Detection of distal ulna and radius fractures using thermal imaging as a diagnostic tool on children in the Emergency Department setting.

By

Alan Charters M.A, BSc (Hons), PgDip ed, Rgn, Rscn, Rnt.

The thesis is submitted in partial fulfillment of the requirements for the award of the degree of Professional Doctorate in Health Science of the University of Portsmouth.

Submitted September 2014
Abstract

Aims of the study

The aim of this pilot study was to examine whether a full phase III study would be beneficial in determining whether thermal imaging can be used as a diagnostic tool to detect distal ulna and radius fractures in children who attend the emergency department with an injury to their wrist when compared with the gold standard of X-rays.

Methods: Following ethical approval and informed consent, patients meeting the inclusion criteria with injuries to their distal forearms were recruited into this investigation. The pilot study design was a quasi-experimental controlled trial of 67 patients evaluating whether thermal imaging could detect fractures in children's distal ulna and radius. All patients enrolled into this trial were treated in accordance with the European Thermography Association standard for carrying out diagnostic studies using infra imaging (Clark & DeCalcina-Goff, 1997). All of the children enrolled into this study had thermal images taken of their injured arm (case) and their uninjured arm (control). The thermal imaging took place alongside the X-ray, ensuring that the same person conducted the positioning of the child’s wrist, thus ensuring consistency in image capture. The child was then treated appropriately in accordance to the X-ray results. The data from the thermal imaging was not analysed for six-months post the child’s attendance at the ED in order to reduce the chances of interpreter bias.

Results: The results from this study found that there was a statistically significant difference in surface temperature of the injured arm when compared to the control (mean difference 0.90°C, 95% CI: 0.72 to 1.07, p < 0.0001). The magnitude of the difference is significant enough to suggest that a pathological change had taken place. Thirty-one out of thirty four children diagnosed with fractures on X-ray showed a
surface temperature difference of $1^\circ C$ or greater when compared with the control
(mean difference = 1.28, 95% CI $0.889$ to $1.689$). When the fracture group was compared
with the injured non-fractured group, a mean difference of $1.084^\circ C$ (95% CI = $0.62$ to
$1.54$, $p<0.0001$) was found. When compared with radiographs, thermal imaging
returned a sensitivity of $91.18\%$ with a specificity of $87.85\%$; the sensitivity is
increased to $96.7\%$ when the clinical examination is taken into account. In this study
the likelihood ratio for the positive test was calculated to be $7.52\%$. The negative
likelihood ratio was calculated to be $0.1\%$.

**Conclusion:**

This study has shown that thermal imaging may be useful in detecting fractures of the
distal ulna and radius in children's wrists, however its diagnostic accuracy is
questionable, returning a sensitivity of only $91.8\%$ when compared with X-rays
(96.8%) however, when used alongside clinical examination the results demonstrate a
sensitivity of up to $96.7\%$. This study has demonstrated that thermal imaging can
detect quantifiable differences in temperature, between an uninjured wrist, a soft tissue
injury and a fracture. However its accuracy in diagnosing a fracture cannot be
guaranteed and does not reach the accuracy of X-rays, which are considered to be the
current diagnostic gold standard. A full phase III multi centered study would be useful
in determining whether thermal imaging could be a useful adjunct to the diagnosis of
fractures within the wider health care setting, to elucidate whether thermal imaging
has a role in reducing the amount of unnecessary x-rays carried out on children with
suspected fractures to their wrists.
# Table of contents:

**Preface**
- Abstract
- List of contents
- List of tables
- List of figures
- Declaration
- Acknowledgement and dedication
- Dissemination

**Chapter 1: Introduction and background**
- 1.1 Introduction
  - 1.1.1 Background of medical thermal imaging
  - 1.1.2 The relationship of thermal imaging and human physiology
- 1.2 Introduction to study
  - 1.2.1 The objective of a pilot study
  - 1.2.2 Aims of the study
  - 1.2.3 Definition of a diagnostic study
  - 1.3 Physiology behind the inflammatory response to bone healing
- 1.4 Types of fractures
- 1.5 Summary

**Chapter 2: Literature review**
- 2.1 Search strategies
- 2.2 Thermal imaging for the detection of fractures
  - 2.2.1 The use of thermal imaging in the medical diagnosis of fractures
  - 2.2.3 Further alternatives to X-ray.
- 2.2.4 Limitations associated with thermal imaging

**Chapter 3: Research design and sampling**
- 3.1 Conceptual framework
- 3.2 Research question
- 3.3 Standard approach to infrared Imaging
  - 3.3.1 Location of thermal imaging
  - 3.3.2 The imaging system
  - 3.3.3 Patient manipulation
- 3.4 The research design
- 3.5 The Quasi-experimental design
- 3.6 Methodology
- 3.7 Population and sample
  - 3.7.1 Inclusion criteria:
  - 3.7.2 Exclusion criteria:
- 3.8 The Clinical trial
Chapter 4. Results and data analysis

4.1 Introduction 70
4.2 Demographic data 70
4.2.1 Results from the Data Collection Forms 72
4.2.2. Inclusion criteria met 75
4.3 Results from the thermal imaging data 75
4.3.1 Study group versus control (Uninjured arm) 76
4.4 Study group: Fractured wrist compared with injured non-fractured group 79
4.5 Fracture group compared with control (Uninjured wrist) 81
4.6 Non fractured Injury group compared with control (Uninjured wrist) 83
4.7 Sensitivity and specificity 85
4.8 Likelihood Ratios 85
4.9 Summary 87

Chapter 5: Discussion

5.1 Introduction 89
5.2 Primary objective for this study 89
5.3 Secondary objectives for this study 101
5.4 Limitations 105
5.5 Could thermal imaging be used as a screening tool 110

Chapter 6: Conclusion

6.0 Conclusion 114
6.1 Summary 116
6.1.1 Key findings 117
6.2 Implications for practice 118
6.3 Dissemination of findings 119

Chapter: 7 Reflections on the doctorate programe 121

Bibliography 127

Appendices: 145
List of tables

Table 2.1: Discounted papers 21
Table 2.2: Methodology for assessing diagnostic accuracy 22
Table 2.3: Summary of the papers reviewed within this chapter 23
Table 4.1: Demographic data 72
Table 4.2: Summary of the clinical data (Fracture group) 73
Table 4.3 Summary of clinical data (soft tissue group) 74
Table 4.4: Inclusion criteria 75
Table 4.5: Study group versus control 76
Table 4.6: Summary of results: study Group VS control 78
Table 4.7: Comparison of fracture group with non fracture injury group 79
Table 4.8: Summary of results: fracture VS non fracture (Injury group) 80
Table 4.9: Children with fractures compared with the control 81
Table 4.10: Summary of results comparison of fractures VS control 82
Table 4.11: Non- fractured injury group VS Control 83
Table 4.12: Summary of results non Fractured group VS control 84
Table 4.13: Sensitivity and specificity of thermal imaging when compared with X-rays 85
Table 4.14: Likelihood Ratios 86
## List of figures:

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limb Segment Model.</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>X-ray of a child’s wrist demonstrating a Buckle fracture</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Classifications of fractures</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Flow diagram of the literature review process</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>Conceptual framework</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>Example of thermal image</td>
<td>53</td>
</tr>
<tr>
<td>7</td>
<td>Patient journey through the department preceding trial</td>
<td>61</td>
</tr>
<tr>
<td>8</td>
<td>Flow chart of clinical trial</td>
<td>62</td>
</tr>
<tr>
<td>9</td>
<td>Flow diagram: Patients enrolled into pilot study</td>
<td>71</td>
</tr>
<tr>
<td>10</td>
<td>A Nomogram for applying Likelihood ratios</td>
<td>98</td>
</tr>
</tbody>
</table>
Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

Word count: 33420
Acknowledgement and Dedication

I would like to thank the parents and children that attended the emergency department and helped so enthusiastically with this study. Without them none of this research paper would have been possible.

I am indebted to Mr Simon Mullet clinical directors of the Emergency Department Mr Simon Hunter and Isobel Gaylard, clinical leads for the division of Emergency Medicine, for their unending support and encouragement.

I am very grateful and recognise the immense support that Dr Isobel Ryder and Professor Graham Mills have shown me throughout my whole Doctoral experience.

I would also like to thank the patient and understanding staff of the children’s emergency department who have badgered and encouraged me to complete this study over the many years it has taken to complete.
Dissemination: