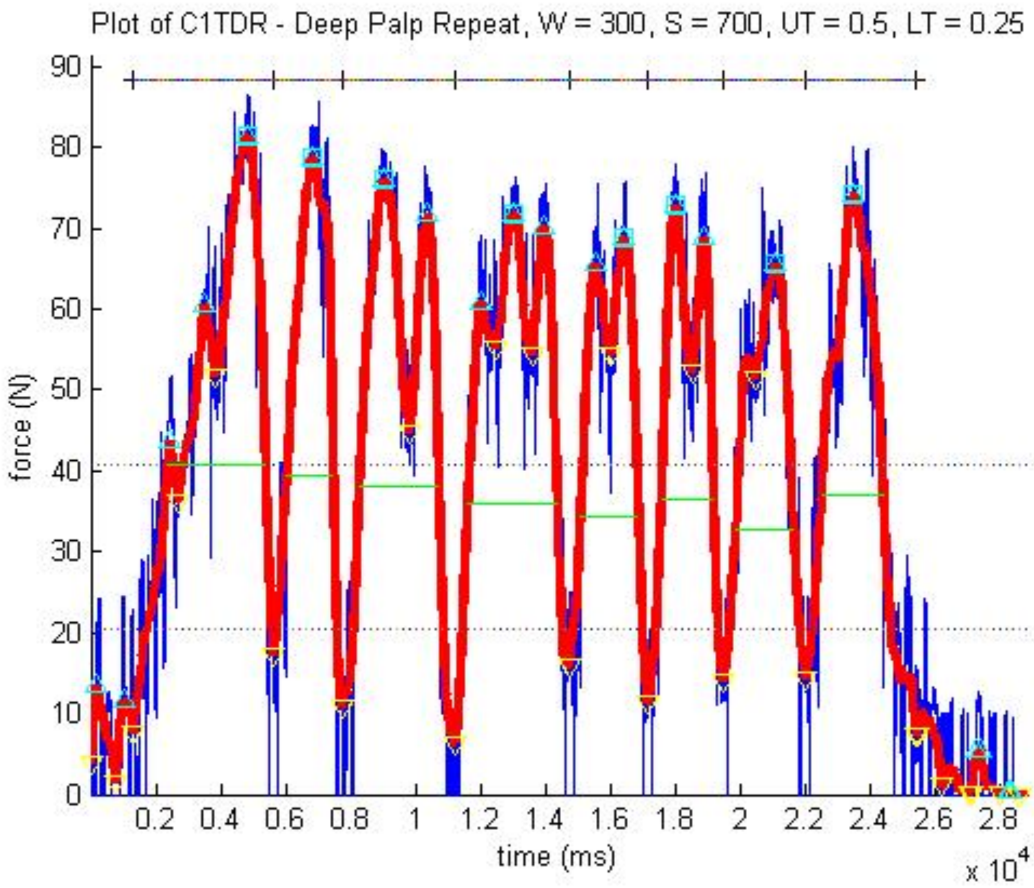


Figure 114. Clin1 Deep Palpation Repeats

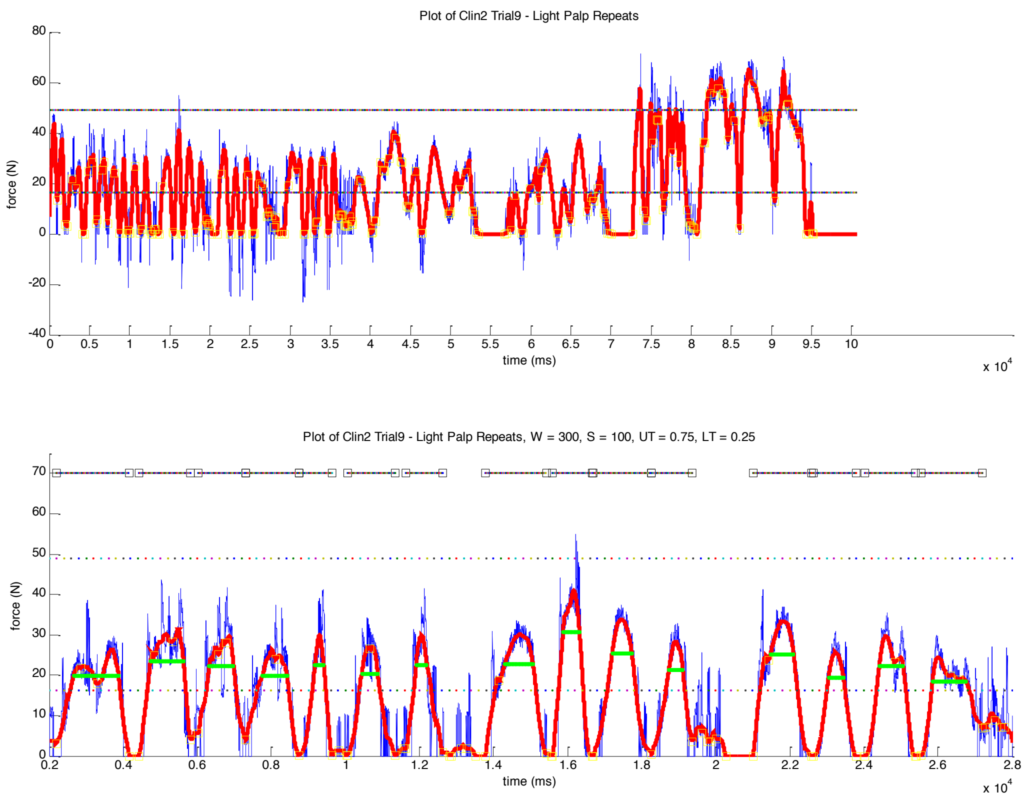


Figure 115. Clin2, Light Deep Summaries

Figure 116. Clin2, Deep Palpation Repeats

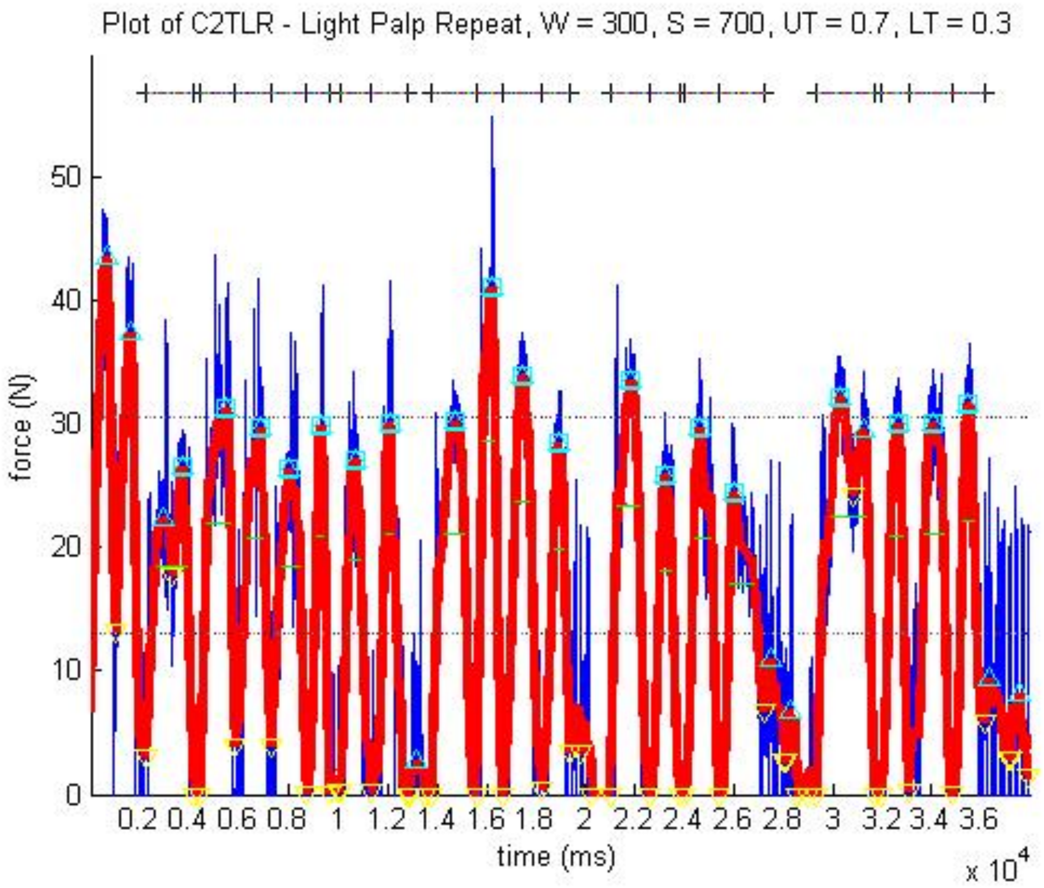


Figure 117. Clin2 Light Palpation Repeats

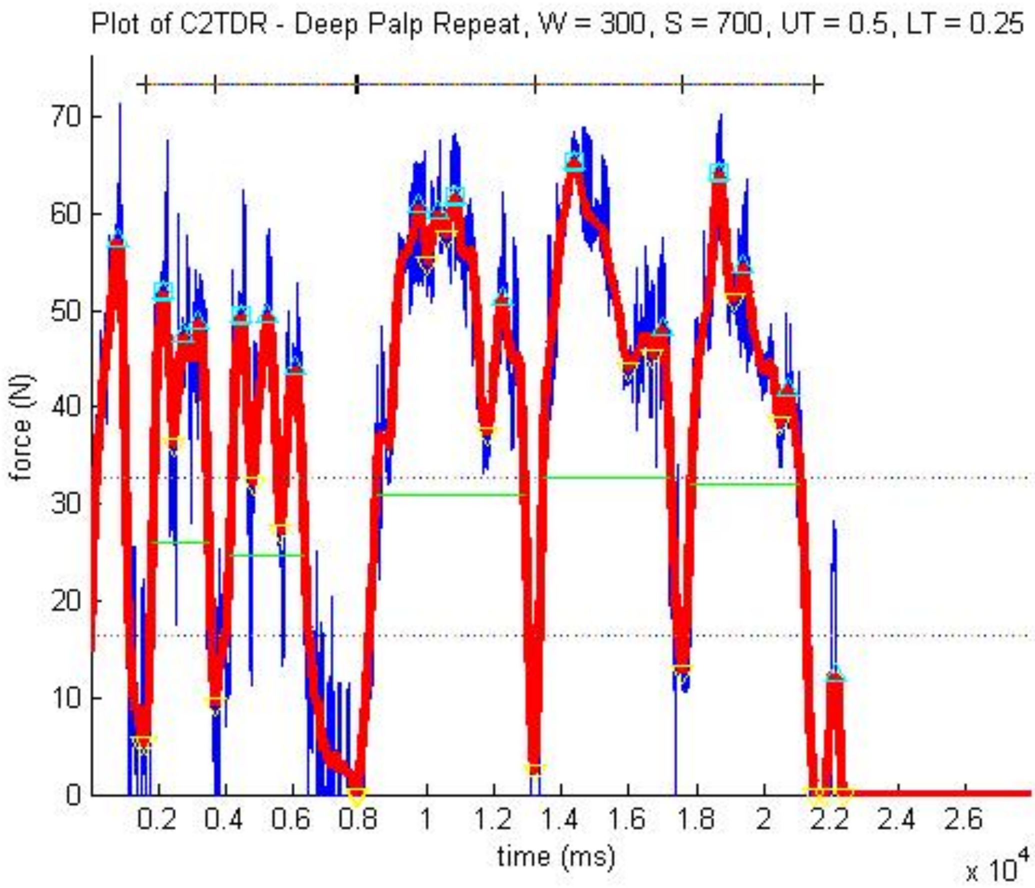


Figure 118. Clin2 Deep Palpation Repeats

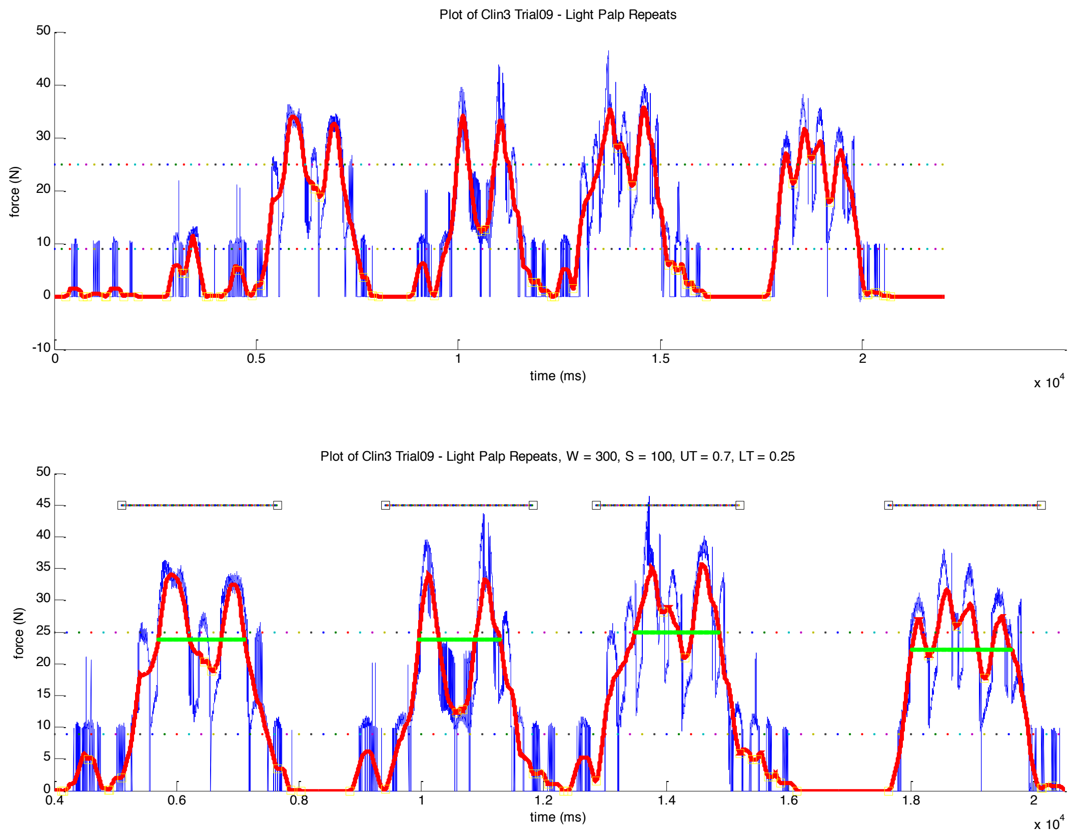


Figure 119. Clin3, Light Palpation Repeats

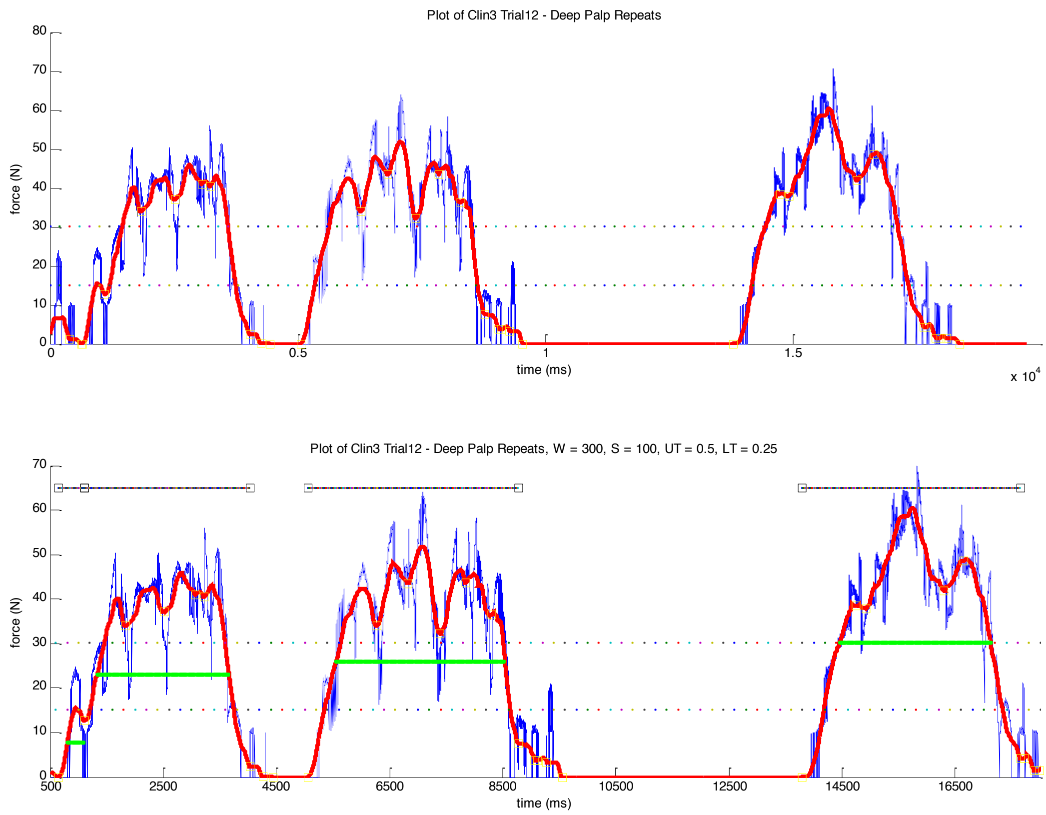


Figure 120. Clin3, Deep Palpation Repeats

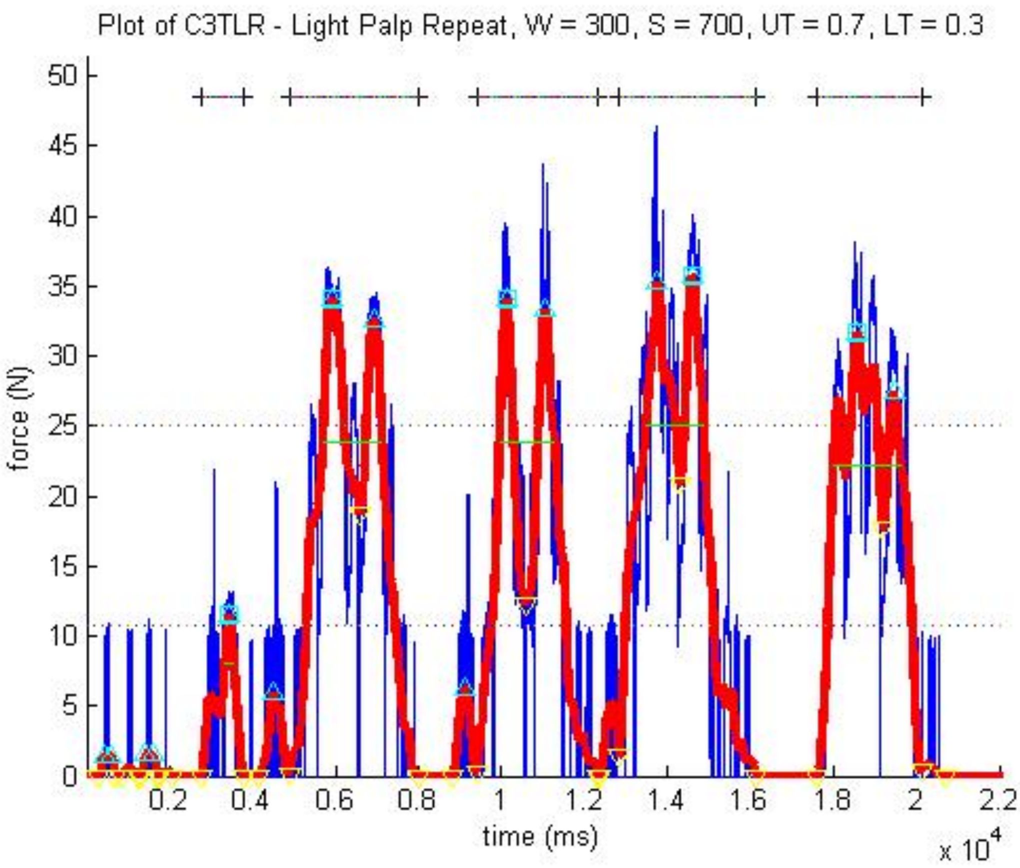


Figure 121. Clin3 Light Palpation Repeats

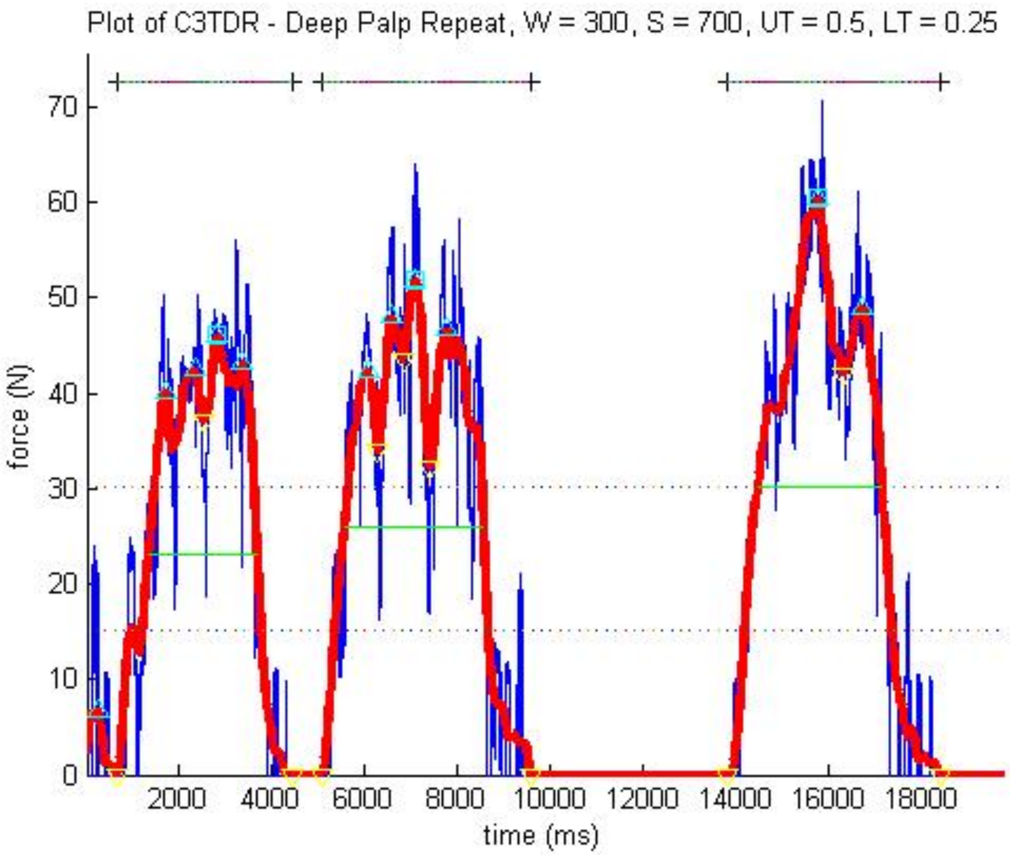


Figure 122. Clin3 Deep Palpation Repeats

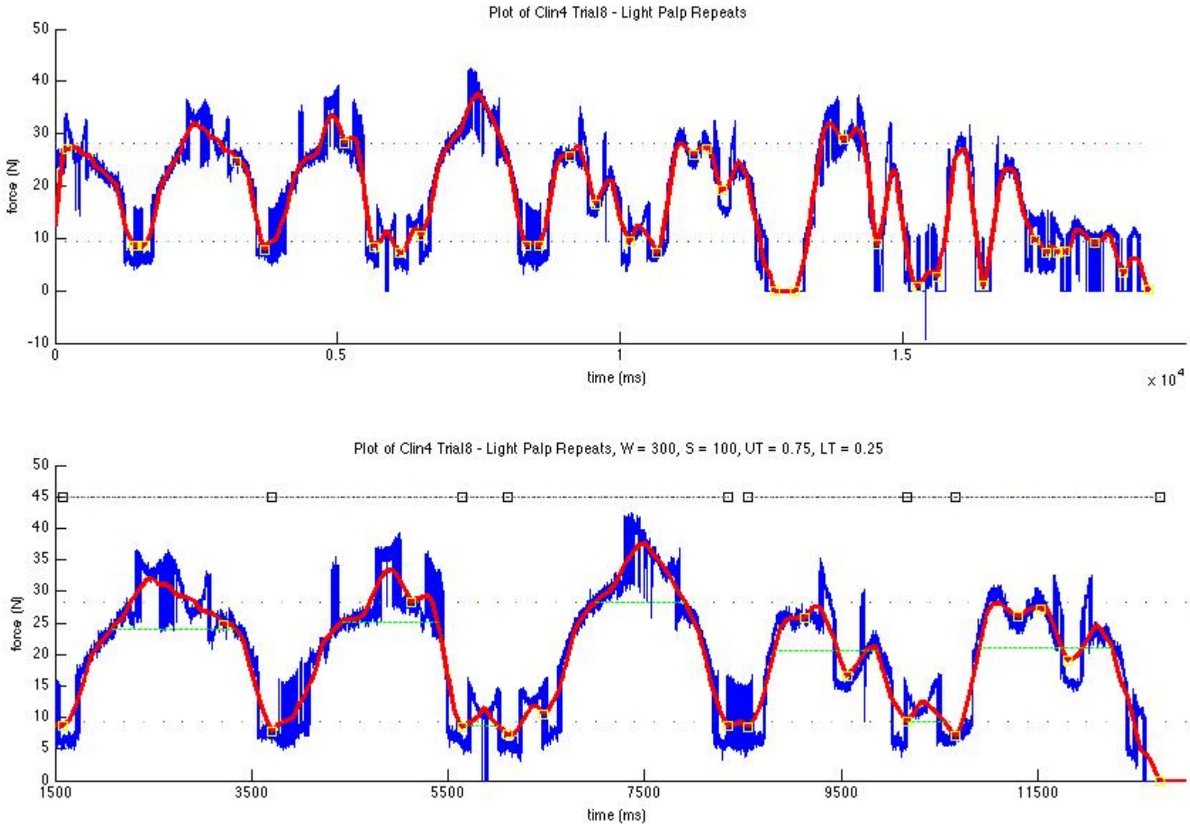


Figure 123. Clin4, Light Palpation Repeats

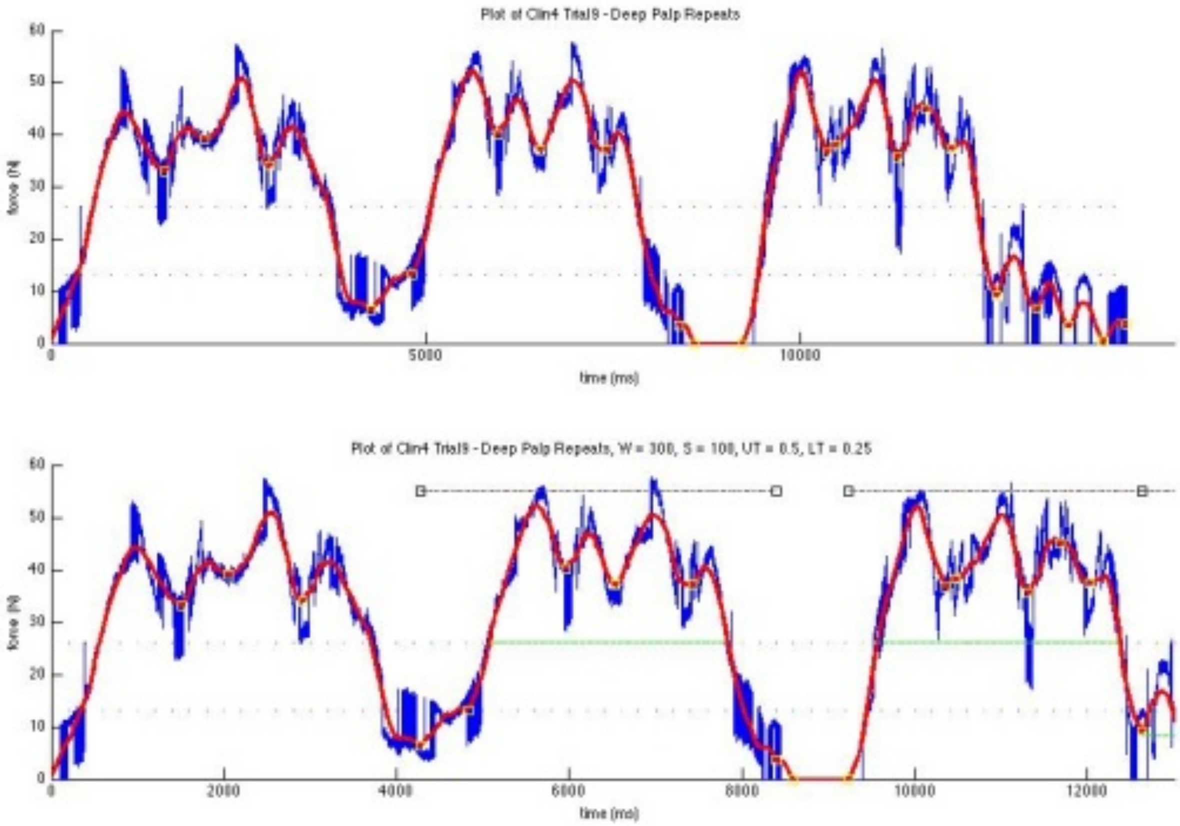


Figure 124. Clin4, Deep Palpation Repeats

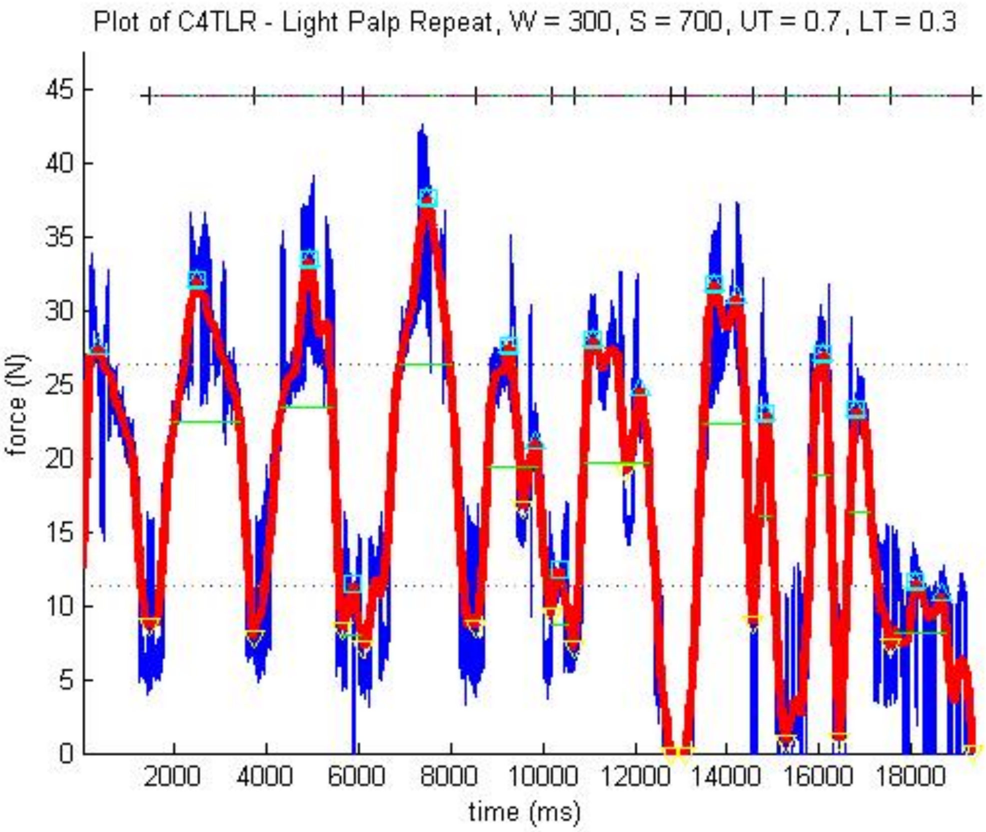


Figure 125. Clin4 Light Palpation Repeats

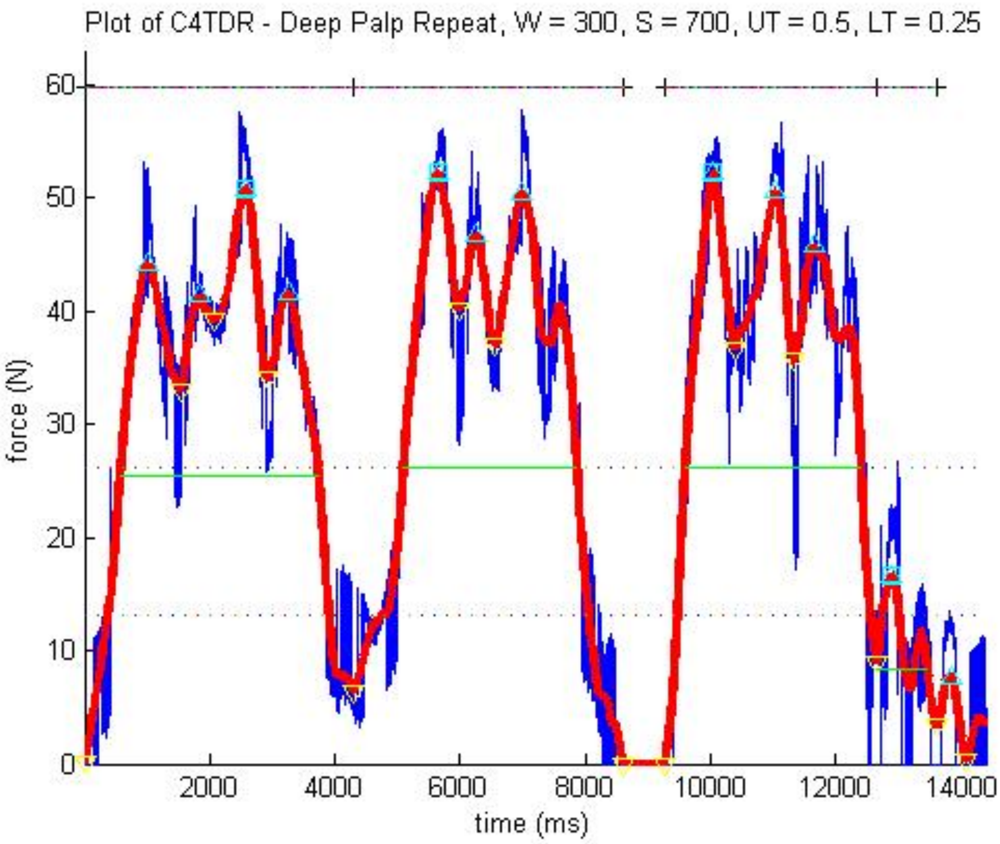


Figure 126. Clin4 Deep Palpation Repeats

10.7 Questions Feedback

Table 51. HHDCP Clinician Feedback to Questions

Feedback Questions	Clin01	Clin02	Clin03	Clin04	Clin05
Q1.1 Do you initially examine a patient's abdomen the same way every time?	Yes	Yes	Yes	Yes	Generally
Q1.2 Why/Why not?	Systematic	Habit	-	Exam system - reflex behaviour	Not necessarily - but always methodically
Q1.3 Why did you use the sequence just performed today to examine the abdomen?	-	-	-	Way learnt	Methodically - 9 zones
Q2: If this was not the sequence you normally use to examine the abdomen:	-	-	Yes	-	-
Q2.1: How was it different?	What you are taught	Normal	Were taught 9 regions	-	-
Q2.2: Do you think it is more/less effective?	Taught this way at Adelaide	To cover the territory - to make sure thorough	Habit	-	-
Q2.3: Why/Why Not?	-	-	-	-	-
Q3.1: Do you think you were consistent in the amount of force applied?	Yes	Yes	Reasonably - was forceful to finish off	Yes	Yes tried to be
Q3.2 In a clinical setting do you think you are consistent?	Yes	Yes	Yes	No	Dependent on abdominal pain
Q3.3 Why/Why not?	Normal BMI	Yes	do not usually have to do very often	Vary based on what you see, sensory input, guarding, modify based on patient. (If) No abnormalities (then) same consistent	Screening exam - consistent

Appendix B. Chapter 6 Prototype Design Supplementary Information

10.8 Moulding

10.8.1 Moulding Materials List

- Body Double release cream: 0.1kg x 2
- Body Double 'Apply to skin' moulding silicone: comes in an 8.2kg pack
- Brush on 40 artificial skin urethane rubber
- Colour pigment 'Fleshtone" by smooth on
- Universal Mould Release
- Flex-Foam-it-X urethane expanding liquid foam (body cavities)
- Dynacast Safety Splint from Smith & Nephew – 12.5cm wide roll of 4.6m length

10.8.2 Moulding Instructions

The Body Double mould was used to case the middle and base layers.

The middle Soma Foama layer was cast first (as per manufacturer instructions) for the shape of the rectus muscles, shaped, then the FlexFoam-iT X was cast for the whole mould on top of that so that the foam fit precisely together.

Soma Foama 15 (Flexible Platinum Silicon Foam) – <u>Instructions</u> <u>[151]</u>

<u>Mix ratio is: 2A:1B by Volume</u>

- A release agent was applied to facilitate demoulding
- 2A + 1B by volume were mixed thoroughly for 30 seconds and poured into mould.
- Mixture was rated to expand 4 times original volume with uniform 240kg/m^3 cell structure
- Pot life was 50 seconds, handling time 20 minutes, full cure was 1 hour.
- Excess removed and shaped to size.

FlexFoam-iT^{TM} X (Flexible Polyurethane Foam) - <u>Instructions</u>

<u>Mix ratio is: 1A:1B by Volume</u>

- Release agent was applied on top of Soma Foama in body mould.
- A+B were mixed in equal amounts by volume thoroughly and poured into mould
- Mixture rated to expand 6 times original volume with uniform 160kg/m^3 cell structure.
- Foam expanded to full volume in 5 minutes, developed handling strength in 30 minutes and fully cured in two hours.

Figure 127. AbSIM layers within torso

10.9 Force sensing design Options

A range of methods were considered to measure and model contact forces in a tactile setting including pressure sensing mats, force sensor arrays, point force sensors, artificial muscles, shape memory alloys, electroactive polymers (see Table 52). These methods utilised various technologies to detect strain, deformation or deflection including resistive, capacitive, optical, pressure differential, proximity, and diaphragm. Many of the options were cost prohibitive, would have likely been damaged and deformed under the conditions of abdominal palpation, or would be unsuitable for the contours and depth of the abdomen. Appropriate options were preferably transducers that converted mechanical forces into electrical signals and compatible with the depth of palpation.

Table 52. Commercially available force sensing options in a tactile setting in 2007

Type, Products	Details	Suitability for application
Sensor Mats / Force array surfaces - Sensor Products Inc., Tactilus (piezoresistive) [188] - Pressure Profile Systems (PPS) TactArray T2000 (capacitive) [189] - Vista Medical, Force Sensitive Applications (FSA) (piezoresistive) [190] - Tekscan CONFORMat (piezoresistive) [191] - Tactex Kinotex (optical) [192] - Novel [193]	- Used for pressure mapping in various applications, including wheelchairs and pressure sores, detection of breast cancer using tactile sensing to detect differences in tissue hardness. - Pressure ranges vary depending on manufacturer/model, but come in ranges such as: 0.01-5, 0-4, 0-50, 10-20 PSI - Provides real-time analysis - Pressure and temperature measurement in real-time - Longitudinal and latitudinal analysis - Flexible and durable sensor element - If more pressure is applied than design allows for, the display will indicate the maximum it can detect - The sensor will comply to a deflection as long as there is no tension	- Can determine the contact impression through determination of forces applied to a matrix of discrete point force sensing elements - Positional resolution directly proportional to/dependant on number and spacing of individual sensing elements. - Ranges may not capture full range required for abdominal palpation - Accuracy, repeatability and hysteresis values good. - Cost prohibitive, models start from USD$7000-$30,000+ - Risk of deformation a significant problem (and expensive where permanent damage) if tension occurs in mat when force is applied to isolated points, which is highly likely in palpation as sides would be fixed and palpation point be under tension.

Glove sensors - PPS – FingerTPS/ ConTacts [189] - Tekscan Grip System [191] - FSA Glove [190]	- Gloves with force sensors, using resistive or capacitive technology - Force range (0-10lb)	- Cost prohibitive >USD$10,000 - Range likely too small - Could be ideal for palpation if could map location of glove to area of abdomen within specification limits
Force sensors - PPS – DigiTacts/ ConTacts - Tekscan – Flexiforce - Load Cells	- Single element sensors: contact resistive, thin film, strain gauge - Detect force acting through a known point	- Consider use of multiple single element sensors to create a matrix structure. - Similar obstacles to existing matrix/array sensor mat options with regards to deformation with palpation - By using point force sensing on corners of a plate – can determine magnitude and position of the centroid of a contacting force, force plate
Artificial Muscles - Ionic polymer metal composites (IPMCs) - Electroactive Polymer Artificial Muscle (EPAM) - McKibben artificial muscles - Laser	IPMCs - used as actuators, artificial muscles and transducers EPAM - can duplicate behaviour of natural muscle McKibben artificial muscles - Pneumatic muscles consisting of a silicon tube surrounded by a helical braid Laser - Laser beam used to quickly shrink and swell tiny coils of polymer gel	- Would be difficult to use for detection and simulation of palpation for the abdomen, technology difficult to control precisely at this stage. - Technology outside of area of expertise of researcher, supervisors and research group
Shape Memory Alloys - Nitinol (Nickel, Titanium and Navel Ordnance Lab) - Dynalloy Inc. Flexinol® wire	“Smart” material capable of remembering a previously memorised shape, with the mechanical shape memory effect of superelasticity, where temperature changes lead to the thermal shape memory effect. General properties of interest are flexible, shape changing, can assume different forms or 'phases' at distinct temperatures, when heated it contracts, when cooled it returns to its original shape, the degree of contraction is controlled by varying the duty cycle, at room temperature are easily stretched by a small force. [194-196]	- Requirement for material to cool to relax would limit functionality for palpation application. - Possible application for simulation of pathologies, guarding of the abdomen, or localised response to pressure applied to a tender area - When conducting an electrical current, the wire heats and changes to a much harder form i.e. the wire shortens in shape with an amount of force (like a reflex)

10.10 Custom force sensing platform

In the initial stages of research investigation, a custom force sensing platform was developed (see Figure 128), using aluminium plates and mounted strain gauges, interfaced to LabVIEW (see Figure 129) using National Instruments data acquisition USB device NI USB-6009 [197].

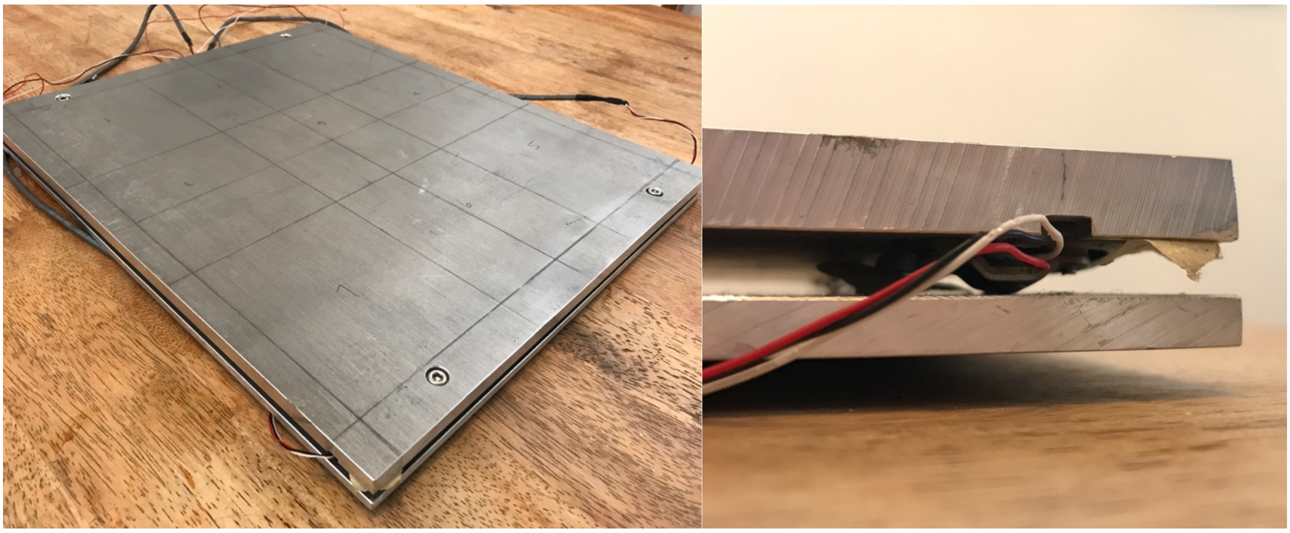


Figure 128. Custom Aluminium Force Platform

The loading response of the force platform was tested. In controlled conditions, when a linear load was applied a linear response was obtained with the following trend lines for each of the four strain gauges (SG1, SG2, SG3, SG4) and R^2 values approximated 1.

SG1 = 5.78x + 2494.1, R^2 = 0.98
SG2 = 5.95x + 2152.4, R^2 = 0.98
SG3 = 5.91x + 2125.9, R^2 = 0.98
SG4 = 6.09x + 2639.2, R^2 = 0.99

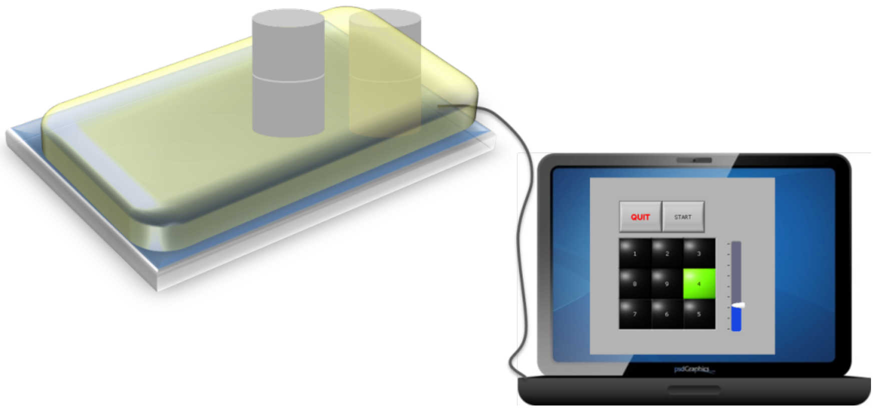


Figure 129. Force Platform and Foam interfaced with Labview, with masses for testing

When interfaced with Labview (Figure 129) the input signal was quite noisy, and additional filtering was required to refine the signal. Difficulties with drift over time and noise were problematic.

10.11 WBB Calibration

Calibration of the WBB involved placing masses on the WBB over each of the sensors, recording the data, then plotting the graph to find the linear equation.

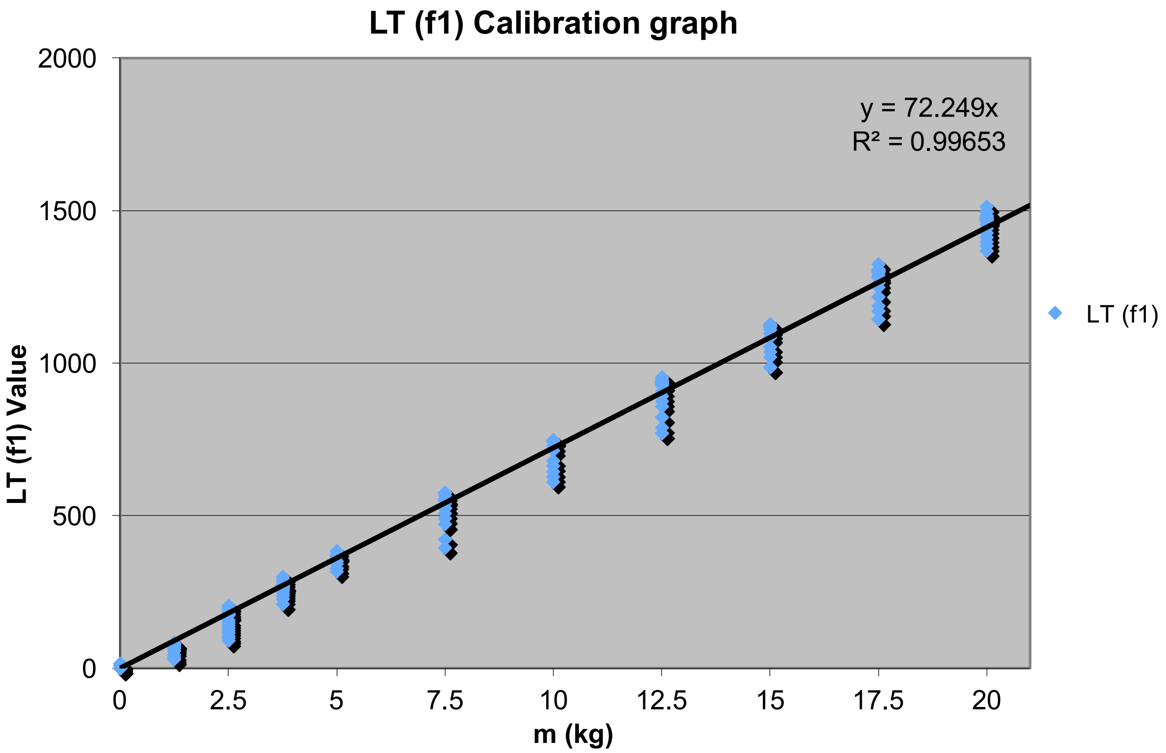


Figure 130. Left Top (LT) sensor calibration graph

For the Left Top (LT) sensor calibration graph:

The trendline $y = 72.25x, where\ y = LT, x = m(kg)$

Since F = mass x acceleration, assumed to be gravity at a value of 9.8 m/s^2 :

$y = 72.25 \times m$

$LT = 72.25 \times \frac{F\ (N)}{9.8m/s^2}$ therefore $F_1(N) = LT \times \frac{9.8m/s^2}{72.25}$

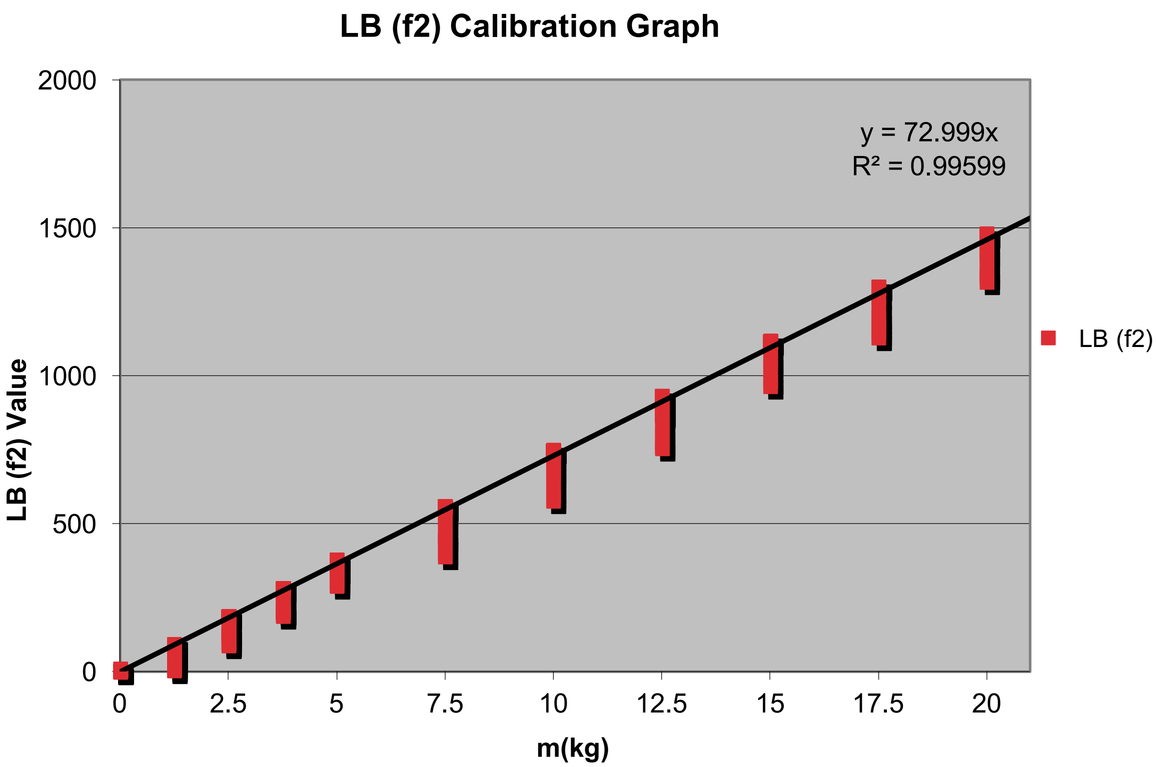


Figure 131. Left Bottom (LB) sensor calibration graph

For the Left Bottom (LB) sensor calibration graph:

The trendline $y = 72.999x, where\ y = LB, x = m(kg)$

Since F = mass x acceleration, assumed to be gravity at a value of 9.8 m/s^2 :

$y = 72.999 \times m$

$LB = 72.999 \times \frac{F\ (N)}{9.8 m/s^2}$ therefore $F_2(N) = LB \times \frac{9.8 m/s^2}{72.999}$

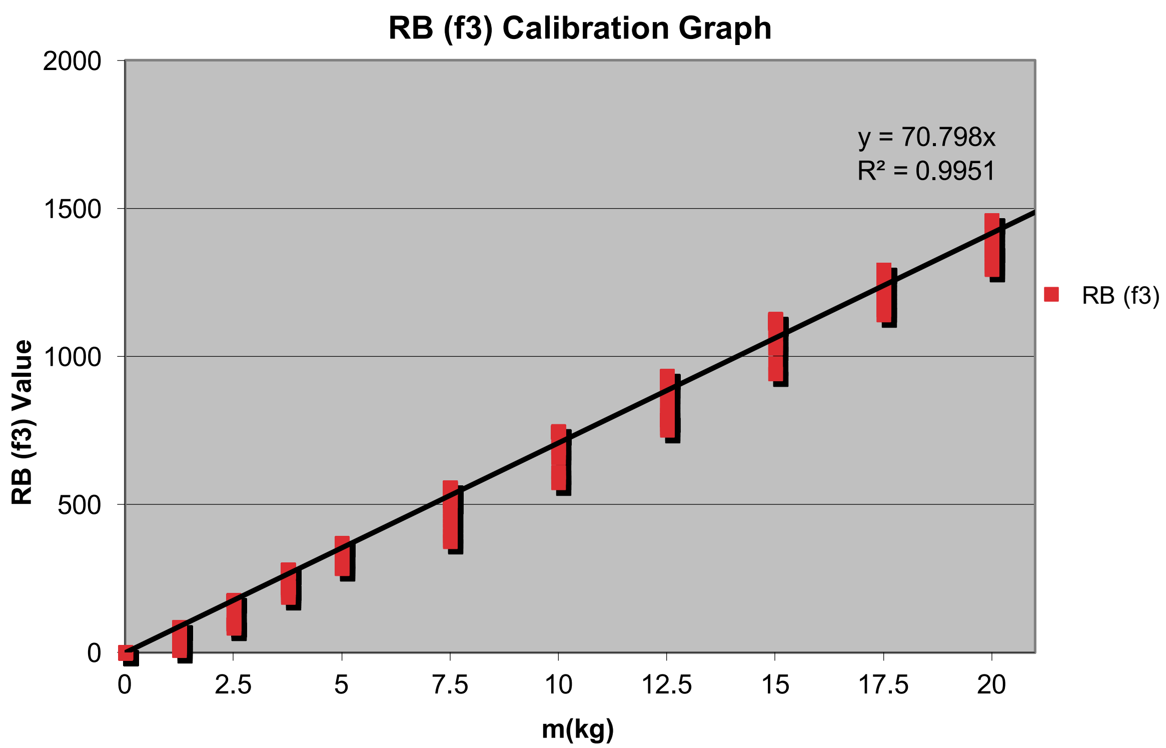


Figure 132. Right Bottom (RB) sensor calibration graph

For the Right Bottom (RB) sensor calibration graph:

The trendline $y = 70.798x, where\ y = RB, x = m(kg)$

Since F = mass x acceleration, assumed to be gravity at a value of 9.8 m/s^2 :

$y = 70.798 \times m$

$RB = 70.798 \times \frac{F\ (N)}{9.8m/s^2}$ therefore $F_3(N) = RB \times \frac{9.8m/s^2}{70.798}$

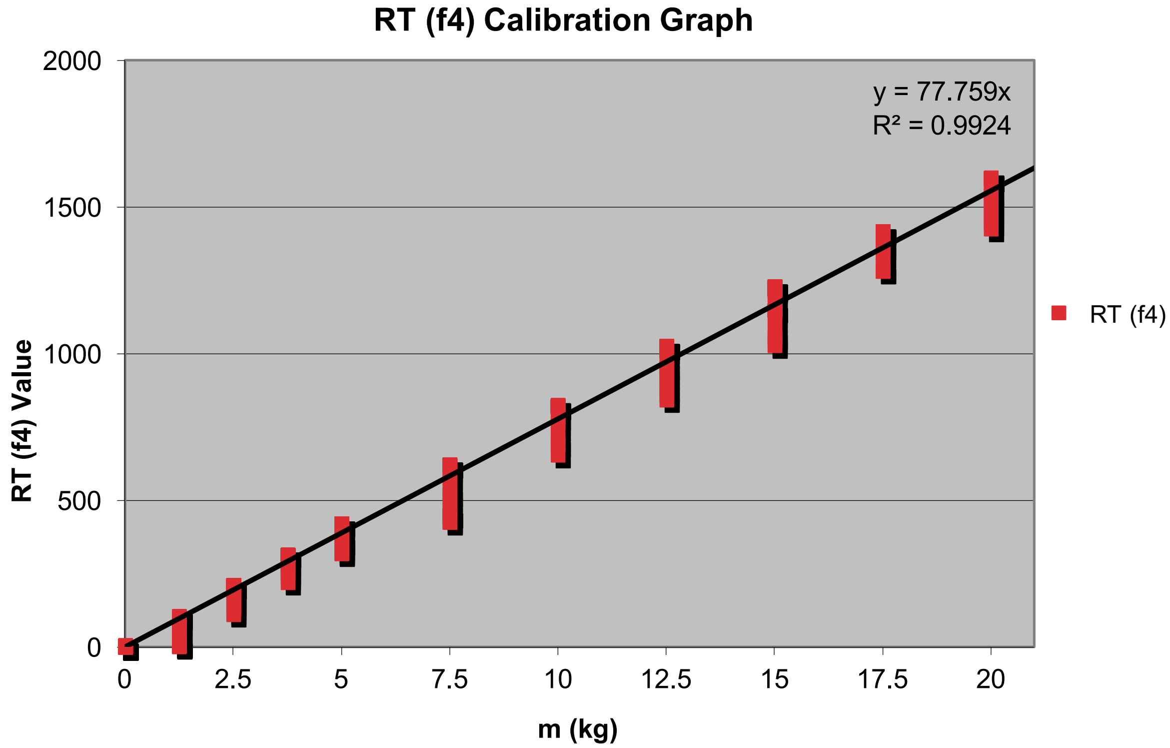


Figure 133. Right Top (RT) sensor calibration graph

For the Right Top (RT) sensor calibration graph:

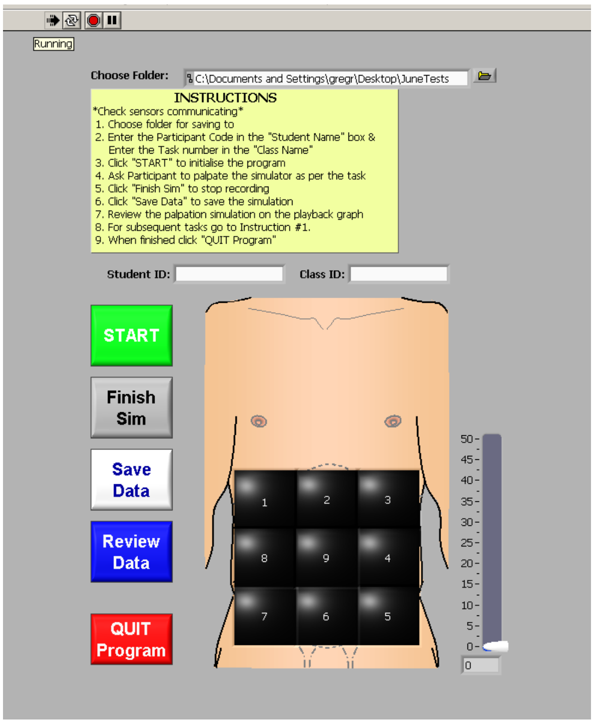
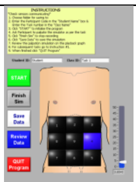
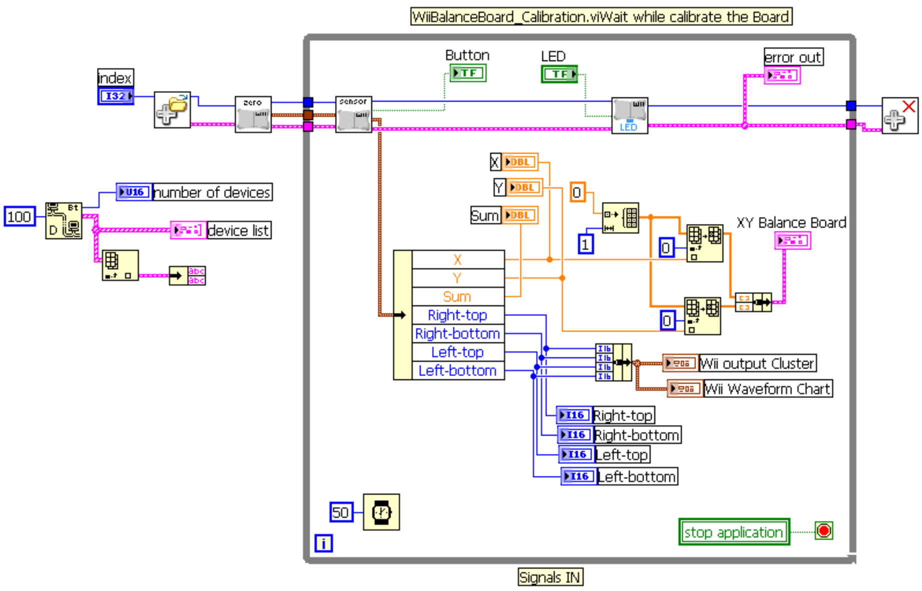
The trendline $y = 77.759x, where\ y = RT, x = m(kg)$

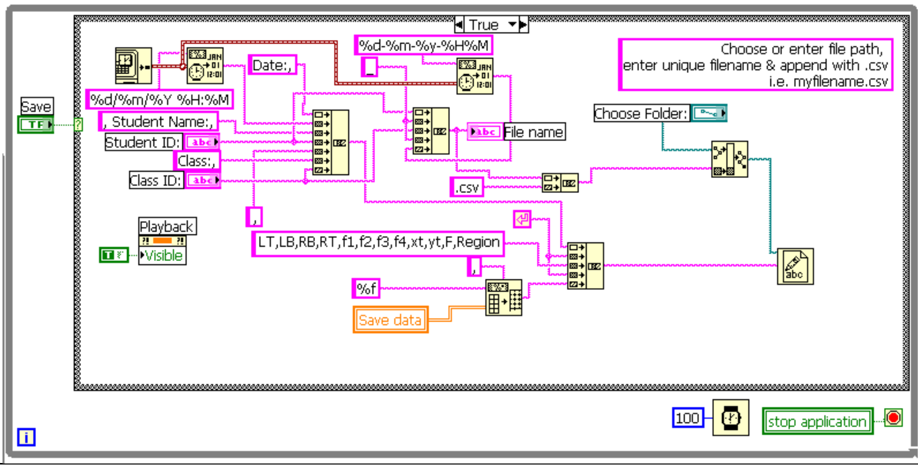
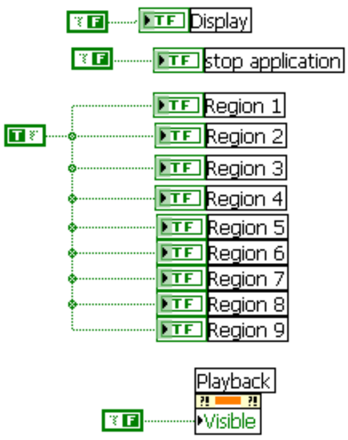
Since F = mass x acceleration, assumed to be gravity at a value of 9.8 m/s^2 :

$y = 77.759 \times m$

$RT\ = 77.759 \times \frac{F\ (N)}{9.8m/s^2}$ therefore $F_4(N) = RT \times \frac{9.8m/s^2}{77.759}$

10.12 Labview code

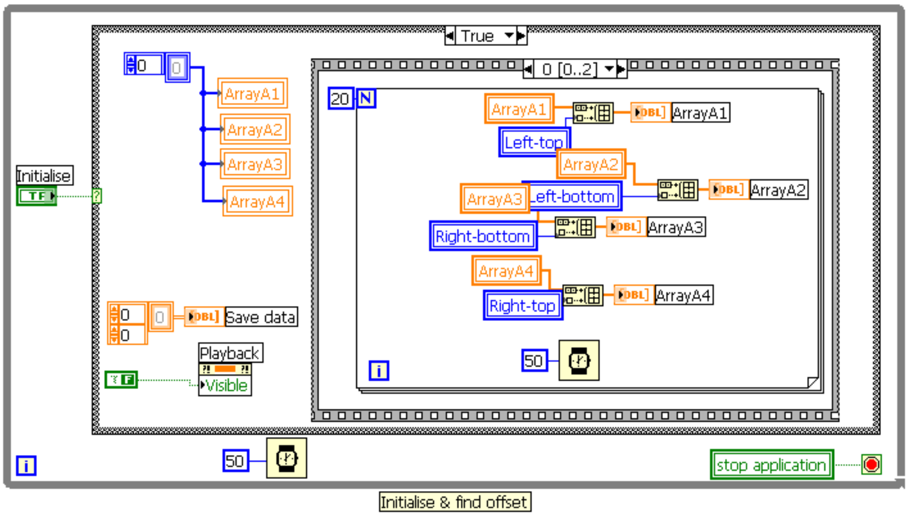
RUN Simulation Program	The software must be executed so it is running and waiting for input from the user via the GUI. 
 RETRIEVE DATA FROM SENSORS	"Signals IN" WBB version:  LB = left bottom, RB = right bottom, LT = left top, RT = right top Wiimote vi modified from open source version on NI discussion forums [198]

<table>
<tr>
<td>
</td>
<td>The user enters their appropriate identification number or username, and class/task identifier into the input boxes on the GUI so that the data can be saved with them.

</td>
</tr>
<tr>
<td>
</td>
<td>The simulator waits in standby mode until the start button on the GUI is pressed.</td>
</tr>
<tr>
<td>
</td>
<td>The data from each sensor is initialised and an offset found for each.


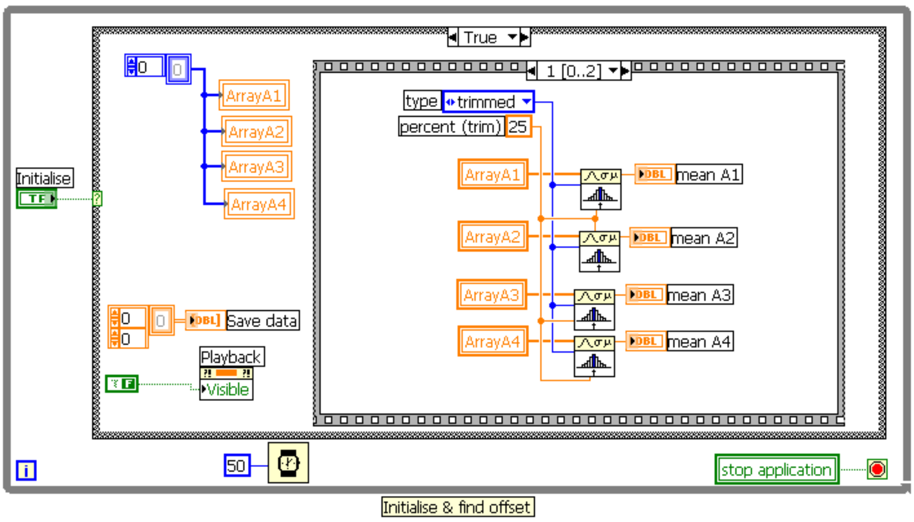
Initialise values:
In the “Initialise & find offset” loop
The False case is empty – no action.
The True case has a stacked sequence structure with Cases 0-2:
“Initialise” = START button on GUI
INITIALISATION & OFFSET DETERMINATION LOOP
Initialise empty arrays: ArrayA1..ArrayA4
Store 20 data points A1..A4 in new arrays
Find mean of 20 points (after outliers trimmed)
Turn on display
Outputs:
Offsets: mean A1…mean A4
Display = True</td>
</tr>
</table>

WBB Version:

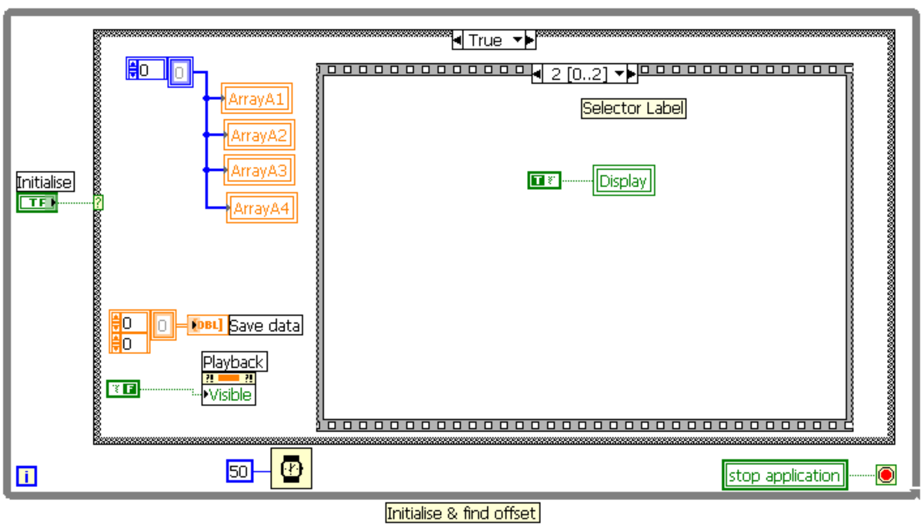
Case 0: Add 20 input values to each array



Case 1: Find the mean (offset)



Case 2: Turn on the Region Abdominal displays

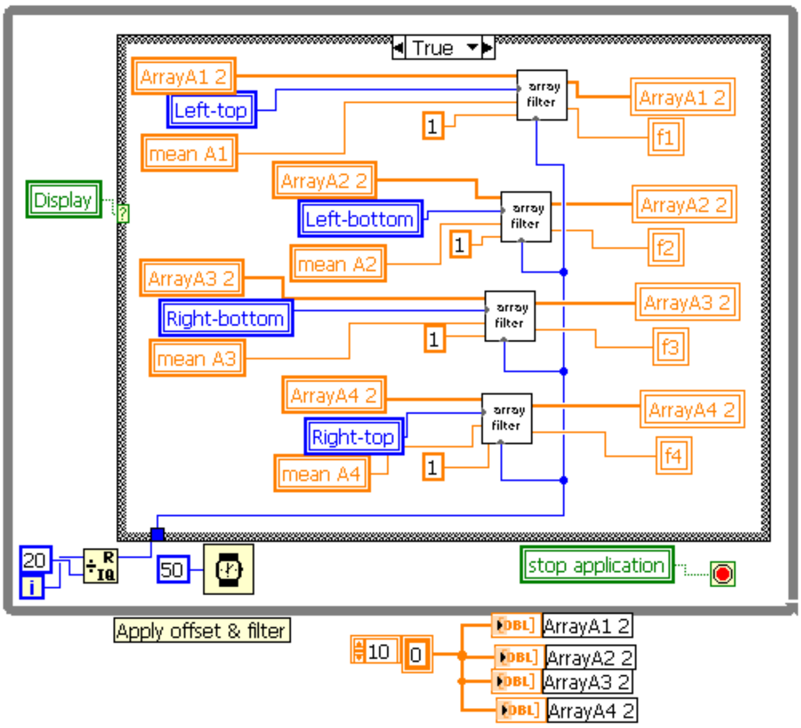


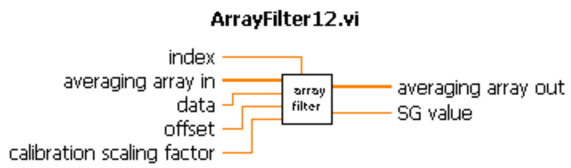
APPLY OFFSET & FILTER INPUTS

Apply Offset & Filter

- Inputs:
  - New empty arrays 10 points: ArrayA1 2…ArrayA4…2 (averaging arrays)
  - A1..A4
  - mean A1…mean A4
  - Calibration factor
- Outputs:
  - f1…f4 (filtered data)

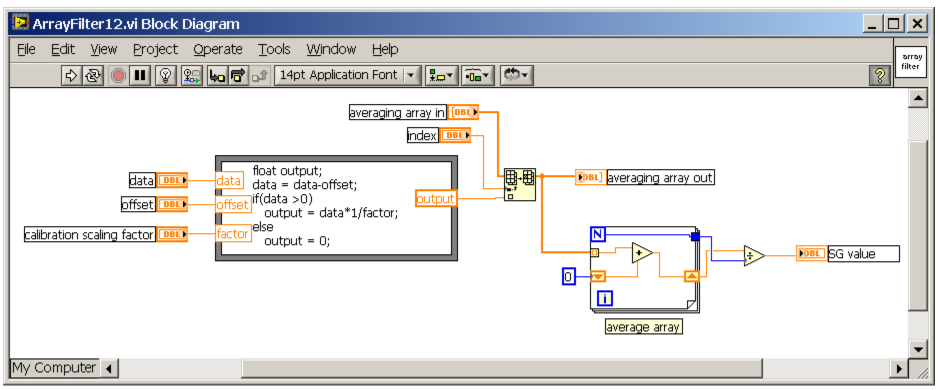
WBB version:





ArrayFilter.vi

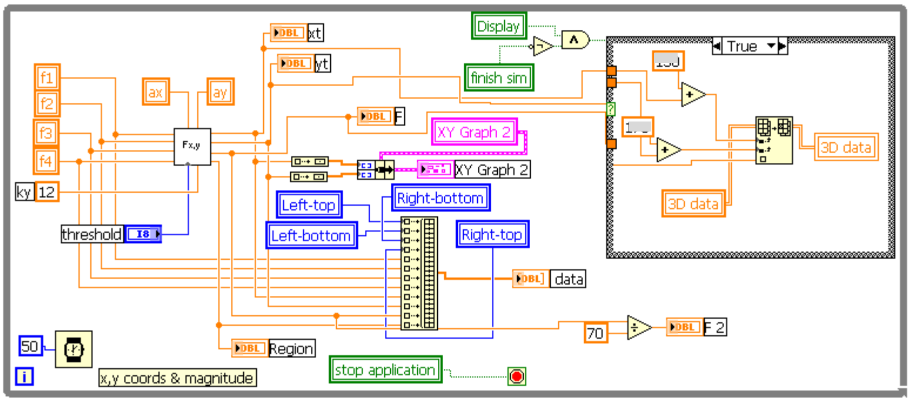
- Apply offset & calibration scaling factor to data then average

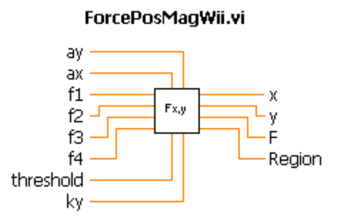


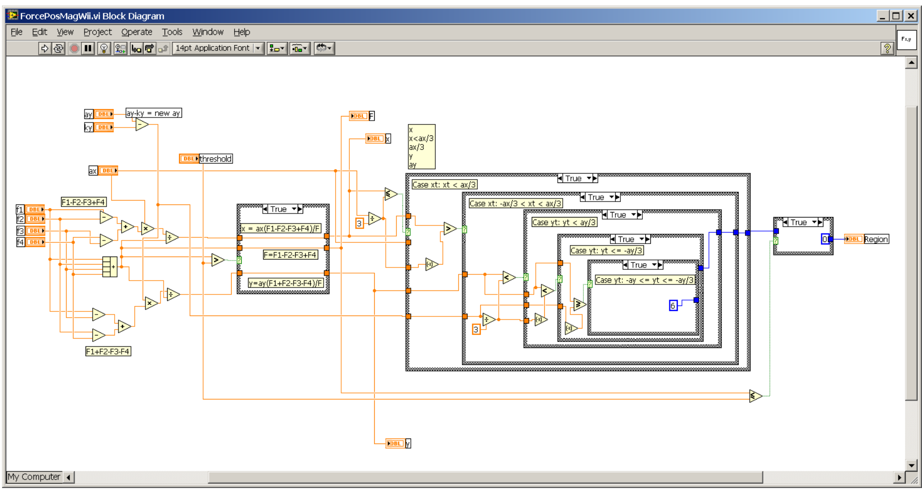
DETERMINE X,Y COORDINATES & MAGNITUDE

x,y coords and magnitude

- Calculations to determine x(t), y(t), F(t), Region (t) where t is any point in time
- Inputs:
  - f1..f4
  - ax = width plate
  - ay = length plate
  - threshold – value below which data is disregarded
- Outputs: xt, yt, F, Region

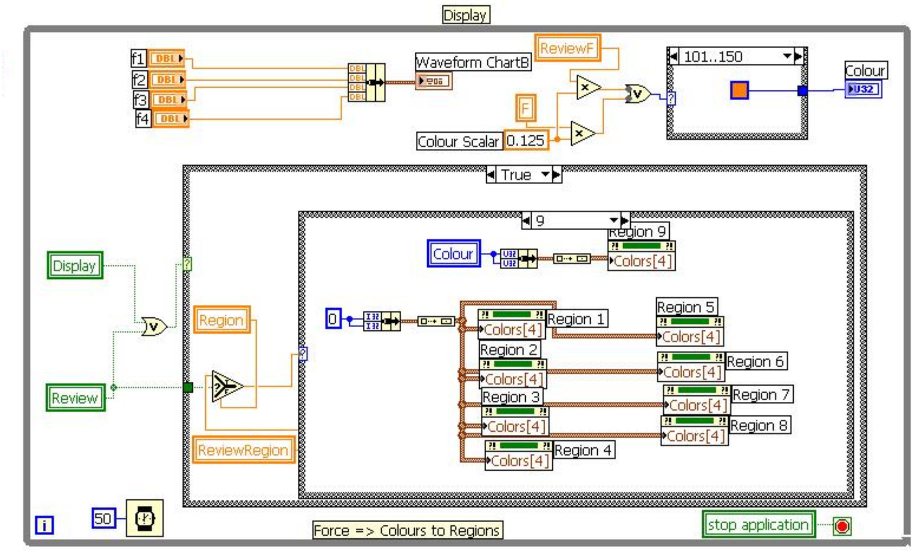
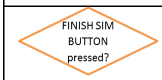
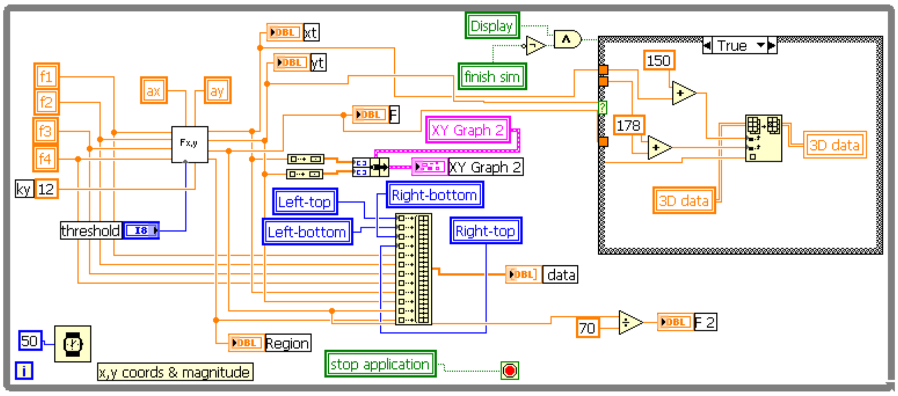






Conditions are used to determine the region the force is being applied (see Table 11).

<table>
<tr>
<td>
</td>
<td>Forces within different ranges are displayed as colour on the region box according to region and force.


</td>
</tr>
<tr>
<td>
</td>
<td>
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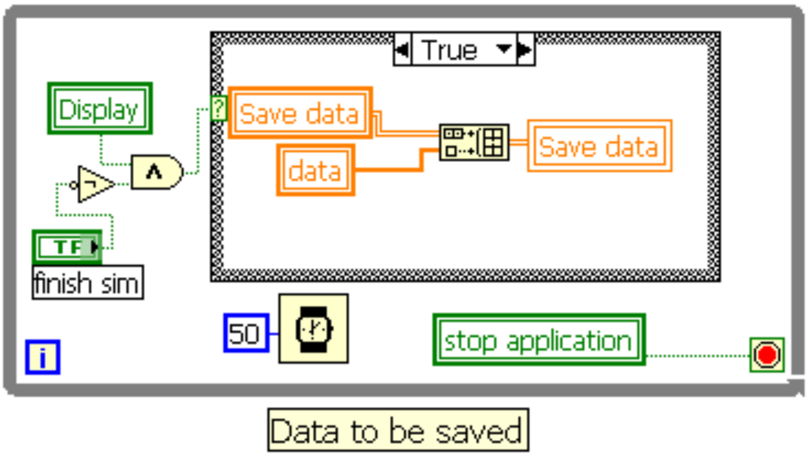
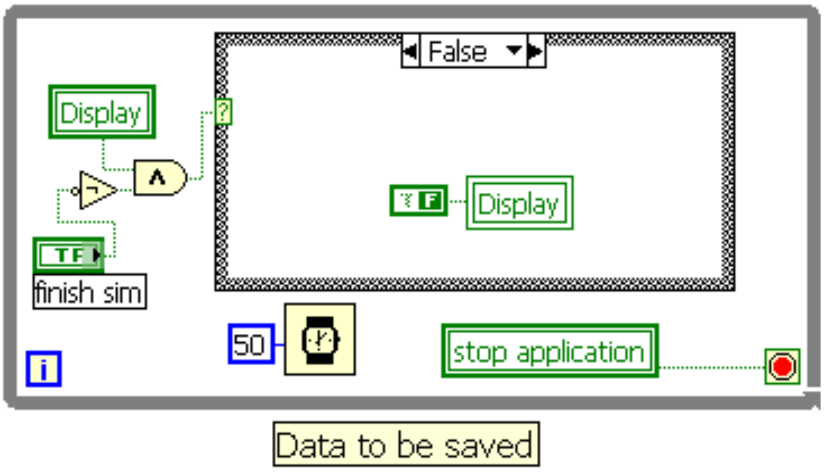
Data to be saved loop

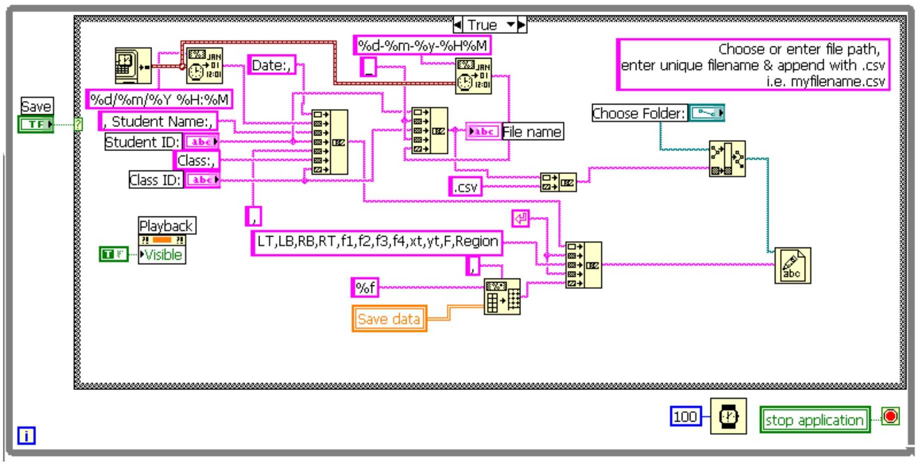
Build array of data to be saved.



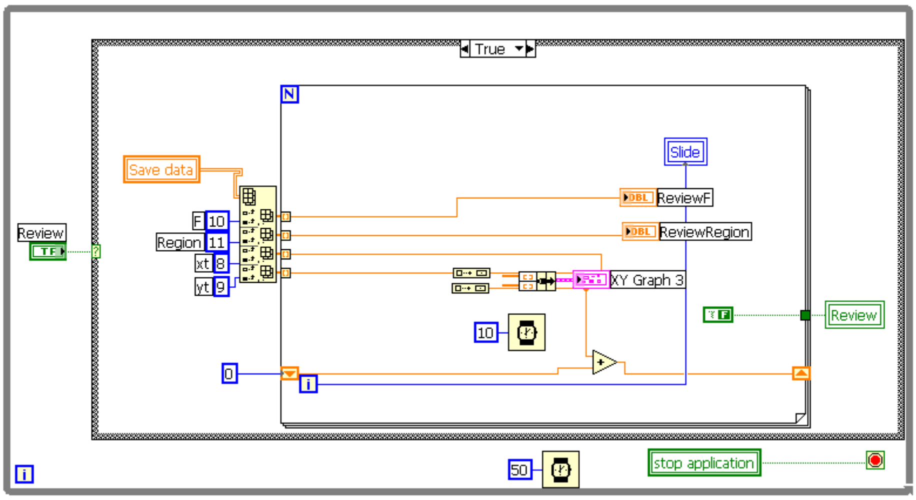
False condition = F to Display</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>


Save button loop – adds Student identifiers to data to be saved array and sets the filename and path location.



(False Condition is empty)
</td>
</tr>
<tr>
<td>


</td>
<td>


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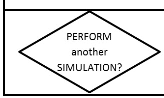
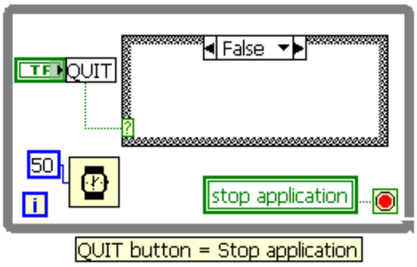
<tr>
<td>


</td>
<td>Return to Start</td>
</tr>
</table>

Press QUIT BUTTON	QUIT button loop – Connects all loops to single QUIT button to terminate program whenever pressed. 

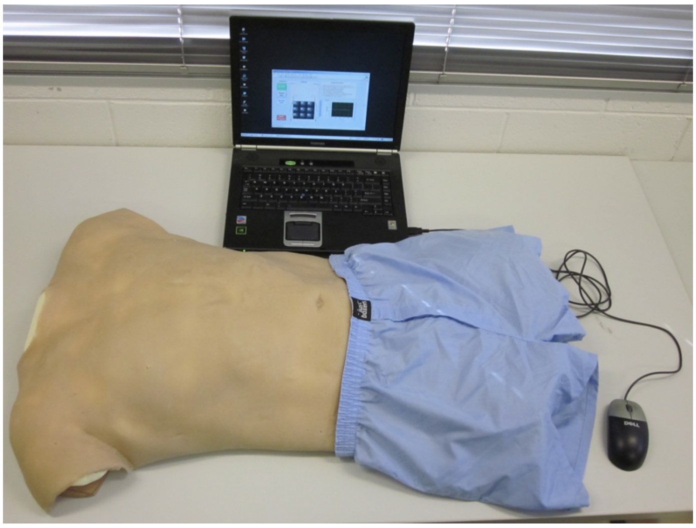
Appendix C. Chapter 7 Discussion Supplementary Information

10.13 Trial Ethics Approval Documents

10.13.1 Application Form Text

The project

An abdominal palpation simulation prototype has been built (see Figure) as part of a PhD project with Flinders University.



We hope to improve teaching of medical students in abdominal palpation. The next step is to trial and validate the simulator in a training scenario.

- Validate with *medical graduates* who routinely palpate abdomens as part of their clinical work, by using the device and then a brief questionnaire.
- Test the simulator with *medicals students*.

After each person has used it they will be shown the display of their performance.

Significance

At the moment the only way to estimate how well a student has learnt to palpate is by observing them carefully. This is tiring and imprecise. We hope this device will identify students that have technique needing improvement.

Research objectives

To validate and test the use of an abdominal palpation simulator for use as an educational tool in training and testing abdominal palpation skills.

Outline of research method

There will be 2 types of participants: Medical Graduates and Medical Students

1) *Medical Graduates*

Medical graduate will be asked to palpate the abdomen and give feedback as to whether it is not unrealistic. The data will also provide information as to how hard they press when they palpate.

2) *Medical Students*

The students will be given a clinical briefing and *scenario*: "This abdomen is of a young man, who was playing football. During the game he was kicked and fell and complained of abdominal pain. The coach told him to go to the Emergency Department."

Then students will be asked to palpate the abdomen as they would in this clinical scenario, and record their findings in patient notes.

After each participant has completed the task, the investigator will ask them some brief questions about the simulator.

How addresses research objectives

Analysis of the data will help to ensure tool is suitable for training, identify gaps in training, and help determine differences in performance depending on experience.

Analysis of the questionnaires will help to gauge whether the simulator is of benefit to students in the training of their technique and building of confidence at the task.

Who & basis of recruitment

Participants: FMC Clinicians and GEMP Students.

Basis for their recruitment: willing to participate and not being taken away from patient care or studies.

How many, number, population pool

Medical Graduate Participants

- Approach up to 25, to aim for 12-20 participants from a pool of 60.

Medical Student Participants

- Approach up to 160, to aim for 100-120 participants from a pool of 300.

We expect most of those approached to consent because of the innocuous nature and short-time involved.

Source

Students and Clinicians from the School of Medicine at Flinders University.

How participants contacted & recruited:

1) Flyer to be put up in the area (see attached)
2) The principle researcher will approach potential participants directly with a non-threatening introduction, asking if they have time, then explain how to participate. This method makes it easy for people to decline if they wish (verbal script included below).

Verbal script (eg, telephone call, face-to-face recruitment) (if applicable)
Hi, my name is Lynne Burrow and I am a Biomedical Engineering PhD student. Do you have some time?

I have developed a new abdominal palpation simulator and need some volunteers to test it. Would you have 7-8 minutes to participate in trialling it and answer a few brief questions about your year level (students) /experience (medical graduates) and background and about the simulator once you have used it? At no point will you be able to be individually identified.

What information will be given to participants?

Letter of Introduction, Consent form, Information Sheet, Questionnaire (includes questions about their current level of training & experience) – will be given during recruitment of participants

Principle investigator will then give a brief verbal explanation of the task and read out the clinical scenario card.

Feedback interview questions - Upon completion of the palpation task, the investigator will ask the participant some brief questions about the simulator.

Students will be asked not to pass on their findings to other students.

When will the information be given to participants?

See above.

The letter of introduction and information sheet will clearly state that participation is voluntary.

The principle investigator will approach potential participants as she has no relationships with the participants and so there is no perception of coercion.

All data will be stored in de-identified form, with the principal researcher having access to the identification information, which will be stored on private hard disk. It will be made clear that the educational tool is being assessed, not the participants, so their results will not be used as an indicator of their actual skill. These results will not be shared with participants' assessors.

Time-commitment

It is expected a maximum of 7-8 minutes in total to complete the abdominal palpation task and answer questions.

Locations:

Medical Graduates – Non-clinical area in hospital

Medical Students – Clinical Simulation Unit

Value and benefits of the project to the participants, the discipline, the community etc

In theory all students should be observed performing a task and be given constructive feedback. Currently there are approximately 8 students at a time per clinical skills tutorial so there is not a lot of time to observe students. An educational tool such as this, will assist in identifying whether medical students palpate the abdomen in a systematic way, and determine if they have an appropriate methodology when identifying a lesion to determine the nature of it.

The participation of the medical graduate clinicians and medical students now, will benefit future medical students in their training and skills development, and ensure appropriate level of skills for serving the community.

Burdens and/or risks

There are no risks to the participants of the study as the participant is the one applying force through palpation to the abdominal mannequin. The only burden of the study to participants or other people is the time required to participate, and the time of availability of location to conduct the study.

Questionnaire

Participants will complete and hand in the short questionnaire at the time of the study. The principle investigator will retain these and they will remain in a de-identified form, which is noted on the information sheet.

Data transcription issues

Data from the task will be automatically saved during the exercise so no transcription is required.

The questionnaire and brief interview questions will be transcribed by the primary investigator.

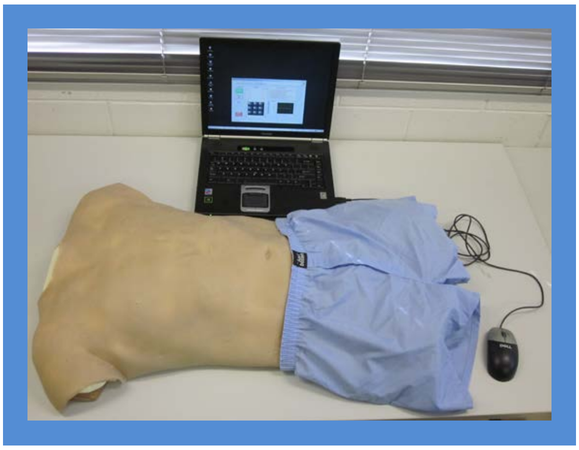
10.13.2 Trial Promotional Flyer

Flinders UNIVERSITY

SEEKING **MEDICAL GRADUATE** and **MEDICAL STUDENT** VOLUNTEERS

for

A trial of a prototype clinical educational tool for training medical students in abdominal palpation



Ms Lynne Burrow is a postgraduate student undertaking a Research Higher Degree PhD in Biomedical Engineering in the School of Computer Science, Engineering and Mathematics (CSEM) at Flinders University.

Participants will be given a clinical scenario and asked to palpate the abdomen and answer a few questions.

A maximum of 7-8 minutes is required.

This information will help to test and validate the simulator as part of research leading to the production of a thesis and other publications. All information will be confidential and participants will not be able to be identified.

Interested in Participating?

Contact the Principal Researcher Lynne Burrow via

Call/SMS: [redacted] *or*

Email: Lynne.Burrow@flinders.edu.au

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 5771). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

10.13.3 Trial Letter of Introduction

School of Computer Science
Engineering & Mathematics

GPO Box 2100
Adelaide SA 5001

Tel: 08 8201 5190
Fax: 08 8201 2904
Karen.Reynolds@flinders.edu.au

flinders.edu.au/science_engineering/csem/

CRICOS Provider No. 00114A

LETTER OF INTRODUCTION

Dear Potential Participant,

This letter is to introduce Ms Lynne Burrow who is a Biomedical Engineering PhD student in the School of Computer Science, Engineering and Mathematics (CSEM) at Flinders University.

She is undertaking research leading to the production of a thesis and other publications relating to this project: "A trial of a prototype clinical educational tool for training medical students in abdominal palpation."

She would be most grateful if you would volunteer to assist in this project by participating in a pilot study that involves a trialling the use of this new tool and answering a few feedback questions. No more than 8 minutes of your time would be required.

Be assured that any information provided will be treated in the strictest confidence and none of the participants will be individually identifiable in the resulting thesis, report or other publications. You are, of course, entirely free to discontinue your participation at any time or decline to answer particular questions.

Any enquiries you may have concerning this project should be directed to Lynne Burrow by email Lynne.Burrow@flinders.edu.au or to myself.

Thank you for your consideration and assistance.

Yours Sincerely,

Prof Karen Reynolds

Director
The Medical Device Partnering Program (MDPP)
The Medical Device Research Institute (MDRI)

Deputy Dean
School of Computer Science, Engineering & Mathematics
Flinders University

Sturt Road, Bedford Park SA 5042
GPO Box 2100 Adelaide SA 5001
P: 8201 5190 | E: Karen.Reynolds@flinders.edu.au

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project 5771). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

10.13.4 Trial Participant Information Sheet

Ms Lynne Burrow
School of Computer Science,
Engineering & Mathematics
Faculty of Science & Engineering

GPO Box 2100
Adelaide SA 5001

Tel:
Lynne.Burrow@flinders.edu.au

Web: flinders.edu.au/science_engineering/csem

INFORMATION SHEET

Title: 'A trial of a prototype clinical educational tool for training medical students in abdominal palpation.'

Principal Investigator:
Ms Lynne Burrow
School of Computer Science, Engineering & Mathematics
Flinders University
Ph:

Description of the study:
This study is part of the project entitled *'A trial of a prototype clinical educational tool for training medical students in abdominal palpation'.* This project will investigate the validity of a custom-developed abdominal palpation simulator as an educational tool for clinical training. This project is supported by Flinders University School of Computer Science, Engineering and Mathematics.

Purpose of the study:
This project aims to validate and test the use of an abdominal palpation simulator for use as an educational tool in training and testing abdominal palpation skills.

What will I be asked to do?
If you choose to volunteer as a participant you will be asked to read a clinical scenario and palpate the abdomen of the simulator exactly as you would if this was a real patient and record your findings.
Whilst doing this the system will record the location and the force you apply to the skin. At the end you will be asked some questions about the simulator and general information regarding your experience. You will also be given the opportunity to look at the information recorded on the system. We ask that you do not pass on your findings to others.
The exercise and questionnaire will take 7-8 minutes of your time.

What benefit will I gain from being involved in this study?
Your participation in the study will help to improve the development of this tool and determine whether its further development and use in future training programs is valid. We are very keen to develop a tool which enhances the learning experience and benefits clinical training and future patients as a result.

Will I be identifiable by being involved in this study?
We do not need your name and you will be anonymous. Once the data has been collated and saved, any identifying information will be removed. Your exercise data and comments will not be linked directly to you.

Are there any risks or discomforts if I am involved?
Other participants may know that you have also been a participant. The investigator anticipates few risks from your involvement in this study. If you have any concerns regarding anticipated or actual risks or discomforts, please raise them with the investigator.

How do I agree to participate?
Participation is voluntary. You may answer 'no comment' or refuse to answer any questions and you are free to withdraw from the study at any time without effect or consequences. A consent form accompanies this information sheet. If you agree to participate please read and sign the form.

How will I receive feedback?
Outcomes from the project may be summarised and given to you by the investigator if you indicate you would like to see them.

Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

Ms Lynne Burrow
Research Higher Degree PhD Candidate
School of Computer Science, Engineering & Mathematics
Flinders University
Ph: (
Lynne.Burrow@flinders.edu.au

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number 5711). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au

10.13.5 Trial Consent Form

CONSENT FORM FOR PARTICIPATION IN RESEARCH

(by experiment)

A trial of a prototype clinical educational tool for training medical students in abdominal palpation

I …...

being over the age of 18 years hereby consent to participate as requested in the Letter of Introduction and Information Sheet for the research project: *'A trial of a prototype clinical educational tool for training medical students in abdominal palpation.'*

1. I have read the information provided.
2. Details of procedures and any risks have been explained to my satisfaction.
3. I am aware that I should retain a copy of the Information Sheet and Consent Form for future reference.
4. I understand that:
   - I may not directly benefit from taking part in this research.
   - I am free to withdraw from the project at any time and am free to decline to answer particular questions.
   - While the information gained in this study will be published as explained, I will not be identified, and individual information will remain confidential.
   - Whether I participate or not, or withdraw after participating, will have no effect on any treatment or service that is being provided to me.
   - Whether I participate or not, or withdraw after participating, will have no effect on my progress in my course of study, or results gained.
   - I may ask that the simulation be stopped at any time, and that I may withdraw at any time from the session or the research without disadvantage.
5. I agree/do not agree to the data being made available to other researchers who are not members of this research team, but who are judged by the research team to be doing related research, on condition that my identity is not revealed.

Participant's signature…………………………………Date…………………..

I certify that I have explained the study to the volunteer and consider that she/he understands what is involved and freely consents to participation.

Researcher's name…………………………………………………….................

Researcher's signature………………………………..Date……………………

/Users/Lynne/Desktop/Ch9 Refs/AbSIM Study SBREC docs/Consent-LMBurrow.doc
Updated 28 June 2006

10.13.6 Investigator Protocol

Medical Students

INVESTIGATOR PROTOCOL FOR: "A TRIAL OF A PROTOTYPE CLINICAL EDUCATIONAL TOOL FOR TRAINING MEDICAL STUDENTS IN ABDOMINAL PALPATION"

MEDICAL STUDENT PARTICIPANT

1. Set up Abdominal Palpation Simulator in the Clinical Skills Aare
2. Recruit participants by direct approach face-to-face (see verbal script in application)

Hi, my name is Lynne Burrow and I am a Biomedical Engineering PhD student. Do you have some time? I have developed a new abdominal palpation simulator and need some volunteers to test it. Would you have 7-8 minutes to participate in trialling it and answer a few brief questions about your year level and background and about the simulator once you have used it? At no point will you be able to be individually identified.

3. Provide:
    - Letter of Introduction
    - Information Sheet
    - Consent form – ENSURE THIS IS SIGNED
4. Brief the student by reading out the **clinical scenario** and ask them to **palpate** the abdomen as they would in this situation and record their findings on the patient notes sheet. Mention that obviously in real life you often have to ask the patient to breathe in and out, but that this is not a current feature.

Scenario: *"This abdomen is of a young man, who was playing football. During the game he was kicked and fell and complained of abdominal pain. The coach told him to go to the Emergency Department."*

- **ENSURE THE DATA IS SAVED CORRECTLY**
  & that PARTICIPANT NUMBER on FORM & COMPUTER are the same

5. Ask the participant to answer the questions on the response form.
6. Show the participant the recorded data on the screen if they wish to see it.
7. Thank the participant for their time.

Medical Graduates

INVESTIGATOR PROTOCOL FOR: "A TRIAL OF A PROTOTYPE CLINICAL EDUCATIONAL TOOL FOR TRAINING MEDICAL STUDENTS IN ABDOMINAL PALPATION"

MEDICAL GRADUATE PARTICIPANT

1. Set up Abdominal Palpation Simulator in non-clinical area
2. Recruit participants by direct approach face-to-face (see verbal script in application)

Hi, my name is Lynne Burrow and I am a Biomedical Engineering PhD student. Do you have some time? I have developed a new abdominal palpation simulator and need some volunteers to test it. Would you have 7-8 minutes to participate in trialling it and answer a few brief questions about your experience and background and about the simulator once you have used it? At no point will you be able to be individually identified.

3. Provide:
    - Letter of Introduction
    - Information Sheet
    - Consent form – ENSURE THIS IS SIGNED
4. Ask the participant to palpate the simulator abdomen as they would normally, providing the patient notes sheet (on back of the response form). Mention that obviously in real life you often have to ask the patient to breathe in and out, but that this is not a current feature.
    - **ENSURE THE DATA IS SAVED CORRECTLY**
      & that PARTICIPANT NUMBER on FORM & COMPUTER are the same
5. Ask the participant to answer the questions on the response form.
6. Show the participant the recorded data on the screen if they wish to see it.
7. Thank the participant for their time.

10.13.7 Participant Response Forms

FRONT PAGE – Medical Graduates Response Form

INVESTIGATOR USE ONLY	
Participant No:	
Task No:	
This helps to match data from the tool to the feedback responses. It is not to identify individuals	

RESPONSE FORM: *"A TRIAL OF A PROTOTYPE CLINICAL EDUCATIONAL TOOL FOR TRAINING MEDICAL STUDENTS IN ABDOMINAL PALPATION"*

MEDICAL GRADUATE PARTICIPANT INFORMATION

Gender: MALE | FEMALE

Years since graduation: _______________ **Discipline:** ___________________________

FEEDBACK REGARDING THE ABDOMINAL PALPATION EDUCATIONAL TOOL

Q: How realistic did you find the palpation trainer? (Please circle one)

e. Extremely realistic
f. Sufficiently realistic to learn this technique
g. Vaguely comparable to an abdomen
h. Not comparable at all

Please **comment** on the ***physical realism*** of the model:

FRONT PAGE – Medical Students Response Form

INVESTIGATOR USE ONLY	
Participant No:	
Task No:	
This helps to match data from the tool to the feedback responses. It is not to identify individuals	

RESPONSE FORM: *"A TRIAL OF A PROTOTYPE CLINICAL EDUCATIONAL TOOL FOR TRAINING MEDICAL STUDENTS IN ABDOMINAL PALPATION"*

MEDICAL STUDENT PARTICIPANT INFORMATION

Gender: MALE | FEMALE

Year Level: ____________ **First Degree(s):** ______________________________________

Number of human abdomens palpated (please circle): <10 | 10-50 | 50+

FEEDBACK REGARDING THE ABDOMINAL PALPATION EDUCATIONAL TOOL

Q: How realistic did you find the palpation trainer? (Please circle one)

a. Extremely realistic
b. Sufficiently realistic to learn this technique
c. Vaguely comparable to an abdomen
d. Not comparable at all

Please **comment** on the ***physical realism*** of the model:

BACK PAGE – Response Form both Participant Types

Date	**Patient Notes**

Appendix D. Chapter 8 Results Supplementary Information

10.14 Results Appendices

10.14.1 Full Sequences of Patterns

Full Sequence of Participants	Number of Participants	% of Total
1-2-9	1	0.7%
1-2-9-8-4-6-3--	1	0.7%
1-8-9	1	0.7%
1-8-9-2-4-3-5-7-6	1	0.7%
2-1-8	1	0.7%
2-1-8-9-4-3-5--	1	0.7%
2-1-9	2	1.4%
2-1-9-4-8-3---	2	1.4%
2-3-9	2	1.4%
2-3-9-4-8----	1	0.7%
2-3-9-8-4-5---	1	0.7%
2-4-3	1	0.7%
2-4-3-9-8----	1	0.7%
2-9-3	3	2.1%
2-9-3-4-----	1	0.7%
2-9-3-4-5-8-1-6-7	1	0.7%
2-9-3-4-8----	1	0.7%
2-9-4	2	1.4%
2-9-4-3-8-1-7-6-	1	0.7%
2-9-4-6-3----	1	0.7%
2-9-8	4	2.8%
2-9-8-1-4-3-6--	1	0.7%
2-9-8-1-4-3-7--	1	0.7%
2-9-8-4-1-3---	1	0.7%
2-9-8-4-6-5-1--	1	0.7%
3-2-9	1	0.7%
3-2-9-4-8-1-7-6-	1	0.7%
3-4-9	1	0.7%
3-4-9-8-1-2-5--	1	0.7%
4-3-2	1	0.7%
4-3-2-9-8-7-6-5-1	1	0.7%
4-3-9	2	1.4%
4-3-9-2-8----	2	1.4%
4-7-8	1	0.7%
4-7-8-6-9-2-1-3-5	1	0.7%
4-8-9	1	0.7%

Full Sequence of Participants	Number of Participants	% of Total
4-8-9-2-1-6-7-5-3	1	0.7%
4-9-2	5	3.5%
4-9-2-3-----	1	0.7%
4-9-2-3-7-8---	1	0.7%
4-9-2-3-8----	1	0.7%
4-9-2-6-8-7-5--	1	0.7%
4-9-2-8-7-6-5--	1	0.7%
4-9-3	1	0.7%
4-9-3-2-8-1---	1	0.7%
4-9-6	1	0.7%
4-9-6-8-3-2-5--	1	0.7%
4-9-8	3	2.1%
4-9-8-1-2-3-7-6-5	1	0.7%
4-9-8-2-1-5-3--	1	0.7%
4-9-8-3-2-5-6-7-1	1	0.7%
5-4-9	1	0.7%
5-4-9-2-6-8---	1	0.7%
5-6-9	2	1.4%
5-6-9-8-2-4-7-1-3	1	0.7%
5-6-9-8-4-3-2-1-	1	0.7%
5-9-8	1	0.7%
5-9-8-4-6-1-2-3-	1	0.7%
6-4-9	1	0.7%
6-4-9-2-3-8-7-5-	1	0.7%
6-5-9	1	0.7%
6-5-9-7-8-4-2-3-	1	0.7%
6-7-8	1	0.7%
6-7-8-9-2-4-3-1-	1	0.7%
6-8-9	1	0.7%
6-8-9-4-3-2-7--	1	0.7%
6-9-4	1	0.7%
6-9-4-8-7-2---	1	0.7%
6-9-8	1	0.7%
6-9-8-7-4-2-5--	1	0.7%
7-6-4	1	0.7%
7-6-4-9-2-3-8--	1	0.7%
7-6-8	1	0.7%
7-6-8-9-4-5-2-3-	1	0.7%
7-6-9	1	0.7%
7-6-9-4-8-2-5--	1	0.7%

Full Sequence of Participants	Number of Participants	% of Total
7-8-9	1	0.7%
7-8-9-2-3-4---	1	0.7%
8-6-4	1	0.7%
8-6-4-5-9-7-3-2-1	1	0.7%
8-7-9	1	0.7%
8-7-9-2-4-5-6-3-	1	0.7%
8-9-2	5	3.5%
8-9-2-1-3-4-7-6-	1	0.7%
8-9-2-3-4-7---	1	0.7%
8-9-2-4-3----	1	0.7%
8-9-2-4-3-5---	1	0.7%
8-9-2-4-3-6---	1	0.7%
8-9-4	2	1.4%
8-9-4-2-3-5---	1	0.7%
8-9-4-3-7-2---	1	0.7%
8-9-6	1	0.7%
8-9-6-7-4-2-3-5-	1	0.7%
9-2-1	4	2.8%
9-2-1-8-4-3---	1	0.7%
9-2-1-8-4-3-5--	1	0.7%
9-2-1-8-7-3-4--	1	0.7%
9-2-1-8-7-6-4-3-5	1	0.7%
9-2-3	10	7.0%
9-2-3-1-4-5-6-8-7	1	0.7%
9-2-3-4-5----	1	0.7%
9-2-3-4-6-7-8-1-	1	0.7%
9-2-3-4-8-1---	2	1.4%
9-2-3-4-8-1-5--	1	0.7%
9-2-3-4-8-1-7--	1	0.7%
9-2-3-4-8-6-5--	1	0.7%
9-2-3-4-8-6-7-1-	1	0.7%
9-2-3-5-4-6---	1	0.7%
9-2-4	12	8.4%
9-2-4-3-5----	1	0.7%
9-2-4-3-8-1---	2	1.4%
9-2-4-3-8-6-1--	1	0.7%
9-2-4-6-7-8-5-1-3	1	0.7%
9-2-4-8-1-3-6-7-	1	0.7%
9-2-4-8-3----	1	0.7%
9-2-4-8-3-1-5-6-7	1	0.7%

Full Sequence of Participants	Number of Participants	% of Total
9-2-4-8-5-6-7-3-	1	0.7%
9-2-4-8-6----	1	0.7%
9-2-4-8-7----	2	1.4%
9-2-8	2	1.4%
9-2-8-4-3----	1	0.7%
9-2-8-5-6-4-1--	1	0.7%
9-3-2	1	0.7%
9-3-2-8-7-4-5-6-1	1	0.7%
9-3-4	3	2.1%
9-3-4-2-8-1---	1	0.7%
9-3-4-2-8-5-6-7-	1	0.7%
9-3-4-2-8-6-7-5-1	1	0.7%
9-4-2	7	4.9%
9-4-2-1-8-3---	1	0.7%
9-4-2-3-1-8-5--	1	0.7%
9-4-2-3-1-8-7-6-5	1	0.7%
9-4-2-3-8----	2	1.4%
9-4-2-6-3-1-8--	1	0.7%
9-4-2-6-8-3-5--	1	0.7%
9-4-3	3	2.1%
9-4-3-2-6-8---	1	0.7%
9-4-3-2-8-1---	1	0.7%
9-4-3-2-8-7-1--	1	0.7%
9-4-6	4	2.8%
9-4-6-2-3-7-8--	1	0.7%
9-4-6-2-3-8-7-5-	1	0.7%
9-4-6-3-2-8-1--	1	0.7%
9-4-6-5-8-7-2-3-	1	0.7%
9-4-8	3	2.1%
9-4-8-2-3----	1	0.7%
9-4-8-2-3-5-6--	1	0.7%
9-4-8-2-3-5-7-1-6	1	0.7%
9-5-4	1	0.7%
9-5-4-6-2-1-8-7-	1	0.7%
9-5-6	1	0.7%
9-5-6-8-7-1-4--	1	0.7%
9-6-2	2	1.4%
9-6-2-1-3-4-5--	1	0.7%
9-6-2-3-4-8-1-7-	1	0.7%
9-6-3	1	0.7%

Full Sequence of Participants	Number of Participants	% of Total
9-6-3-2-7-8-4-5-	1	0.7%
9-6-7	6	4.2%
9-6-7-4-2-5-8-1-	1	0.7%
9-6-7-5-4-8---	1	0.7%
9-6-7-8-1-2-4-3-	1	0.7%
9-6-7-8-2-3-4-1-	1	0.7%
9-6-7-8-4-3-2--	1	0.7%
9-6-7-8-5-4-2-3-1	1	0.7%
9-7-6	1	0.7%
9-7-6-4-8-2-3--	1	0.7%
9-8-1	1	0.7%
9-8-1-2-4-3-7--	1	0.7%
9-8-2	13	9.1%
9-8-2-1-4-3---	1	0.7%
9-8-2-1-4-3-6-5-7	1	0.7%
9-8-2-1-4-3-7--	1	0.7%
9-8-2-3-4-1---	1	0.7%
9-8-2-3-4-6-1--	1	0.7%
9-8-2-3-4-7-1--	1	0.7%
9-8-2-3-4-7-6-5-1	1	0.7%
9-8-2-4-3----	1	0.7%
9-8-2-4-3-1---	1	0.7%
9-8-2-4-3-1-6--	1	0.7%
9-8-2-4-3-1-7--	1	0.7%
9-8-2-4-3-7---	1	0.7%
9-8-2-4-6-5-7--	1	0.7%
9-8-4	6	4.2%
9-8-4-2-3-6---	1	0.7%
9-8-4-2-3-6-1-5-	1	0.7%
9-8-4-2-3-7---	1	0.7%
9-8-4-3-2----	1	0.7%
9-8-4-3-2-7---	2	1.4%
9-8-5	1	0.7%
9-8-5-4-1-2-3--	1	0.7%
9-8-6	1	0.7%
9-8-6-2-3-1---	1	0.7%
9-8-7	2	1.4%
9-8-7-2-1-4-6-5-3	1	0.7%
9-8-7-2-1-6-4-3-	1	0.7%
Grand Total	**143**	**100.0%**

10.14.2 Participant Comments

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
MG1	Medical Graduate	Female	Normally deep palpation as increase pressure, decrease resistance from patient, but here there was increase resistance as if there was guarding. Felt like I was exerting more pressure to get same depth. Forearm muscles were working harder.		1					
MG10	Medical Graduate	Female	Quite stiff - doesn't have as much give as most people. Difficult to feel. Use more pressure than usual on deep palpation.		1					
MG11	Medical Graduate	Male	Somewhat firmer to palpate than a live subject, however realistic enough to all all aspects of examination required for patient assessment.		1	1				
MG13	Medical Graduate	Male							1	
MG14	Medical Graduate	Female	Plastic is firmer than real live patients but a good starting point for learning abdominal palpation.		1	1				
MG15	Medical Graduate	Male	too firm		1					
MG16	Medical Graduate	Female	Firm to touch. Difficult to be confident of identifying masses etc, given "lumpiness" of the silicone skin. Anatomically is good for identification of the quadrants but not for detailed palpation.	1	1		1			
MG17	Medical Graduate	Female	I thought it was realistic in terms of depth and pressure of palpation required.			1				
MG18	Medical Graduate	Male	Much of abdo exam is patient feedback as your doing it - obviously difficult to simulate in model					1		
MG19	Medical Graduate	Female	Found mass							1

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
MG2	Medical Graduate	Female	The skin seems too thick. It keeps the anatomical landmarks. Feels like a gym guy.	1	1		1			
MG20	Medical Graduate	Female	Skin stiff - doesn't give to let you in like a normal person. Perhaps if he was quite fit (don't often get fit patients). Otherwise pretty realistic.	1	1	1				
MG21	Medical Graduate	Female	Feel was pretty realistic except for funny band between umbilicus and pubis. Realistic feel of organomegaly as it actually may feel + pressure required to specifically feel for this.			1				
MG22	Medical Graduate	Male	Light palpation less realistic due to "stickyness" of the material cf normal skin. Deep palpation organs a little too firm.	1	1			1		
MG24	Medical Graduate	Male							1	
MG25	Medical Graduate	Male	Needs a lot of force to palpate structures, in particular deeper areas.		1					
MG26	Medical Graduate	Male	Feels quite solid - more than normal abdo. Can't roll hand as a bit sticky - skin bunches when you slide across.	1	1					
MG4	Medical Graduate	Female	Generally very realistic. However the general resistance is a bit too much. The rectus abdominal muscle group is a very realistic representation. Costal margin is very realistic too. It's a bit difficult to do deep palpation because of the amount of "resistance". My fingers were tired after doing deep palpation.		1	1	1			
MG5	Medical Graduate	Male	Reasonable training tool. Will still require practice on colleagues for patients but a reasonable start for medical students.			1				

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
MG6	Medical Graduate	Male	The most life like abdominal model that I have seen			1				
MG7	Medical Graduate	Male	Difficult to assess injury without 1) painful response to - superficial/deep palpation 2) bruising 3) peritonism 4) deep palpation for specific organs require respiratory effort.					1		
MG8	Medical Graduate	Male	The skin needs to be more elastic so that the abdominal organs are easily felt. The liver edge and splenic edge needs to be better defined. Pelvic should be better contoured.	1						
MG9	Medical Graduate	Male	Felt a litle fake	1						
MGI1	Medical Graduate	Male							1	
MGI2	Medical Graduate	Male	A lot fimer than a real abdomen.		1					
St1	Student	Female	Very firm in midline. Force I applied normally proportional to habitus to feel organs etc. So as slightly firmer the force I applied might have been more than usual		1					
St10	Student	Female	I find the material hard. I think that is is much less elastic than a real abdomen.		1					
St100	Student	Male	A little firmer than a normal abdomen		1					
St101	Student	Female	Good model for palpating, harder to palpate than a human.		1	1				
St102	Student	Female	I haven't palpating many abdomens so I'm still trying to learn what normal feels like. It seemed a bit stiffer tha abdomens I have felt - but if he was in pain - he might be guarding a bit. Thankyou.		1					1
St103	Student	Female	Quite a bit more firm than most abdomen are.		1					

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St104	Student	Female	The model felt less soft than a normal abdomen, and also could not tell about things like guarding, but generally felt like palpating a real abdomen.		1	1				
St105	Student	Female	The middle "abs" are very hard - could be a bit softer. Otherwise I can see it could be very handy.		1	1				
St106	Student	Female	Realstic to learn technique but usually abdomens are more soft - able to move skin more easily (ie through fat tissue)	1	1	1				
St107	Student	Female	Consistent with fit male - bit harder than any I've palpated. Nice manikin - but than others for feeling.		1	1				
St108	Student	Female	I thought it was fairly realistic. The skin is a bit thicker than a real person's but other than that I think it would make a great learning tool.	1		1				
St109	Student	Male	Extremely realistic if softer foam. Firmer than usual.		1	1				
St11	Student	Male	Possible requires more force to palpate to compensate to real patient.		1					
St110	Student	Female	Ribs higher than expected.							1
St111	Student	Male	Very difficult to deep palpate because it's very firm.		1					
St112	Student	Female							1	
St113	Student	Male	Difficult for deep palpating. (?) mass epigastric/umbilical region. (?) mass RIF		1					1
St114	Student	Male							1	
St115	Student	Male	Too firm compared to a real abdomen. Also a lot longer compared to a "regular" person.		1					1
St116	Student	Male	In my experience real abdomen have more "pliability"		1					
St117	Student	Female	Harder to palpate than a lot of abdomens (feels a bit firm/tense) otherwise good!		1	1				

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St118	Student	Male	On palpation, much more firm than a real abdomen (i.e. write & forearm sort at end of examination). Difficult to determine normal abdominal landmarks (especially lower region).		1					
St119	Student	Female	Abdomen is very firm & difficult to assess underlying organs.		1					
St12	Student	Female	There was much less give on this model compared to a real abdomen. There was a lot of resistance even on light palpation, which made me unsure of how hard to palpate given the feedback to y hand was reduced. My arm got tired quickly during deep palpation.		1					
St13	Student	Female	Felt quite hard compared to a real abdomen. Surface markings however were pretty realistic i.e. was able to locate the hip bones & ribs. Found it difficult to palpate - felt thick.	1	1	1	1			
St14	Student	Male	Did not feel like I could move the abdomen around on deep palpatioin. The skin was sticky, so couldn't get a good circular motion to feel anything underneath. Did feel I was about to get a good depth on deep palpation.	1		1				
St15	Student	Female	It is harder to press than on most real humans		1					
St16	Student	Male	Large round mass in epigastric region							1
St17	Student	Female	It was a lot more rigid and had a lot less give than a real stomach. Given the clinical scenario I would be concerned about this degree of rigidity in a real patient.		1					
St18	Student	Male	Probably more verbal feedback -> visual feedback also (seeing if patient is grimmacing)					1		
St19	Student	Female	Skin v loose & mobile	1						

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St2	Student	Female	Skin - seemed to have differing thicknesses. Liver edge - more transverse than in normal person. Bony landmarks not as prominent as in a normal person that size eg illiac crest, costal margins.	1						
St20	Student	Male	Model feels okay, but lacks feedback one gets apart from touch, i.e. facial expression, stomach muscles tensing/guarding. Otherwise good!			1				
St20	Student	Male	Model feels okay, but lacks feedback one gets apart from touch, i.e. facial expression, stomach muscles tensing/guarding. Otherwise good!					1		
St21	Student	Female	Very rubbery with little movement	1						
St22	Student	Male	Felt a bit rubbery, but still good to palpate	1		1				
St23	Student	Female	Felt reasonably realistic though a little more rubbery and I felt I had to press a little harder than usual, otherwise realistic.	1	1	1				
St24	Student	Male	Abdomen was inconsistently lumpy in different regions. No ability to express pain on palpation. Inability to demonstrate effect of breathing on abdomen.					1		1
St25	Student	Male	Tissue felt real, would like to be able to move model on its side.			1		1		
St26	Student	Female	I think the abdomen felt a lot more firm and did not have as much give as a real abdomen. I found it difficult to perform deep palpation.		1					
St27	Student	Male	It felt a little hard to palpate		1					
St28	Student	Male	The friction from the synthetic skin is much more generally? Than real skin therefore harder to make smooth transitions. Suggest = lubrication (simulating real body oil)	1						
St29	Student	Female	Abdomen was a bit stiff		1					

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St3	Student	Male	Difficult to identify costal margin on inspection - this is easily identifiable even in larger individuals. I am not sure if it was on purpose i.e. programmed pathology of patient, however abdomen was firm in places that was more than you would expect for a normal patient.		1					
St30	Student	Female	A lot firmer than a real abdomen & the skin was not as elastic or smooth.	1	1					
St31	Student	Male	Stomach is a little squishy, lower abdomen seemed firmer. Small section on left upper abdominal side had a blemish on the surface, felt rougher, possibly harder.							1
St32	Student	Male	The model was a bit harder to palpate than a normal person. However, the bone structures underneath (hip bone, ribs) were realistic. Overall, it is pretty useful for learning palpations.		1	1	1			
St34	Student	Female	As I have not had much opportunity to palpate real patients it is a little difficult to say how realistic it is, but I think a real patient would be a bit softer than the model.		1					
St35	Student	Female	Quite realistic, maybe slghtly harder than a human abdomen		1	1				
St36	Student	Female	Abdomen generally soft all 4 quadrants, no pain from patient or guarding.							1
St37	Student	Male	Probably haven't done enogh palpation to have a considered opinion. But seemed good overall, but obviously missing certain aspects like inspiration/expiration. Bladder seemed easily palpable.			1				
St38	Student	Male	Skin feels more course than normal human skin	1						

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St39	Student	Female	No idea because not done before. Doesn't feel like there are real organs inside.							1
St4	Student	Male	The skin is a bit thick - feels a little firmer than a normal abdomen - makes it a bit difficult to assess underlying structure.	1	1					
St40	Student	Female	Realistic enough to learn technique.			1				
St41	Student	Male	Good skin texture & easy to discern rib edges under skin			1				
St42	Student	Male	Looks very real, feels quite realistic. Very effective learning tool			1				
St43	Student	Female	Skin irregularity is an issue - but if in production would be easier to get skin mould in. But texture had enough give (better than the dummies used for CPR). Not able to practice ballottment as only 1/2 abdomen. Difficult for me to assess for realism as have only palpated 1-2 but could feel edge of rectus.	1		1		1		
St44	Student	Female	Much more force required than a real abdomen. Much more difficult to feel. Did not feel like a normal soft abdomen. Much more firm & rigid.		1					
St45	Student	Female	The skin feels very thick and sticky.	1						
St46	Student	Male	Not as soft as I would expect. Some difficulty with liver/spleen palpation. The depth of palpation is different. It is hard to go deeper. The skin doensn't really feel or move as I would expect. I guess what I am missing is an outside layer, which is fairly soft/mobile.	1	1					
St47	Student	Male	Compressability was very similar to human body, but not exactly the same. Not possible to ballot kidneys (need flesh in flank regions for this)			1		1		

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St48	Student	Female	A little more rigid than many patient's abdomens I've palpated, but costal margins & landmarks (ASIS, etc) reasonably accurate. If it's too rigid, may be more difficult to find a mass as compared to a real patient? Thanks		1		1			
St49	Student	Male	Skin could be more softer	1						
St5	Student	Male	The deep consistency is right, its just that the skin (surface) is to rigid, it needs to be softer to better sympalise skin in human patients.	1		1				
St50	Student	Male							1	
St51	Student	Female	More realistic than plastic models and would be helpful in learning abdominal palpation. Model was a bit hard - not sure if it is representative of a real patient, or if technique needs to be improved.		1	1				
St52	Student	Female	This model simulation felt very real and life-like - would be good to be able to percuss and see difference as well.			1		1		
St53	Student	Male							1	
St54	Student	Female	Quite firm to palpate (the patient is a young man probably with abdominal muscles); I haven't palpated this type of abdomen before, so I imagine it's quite realistic.		1	1				
St55	Student	Male							1	
St56	Student	Female	Deep palpation is more difficult with the model because its abdomen is firmer than those of the people we practice on. The model's "skin" is also less easy to move across the surface of.	1	1					
St57	Student	Female	Landmarks of the anterior superior ischial spine not as easily palpable as a real person. More difficult to palpate deeply. Can't palpate under ribs.		1					

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St58	Student	Male	Skin felt really realistic.			1				
St59	Student	Female	Very real! Might want to get students to wear gloves for the sake of the model's longevity! :) A bit tougher than usual, i.e. hard to do deep palpation.		1	1				
St6	Student	Female	Good consistency. If bony landmarks were easier to palpate, would increase realism.			1				
St60	Student	Female	Good difference between what you can feel with light and deep palpation, even though I'm not sure of the significance of GIT types findinds at this stage.			1				
St61	Student	Male	It felt very solid beneath the skin, whereas on people it felt softer. Skin felt pretty realistic.		1	1				
St62	Student	Female	Surface didn't feel like skin. Also harder than real abdomen.	1	1					
St63	Student	Female	I feel that the human abdomen feels very different to this prototype e.g. different texture and prototype was much bigger than a human. Maybe it was just this manniquin, but I think having a prototype for ab palpation will be really useful!		1					
St64	Student	Male	I thought this was actually very good. Although I haven't had much experience (only on healthy subjects). I thought this would be very useful in a teaching setting.			1				
St65	Student	Female	Texture feels similar. Content feels slightly different.			1				
St66	Student	Male	The model is pretty good but was a bit hard for doing deep palpation, felt as if I couldn't press deeper to feel more organs.		1	1				

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St67	Student	Male	It's probably a bit firmer than an actual person, and the rubber makes it harder to do. But overall it gives a similar experience.	1	1	1				
St68	Student	Female	Very realistic. The abdo felt soft but firm enough to be similar to a real abdo. Good to have a face on the abdo because part of training is to watch patient/model's face. Ribcage could be slightly more prominent.			1		1		
St69	Student	Male	Good material compared to other sims			1				
St7	Student	Male	A lot of resistance. Human skin & subcutaneous fat glides over underlying structures, unlike model. Difficult to distinguish bony landmarks.	1	1					1
St70	Student	Male	Found it a lot firmer than any abdomen palpated to date. Found the superficial undulation somewhat distracting.	1	1					
St71	Student	Male	Quite realistic layout of abdominal surface anatomy. More realistic than previous sim-dolls used in med course.			1	1			
St72	Student	Female	Skin on the training dumy was a bit sticky so it was a bit difficult to keep contact on the skin with the hand as you ran your hand across different areas. Some areas of the dumy were a bit tougher to palpate (the foam was a bit stiff in areas).	1	1					
St73	Student	Male	Good. Palpating firm objects but felt generic.			1				
St74	Student	Male	Bit harder to push than real abdomen. Good for teaching technique.		1	1				
St75	Student	Female	Good that ribs weren't low enough to obscure the hypochondrial regions.			1				
St76	Student	Male	Middle abdomen was soft & realistic, but around the supra-pubic area, I could feel the plastic mould.			1				1

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St77	Student	Male	Foam consistency varies throughout.							1
St78	Student	Male	Abdomen was very rigid. So hard to feel organs underneath, but otherwise really good.		1	1				
St79	Student	Female	It was much firmer than a human, making it more difficult to palpate & couldn't get much depth. The amount of force needed for depth on the trainer would be too much I think on a real person.		1					
St8	Student	Female	There was a clear lump that you could feel in the epigastric area, but it was sometimes difficult to distinguish structures in the other areas.							1
St80	Student	Male	To rigid, needs to be softer. Can't tell difference between light & deep. Organs would be good.		1					
St81	Student	Male							1	
St82	Student	Male	Anatomically correct. Not as easy to orient oneself due to absence of hair, etc. A bit firmer than a real person.		1	1		1		
St83	Student	Male							1	
St84	Student	Female	The surface is too tought for deep palpation to be effective. Anatomical landmarks adequate.		1		1			
St85	Student	Female	It was firm especially for the deep palpation		1					
St86	Student	Female	Bit firm		1					
St87	Student	Male	Felt fairly realistic to me			1				
St88	Student	Female	1) I found it quite realistic, perhaps its got more resistance than human. 2) Hard without tutorial first? 3) Abnormality - difficult if the 'model' cannot report pain/tenderness ?		1	1		1		
St89	Student	Male	I could not feel the iliac fossa. There was not a lot of give to the abdomen when I pressed in. The lumbar regions were stiff.		1					
St9	Student	Male							1	

Participant ID	Participant Type	Gender	Comment	Skin Thickness/ Rubbery	Firm/ Resistance/ Stiff	Good/ Realistic/ Teaching Tool	Anatomically correct	Would like patient feedback/ extra features	Comments blank	Other
St90	Student	Female	Too firm		1					
St91	Student	Male	The rubber on the model does not "give" as much as a real human being when palpated.	1						
St92	Student	Female	Bit tougher to palpated at a deep level - thick material. Would be good to have model breathing. Otherwise great, would be fantastic to practice on.	1		1		1		
St93	Student	Male	Good, prefer real people to practice on.			1				
St94	Student	Female	Felt it was a bit harder to palpate esp. deep palpate due to "skin" being tight & not very pliable.	1						
St95	Student	Female	Bit hard. Can't see ribs etc.		1					
St96	Student	Male							1	
St97	Student	Female	Does feel a bit artificial & stiff, but could be worthwhile to practice how much pressure one needs to apply for light vs deep palpation.		1					1
St98	Student	Male	Skin is good. Costal margin is good. Liver is good. Firm feeling overall.		1	1	1			
St99	Student	Female	Bit too stiff for a real abdomen. Visually doesn't really look like an abdomen.		1					1

Appendix E. List of Publications and Presentations

Burrow, L. B., Owen, H., Reynolds, K.J., (2008). *Developing An Abdominal Palpation Simulator: Quantifying Forces Applied During Examination.* Australasian Physical & Engineering Sciences in Medicine **31**(4): 386-387.

Burrow, L. B., Owen, H., Reynolds, K.J., (2008). *Developing an Abdominal Palpation Simulator: Quantifying Applied Abdominal Examination Forces.* SimTecT 2008 Healthcare Simulation Conference, Brisbane, Australia, Simulation Industry Association of Australia.

Burrow, L. M., et al. (2008). *Developing an Abdominal Palpation Simulator: Quantifying Forces Applied During Examination.* Conference Handbook EPSM-ABEC. Christchurch, New Zealand**:** 100.

Burrow, L.M., Owen, H., & Reynolds, K.J., (2011). "ABSIM: Abdominal Palpation Training Simulator." Australasian Physical & Engineering Sciences in Medicine **34**(4): 579.

Burrow, L.M., Owen, H., & Reynolds, K.J., (2012). *A trial of a prototype clinical educational tool for training medical students in abdominal palpation. Project No: 5771.* Social and Behavioural Research Ethics Committee. Flinders University School of Medicine.

Burrow, L.M., Owen, H., & Reynolds, K.J., (2012). *ABSIM: A clinical educational tool for training medical students in abdominal palpation.* The Engineers Australia Biomedical Branch South Australia and the Society for Medical and Biological Engineering, 2012 Biomedical Engineering Student Papers Night.

Burrow, L. B., Owen, H., Reynolds, K.J. (2013). *ABSIM: A Clinical Educational Tool For Training Medical Students in Abdominal Palpation*. Australian Biomedical Engineering Conference 2013. Sydney, Australia.

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