INVESTIGATION OF TROPHIC CHANGES IN CERVICAL DYSFUNCTION AND FROZEN SHOULDER

STEPHANIE GRIFFITHS

UNIVERSITY COLLEGE LONDON

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ABSTRACT

Trophic changes have been identified by several investigators and associated with visceral, articular and neural pathology. There have been claims that trophic changes can be used as clinical indicators of pathology of both visceral (Wesselmann and Lai 1997; Giamberardino et al. 2005; Vecchiet et al., 1990) and somatic structures (Gunn and Milbrandt 1978; Galletti et al., 1990), however no sensitivity analysis has been conducted in any of the studies so far to substantiate these claims. This dissertation consisted of 2 linked studies, both were non-randomized controlled studies, the first aimed to investigate the sensitivity of vasomotor, sensory and motor trophic changes using tests suitable for clinical practice in subjects with cervical sensory radiculopathy (n=31) and frozen shoulder (n=32) (control n=30). The second was a controlled study (n=30) which investigated the effect of intra-articular cortico-steroid injection on trophic changes in frozen shoulder (n=17), before and 4 weeks after injection. The results showed that though there were significant differences between the trophic changes measured in the control and experimental groups, these were not sensitive indicators of pathology in frozen shoulder or cervical radiculopathy. (vasomotor sensitivity 0.31 and 0.06; sensory sensitivity 0.41 and 0.39; and motor sensitivity 0.25 and 0.16, for frozen shoulder and cervical radiculopathy respectively). The results of study 2 also showed that there were no significant differences in trophic changes recorded following cortico-steroid injection (P>0.05), which suggests that anti-inflammatory medication has no impact on their existence.
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CHAPTER 1

INTRODUCTION AND GENERAL BACKGROUND

Introduction
This dissertation is a report of 2 linked studies. The first aimed to investigate the sensitivity of trophic changes using tests suitable for the clinical environment in subjects with cervical sensory radiculopathy and frozen shoulder. The second aimed to investigate the effect of cortico-steroid injection on trophic changes in frozen shoulder. The studies were experimental, controlled studies with subjects drawn from a wide range of primary care medical practitioners in Eastern Birmingham.

This first chapter gives a general background to the study as well as giving an overview of the methodology and the significance of the study. The second chapter discusses the studies which have investigated trophic changes so far, and includes an outline of the aims of the study. The third chapter describes the methodology in detail including participant recruitment, equipment used, reliability analysis, and the data reduction and analysis. Chapter 3 also includes justification for the methods and equipment used highlighting where other outcome measures were considered but rejected. The fourth chapter demonstrates the results and matches the findings to the study aims, and Chapter 5 summarises each study and highlights the key findings along with the study limitations, ending with the conclusions and recommendations.

General Background
Trophic changes are a collection of vasomotor, sensory and motor signs and symptoms which, so far, have not been clearly defined in the literature. It has been proposed by many authors that trophic changes are useful as clinical indicators of pathology particularly in the field of visceral pathology where referred pain may often hinder diagnosis. However these claims are unsubstantiated as none of the studies have conducted sensitivity or specificity analysis. Two studies have investigated trophic changes in musculoskeletal pathology, but neither study considered upper limb or cervical spine pathologies. Subjects with frozen shoulder and cervical sensory radiculopathy were considered to be suitable for this study because they are conditions which are difficult to differentially diagnose, and if
Trophic changes were shown to be sensitive they would have a high impact in the 
management of these conditions. In the studies so far, trophic changes have been 
investigated in the area to which pain normally refers. As frozen shoulder and C5 
sensory radiculopathy refer pain into the same segment they were considered ideal 
for this study.

Trophic changes (vasomotor changes in particular) have been strongly correlated 
with experimentally induced inflammation (Wesselmann and Lai 1997), and these 
findings suggest that administration of anti-inflammatory medicine such as cortico-
steroid may bring about a reduction in trophic changes. So far, the effects of anti-
inflammatory medication or other treatments on the existence of trophic changes has 
only been explored by Dragani et al. (1992), and in their study application of anti-
inflammatory medication did indeed reduce the existence of trophic changes. As 
frozen shoulder is an inflammatory condition often treated by intra-articular cortico-
steroid injection, it was considered to be an ideal model to determine whether trophic 
changes were reduced by administration of cortico-steroid.

**Aim of Study 1**
The purpose of study 1 was to determine whether clinical tests of vasomotor, sensory 
and motor trophic changes were reliable and sensitive clinical indicators of frozen 
shoulder and cervical radicular pathology.

**Aim of Study 2**
The purpose of study 2 was to determine whether administration of intra-articular 
cortico-steroid injection altered trophic changes at the shoulder joint in subjects with 
frozen shoulder.

**Overview of the Methodology**
To ensure that these tests could be widely employed by clinicians, the methodology 
used was determined by the requirement to be compliant with use in clinical 
environments. In experiment 1, to determine the sensitivity of trophic changes, 93 
subjects were consecutively recruited from a physiotherapy centre (control group 
n=30, cervical radiculopathy n=31, frozen shoulder n=32). Three outcomes were 
investigated, vasomotor changes were measured with a newly modified technique
called the modified matchstick test to determine the presence of subcutaneous oedema. Sensory trophic changes were measured with the pressure algometry and motor changes were measured with surface electromyography of the maximum voluntary contraction. All tests were performed in the C5 dermatome, over the deltoid muscle on the lateral aspect of the shoulder.

In experiment 2, 17 subjects who consented to shoulder joint corticosteroid injection were consecutively recruited from the pool of 32 subjects with frozen shoulder in experiment 1, and matched to 30 control subjects. Subjects who did not consent to an injection but who consented to take part in the study as a further control were also recruited (n=10). All subjects underwent the same tests as in experiment 1 at baseline, and then at 4 weeks after injection, or at 4 weeks following baseline tests for those in the control groups.

**Significance of the Study**

Upper quadrant conditions such as cervical sensory radiculopathy and frozen shoulder are two relatively common conditions that are often difficult to diagnose, therefore if trophic change tests were found to be sensitive indicators of pathology they could be very useful to a large number of musculoskeletal, general practice, rheumatological and orthopaedic clinicians to assist with clinical diagnosis.

The effects of treatments and medication such as cortico-steroid have not been thoroughly investigated however if these treatments were shown to reduce trophic changes, they may be useful indicators of recovery and therefore could be of benefit both diagnostically and prognostically.
CHAPTER 2

LITERATURE REVIEW

Introduction
This chapter introduces the concept of trophic changes and attempts to categorize them depending on their underpinning mechanism. Reviewing the literature since 1975, resulted in five studies which specifically investigated the existence of trophic changes, and these are analysed in detail, studies in both animals and humans have been included. The first part of this chapter concludes with the summary that in general trophic changes have been poorly investigated with methodology that lacks reliability or validity, demonstrating the need for further investigation. The importance of trophic changes as diagnostic indicators and their mechanisms are discussed in section 2.3 and 2.4, with the literature pertaining to the effects of interventions on trophic changes being discussed in section 2.5. The chapter concludes with a summary and the study aims. Studies reviewed in section 2.1 to 2.3 include those which have specifically investigated trophic changes (those studies before 1975 have not been included). The studies reviewed in section 2.4, outlining the mechanism of trophic changes are drawn from the wider literature.

2.1 Categorization of Trophic Changes
Trophic changes are an ill-defined, collection of vasomotor, sensory and motor signs and symptoms, reported to occur in the area to which a pathological structure refers pain. Autonomic changes tend to be specifically connected with alterations in vasomotor activity and a variety of changes have been investigated such as plasma extravasation (Wesselmann and Lai 1997), superficial or subcutaneous oedema (Giamberardino et al, 2005; Gunn and Milbrandt 1978) and changes in the flare response (Giamberardino et al, 2005; Galletti et al, 1990). Sensory changes such as subcutaneous and muscular hyperalgesia have also been reported (Gunn and Milbrandt 1978; Giamberardino et al, 2005; Vecchiet et al, 1990), and there have been investigations of motor changes, such as muscle spasm (Giamberardino et al, 2005; Gunn and Milbrandt 1978).

There is debate about whether other autonomic symptoms such as increases in pilomotor and sudomotor activity also belong to the family of trophic changes. Gunn
and Milbrandt (1978) claimed that pilomotor and sudomotor activity may be an indicator of radicular dysfunction, however in their work, Gunn and Milbrandt (1978) did not attempt to measure pilomotor or sudomotor changes because they reported that they are often only momentary and thus cannot be measured accurately. Thus this claim does not arise from experimental evidence but is based on opinion or perhaps clinical experience. In contrast, other authors have suggested that with the exception of vasomotor activity, autonomic signs such as pilomotor and sudomotor activity do not belong to the family of trophic changes. For example in a review paper considering the mechanisms which underpin the symptoms present in complex regional pain syndrome patients, Janig and Baron (2003) reported that pilomotor and sudomotor changes are not mediated by the same mechanisms as vasomotor activity. They reported that increased resting sweat activity cannot be caused by a peripheral mechanism because unlike blood vessels, sweat glands do not develop denervation supersensitivity (though again the original experimental evidence for this statement was not cited). They suggested that re-organisation of central autonomic control is a more likely mechanism to explain sudomotor and pilomotor changes, which led Janig and Baron (2003) to exclude pilomotor and sudomotor activity from the family of trophic changes. Thus until further work identifying the underpinning mechanisms more clearly sudomotor and pilomotor changes were not considered to belong to the family of trophic changes and thus were not investigated in this study.

Abnormalities of the skin, subcutaneous tissues, bone, nails and hair may also be described as trophic changes or trophoneurotic atrophy (On-line Medical Dictionary 2005). These changes also tend to be poorly defined, but have generally been associated with severe damage to a local peripheral nerve (Sunderland 1991; Janig and Baron 2003), though no recent experimental studies were found which documented these changes in human subjects with nerve damage. Tissue thickness changes such as subcutaneous thickening and muscular thinning have been investigated in studies of trophic changes (Vecchiet et al, 1990; Giamberardino et al, 2005), but the cause of these changes and the underpinning mechanism also appears to be unknown, thus making categorization difficult. It is possible that subcutaneous thickness and associated muscle thinning may be a combination of trophic changes with subcutaneous thickening being suggestive of vasomotor involvement, and muscle thinning being suggestive of motor changes.
When searching the wider literature, one experimental animal study was found which investigated the development of epidermal thinning following sensory denervation as well as the reversal of thinning following reversal of nerve crush (Chiang et al, 1998). As these findings are in complete contrast to those proposed by authors of trophic change studies, it appears that this is not the mechanism underpinning subcutaneous tissue thickness changes (though epidermal and subcutaneous mechanisms may not be comparable). Unfortunately the general lack of clarity with regards to the underpinning mechanism reduces the value of tissue thickness findings because it is unclear what these changes represent. Therefore, for the purpose of this study, as with sudomotor and pilomotor changes, tissues thickness changes were not investigated.

Therefore for the purpose of this study, the term ‘trophic change’ was used to represent vasomotor, sensory or motor signs and symptoms in the area of referred pain, but not other autonomic changes such as sudomotor or pilomotor activity, or changes in tissue thickness. (N.B. where they have been measured by other authors these changes will be highlighted).

2.2 Investigation of Trophic Changes
Trophic changes have been documented to occur in visceral pathology (Wesselmann and Lai 1997; Giamberardino et al, 2005; Vecchiet et al, 1990), osteoarthritis (Galletti et al, 1990), and nerve root pathology (Gunn and Milbrandt 1978). The studies are discussed in detail below, most have measured several changes, often investigating one or two from each sub-group (i.e. vasomotor and sensory changes or vasomotor and motor changes).

2.2.1 Trophic Changes in Visceral Pathology
Three studies have reported findings of trophic changes in visceral pathology. Studies in humans have been conducted in gall bladder and renal pathology (Giamberardino et al, 2005 and Vecchiet et al, 1990), and there has been one animal study which has investigated trophic changes in uterine inflammation (Wesselmann and Lai 1997).
**Uterine Inflammation**

Wesselman and Lai, (1997) investigated visceral trophic changes using an animal model of rat uterine inflammation in 7 experimental and 5 control rats. Uterine inflammation was created in the experimental group through injection of mustard oil (using a uterine catheter, shown in previous studies to be reliable and valid). Prior to the procedure both groups had been injected (through an arterial catheter) with Evans blue dye dissolved in sterile water.

Ten minutes following the procedure cutaneous plasma extravasation was shown by the presence of Evans blue dye (blue dots) in the area of skin where referred hyperalgesia normally occurs (over the abdomen). Skin colour changes were quantified by comparing the number of blue dots between the experimental and control groups and it was shown that there were significantly more dots in rats with inflamed uterine pathology (P<0.05). Though this study shows that a significant difference in plasma extravasation between the experimental and control groups occurred, the results show that the pattern and number of dots was very variable with some rats producing unilateral and some bilateral skin changes. The study reported no reliability analysis of the technique used, and therefore it is difficult to be certain that this pattern would be repeated consistently such that it could be employed as a diagnostic test. Despite these failings, the investigators did ensure that leakage from the catheter had not occurred and histology examination demonstrated that significant inflammation was found only in uterine tissue, showing that plasma extravasation on the abdomen was directly related to the experimentally induced uterine inflammation not general abdominal inflammation.

**Gall Bladder Pathology**

Trophic changes in the form of vasomotor and sensory changes have been measured in gallbladder pathology by Giamberardino et al, (2005). In this non-randomized and non-blinded study, 4 separate groups of subjects (n=53) with varying degrees of gall bladder pathology, (classified on the basis of ultrasound examination), were investigated and compared to a control group of 22 subjects. Vasomotor changes were investigated with a method little used called dermographism. This procedure entails vertical parallel lines 2 cm apart being traced on the skin surface using the blunt point of a calibrated dermogaph at a constant pressure of 500g. According to
the authors, red lines appear as a consequence of the manoeuvre (a skin flare type reaction), which fade away progressively, and simultaneously, in normal skin areas. It was reported in this study that an early interruption of these lines occurs in hyperalgesic areas, which they defined as ‘the ischaemic phase of dermographism’. The presence of an ischaemic phase contradicts the findings of Wesselmann and Lai (1997) where plasma extravasation and flare type response is considered to be the mechanism that underpins vasomotor changes.

Interestingly the results of this study showed that early interruption of the skin flare reaction following the dermograph procedure did not occur in any of the 5 groups tested (nor did it occur in the study by Galletti et al, (1990) -see page 20). The fact that an ischaemic reaction following the creation of a flare response has never yet been found, coupled with the findings of Wesselmann and Lai (1997), suggests that dermographism may not be a useful measure of vasomotor trophic change.

Vasomotor changes were also investigated with a clinical test called the ‘fovea sign’ where tissues are digitally depressed and then observed after a certain time period (unspecified) for signs of remaining depression - indicative of superficial oedema (first cited by Galletti et al, 1990). Though this ‘fovea sign’ is reported to be indicative of superficial oedema, original experimental studies showing this finding cannot be found and the results of this test were not reported in this study.

Sensory changes (in the form of skin, subcutaneous and muscular hyperalgesia) were investigated with a constant current electrical stimulator using 18 ms trains of 0.5 ms monophasic square wave pulses, at a frequency of 310 Hz, repeated automatically every 2s. For subcutaneous stimulation a significant effect was observed for the gall bladder referral zone, as well as for the severity of the clinical condition, with symptomatic patients demonstrating lower thresholds than asymptomatic and control subjects (P<0.0001). Muscle stimulation also showed significantly lower pain thresholds for the gall bladder referral zone and for increasing severity of the clinical condition (P<0.01). These results appear to support the suggestion that subcutaneous and muscular hyperalgesia are features of visceral pathology, however no reliability analysis of the electrical stimulation was conducted in this study (or referenced to other work) which would have further strengthened this claim.
Manual techniques were also used to investigate hyperalgesia. ‘Pinch palpation’ (which entails folds of tissue being grasped between the thumb and the index finger and pressed together) was used, with hyperalgesia reported if a reaction of discomfort was shown by the subject. On analysis of the results, pinch palpation was positive in symptomatic patients and negative in asymptomatic patients and normal subjects. However the lack of blinding, reliability analysis or standardisation of pressure delivered, demonstrates that these findings cannot be relied up. Giamberardino et al, (2005) also highlighted the appearance of muscle spasm, but did not formally measure it.

In this study, tissue thickness was also measured bilaterally with ultrasound (however no equipment reliability was performed). Thickness measurements were made at the cystic point, the area to which the gall bladder commonly refers pain sensation. The results showed that subcutaneous tissue thickness measurements were significantly increased in symptomatic patients, along with significantly reduced muscle thickness, when compared to asymptomatic patients. Interestingly the study found that when testing these patients over a number of months the subcutaneous and muscle changes correlated to the greater number of painful episodes rather than to the degree of gall bladder dysfunction. However as discussed earlier the lack of clarity with regards to the underpinning mechanism means that it is difficult to draw conclusions about these findings.

**Renal Pathology**

Vecchiet et al, (1990) investigated trophic changes in visceral pathology in a small non-blinded, non-randomized, non-controlled study, using a group of 9 patients with renal pathology which were split into 2 groups depending on the number of attacks of renal colic (5 in group 1, with 1-2 attacks, and 4 in group 2, with 4-6 attacks). Sensory trophic changes were investigated in the form of hyperalgesic responses to manual palpation, mechanical pressure and electric stimulation. The ‘pincer palpation’ technique was used as in the study by Giamberardino et al, (2005) to determine subcutaneous and muscular hyperalgesia, but the exact method was not clearly described. It was reported that all patients had a hyperalgesic response to digital palpation, and as in gall bladder pathology, hyperalgesia was reported to be more ‘accentuated’ in those suffering from more attacks (group 2). Along with the
unclear methodology, unfortunately there was also no data analysis presented such that it was difficult to analyse the significance of the results summarised in the discussion.

Electrical stimulation was also used to measure hyperalgesia in the obliquis externus muscle and the overlying subcutaneous tissue, bilaterally at the level of L1, using the same procedure as Giamberardino et al, (2005). The results showed that in both groups pain thresholds were significantly lower on the affected side (P<0.001). However the poor methodological detail, the lack of clear data analysis, the lack of a control group, the small sample used and the lack of blinding and randomization means that these findings again are difficult to rely upon.

Vecchiet et al, (1990) also measured pain thresholds to mechanical pressure, bilaterally, at the level of L1 with an electric myometer with a probe of 25mm diameter in the same group of 9 patients. The probe was applied to the cutaneous surface overlying the muscle ‘half way between the anguloscapular and posterior axillary lines and the exerted force was gradually increased in increments of 0.1 ‘kgf’ every second (though it is not clear what kgf is). The definition of the pressure pain threshold used was the point at which the patient defined the pressure applied as, ‘tenderness’. The results showed that pressure thresholds were lower on the affected sides of both groups when compared to the unaffected side (P<0.03 for group 1 and P<0.02 for group 2). As with electrical stimulation these results could have been further strengthened by the use of a control group and blinding of the researcher to the subject group.

As with the study by Giamberardino et al, (2005), ultrasound was also used to determine muscle thinning and subcutaneous thickening in patients with painful (n=3) and non-painful (n=3) renal disease, however the number of subjects in this part of the study was inexplicably reduced from 9 to 6, and unfortunately again, no control group was used. The method used was the same as used by Giamberardino et al, (2005), but again reliability was not tested or discussed. From this small experiment the results showed a mean decrease in muscle thickness of the affected side in both groups (mean difference = 2.0mm) and a mean increase of subcutaneous thickness (mean difference = 3.33mm for group 1, and 3.66mm for group 2). Further
statistical analysis had not been evaluated and without normative data the clinical significance of these findings is again difficult to interpret.

2.2.2 Trophic Changes in Musculoskeletal Pathology
Two studies have investigated trophic changes in musculoskeletal pathology, one in osteoarthritis of the knee joint and the other in lumbar back pain and radiculopathy.

**Osteoarthritis**
Galletti et al. (1990) investigated trophic changes in 6 subjects with osteoarthritis of the knee in a small non-blinded, non-randomized, non-controlled study. Unfortunately both the method and the results are very poorly described in this paper such that clear conclusions about trophic changes are difficult to draw. The methodology outlines that vasomotor changes were investigated using the dermograph machine along with skin observation and digital compression (fovea sign) for subcutaneous oedema. Subcutaneous changes were also evaluated quantitatively with a technique which entailed injecting the knee joint to measure its capacity, though as with the other sections of the study, the procedure was not adequately described. No other trophic change studies have used this technique, and there have been no studies demonstrating its reliability or validity as a method to determine subcutaneous oedema. Subcutaneous and muscle tissue thickness also appear to have been measured by ultrasound, but the methodology does not detail this procedure. Overall the poor methodology and poor detailing of the results prevents thorough evaluation of the study findings.

**Low Back Pain and Radiculopathy**
In a prospective randomised controlled trial, Gunn and Milbrandt (1978) also investigated a series of skin and muscle changes in 2 groups of patients, the first with primary back pain (30 patients) and the second with radicular (specifically sciatic) referred pain (30 patients), compared with a control group of 60 patients. The patients in the study were randomly selected from those attending an outpatient rehabilitation clinic (though the description of randomization is not described). There was no blinding of the researcher to the subject groups identified in the methodology. As with many of the other studies described, a variety of tests to examine trophic changes were conducted which included:
a) Digital compression of motor points (in 2 muscles per segment from L2-S2)

b) Qualitative analysis of subcutaneous tissue by use of skin rolling (which entailed a piece of skin, approximately 5cm in diameter, being gently squeezed between the thumb and index finger, and judged for its ‘peau d’orange appearance’ and the resistance to ‘normal’ skin folding and inelasticity)

c) The matchstick test to determine subcutaneous oedema which entailed a blunt instrument (akin to a matchstick) being pushed firmly against the skin to make a compression indentation in the skin at the level of each lumbar nerve root (bilaterally) and in each lower limb segment. Following the compression, the indentation created was observed and its recovery to normal or the residual persistence of compression in the skin was noted. No time period for measuring compression was given and no explanation of the criteria that had been used to grade skin recovery was reported.

d) Palpation of muscle spasm assessed subjectively and scored on a 0-2 scale for level of firmness. (The criteria used for a positive test was a subjective description of the firmness and shape of the muscle, with a ‘palpably firmer’ muscle and a muscle with an ‘easily discernable shape and size’ constituting a positive finding).

The results of the experiment revealed that the trophic changes investigated occurred more frequently in patients with sciatic referred pain than in those subjects with low back pain alone or the control group, see table 1 below.

**Table 1: Showing the frequency of trophic changes in each group (Gunn and Milbrant 1978)**

<table>
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<th>Control Group</th>
<th>Sciatic Referred Pain Group</th>
<th>Back Pain Group</th>
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<tr>
<td>Tender motor points</td>
<td>1.6%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Subcutaneous oedema</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Palpable muscle spasm</td>
<td>0%</td>
<td>63.3%</td>
<td>20%</td>
</tr>
<tr>
<td>Subcutaneous tissue changes</td>
<td>28.3%</td>
<td>76.6%</td>
<td>53%</td>
</tr>
</tbody>
</table>
These results, though interesting, must be interpreted with great caution as the tests used lacked standardisation and validity. The results were also reported descriptively with no statistical analysis (possibly due to the age of the study), and as such conclusions regarding the significance of the results are difficult to draw. As with other studies, reliability analysis of tests used was not performed.

Summary

In summary the studies reviewed show that several trophic changes have been investigated which have included vasomotor changes such as plasma extravasation or subcutaneous oedema, and sensory changes such as responses to pressure or electric stimulation. The only motor change that has been investigated is palpable muscle spasm, and other motor symptoms which may represent changes in motor function, such as changes in muscle power, strength or electrical activity have not been discussed in the literature.

Overall the quality of the studies reviewed was poor with all scoring 0/5 on the JADAD quality scale, except the study by Gunn and Milbrandt (1978) which scores 1/5 (see tables 2 and 3 at the end of this chapter page...). However studies in the musculoskeletal field particularly [both Gunn and Milbrandt (1978) and Galletti et al, 1990] also have significant methodological limitations such as the lack of standardized and valid measurement techniques. Studies in the visceral field have generally used more standardised techniques but even Wesselmann and Lai (1997) and Giamberardino et al, (2005) have used methods for which reliability has not been demonstrated. Overall the quality of the studies suggests that the results cannot be relied upon, and thus it is not clear whether trophic changes exist at all.

2.3 Trophic Changes as Diagnostic Indicators

It has been claimed by many authors that trophic changes are useful as indicators of pathology as they are thought to be found in the tissues to which pathological or painful structures refer pain (Giamberardino et al, 2005; Gebhart 2000; Cervero 1995; Vecchiet et al, 1990; Galletti et al, 1990; Procacci et al, 1986; Gunn and Milbrandt 1978). Though all the researchers investigating trophic changes have suggested that they could be useful as diagnostic indicators of visceral or neuromusculoskeletal pathology, none of the studies whether old or recent, have
conducted sensitivity or specificity analysis, and thus as yet, their use as diagnostic indicators is unknown. If trophic changes were shown to be sensitive indicators of pathology they could be very useful in clinical practice to supplement the clinical assessment and diagnosis process. It is thus important that tests used in sensitivity studies are suitable for use in clinical practice otherwise such tests are of limited value.

2.4 Mechanism of Trophic Changes
The studies discussed in section 2.2 have suggested several links between trophic changes and specific pathologies, as well as hypothesizing about the underlying mechanisms which exist. Wesselmann and Laï (1997) suggested a link between inflammation and the development of trophic changes following their work in uterine inflammation. Giamberardino et al, (2005) also noted that there was a significant difference in sensory and vasomotor trophic changes in those with a high number of painful gall bladder attacks, irrespective of gall bladder dysfunction, suggesting a link between trophic changes and pain rather than inflammation. The mechanisms underpinning these changes have rarely been investigated in specific trophic change studies, and thus the wider literature was drawn upon. The next section will discuss possible mechanisms thought to underpin trophic changes based on evidence from the wider literature under the heading of each trophic change.

2.4.1 Mechanism of Vasomotor Trophic Changes
Of all the vasomotor changes investigated, plasma extravasation has been studied most widely. Plasma extravasation has long been associated with inflammation and the triple response, typically injury results in an inflammatory process which is characterized by local vasodilation and extravasation of plasma into intercellular spaces. Plasma extravasation has also been associated with neurogenic inflammation (White and Helme 1985; Levine et al, 1985a).

The mechanism underpinning plasma extravasation has been identified as being mediated by a neural pathway following experimental research showing a correlation between plasma extravasation and electrical nerve stimulation (Brodin et al, 1981; White and Helme 1985). In a controlled animal study, White and Helme (1985) demonstrated that experimentally induced antidromic stimulation of the C fibres of
the rat sciatic nerve resulted in neurogenic inflammation, characterised by local vasodilation and plasma extrasvasation. Further studies also showed that Substance P appeared to be the main chemical mediator of neurogenic inflammation (along with calcitonin gene related peptide-CGRP) (McDonald et al, 1996, Rossi and Johansson, 1998). On release, these chemicals act on local blood vessels, increasing blood flow and vascular permeability, thus contributing to the development of oedema and plasma extravasation (Basbaum and Jessell, 2000; Daeman et al, 1998, McDonald et al, 1996).

Levine et al, (1986) found that all categories of nerve fibres were involved in the development of plasma extravasation not just C fibres. Levine et al, (1986) investigated experimentally induced arthritis in rats measuring both plasma extravasation and joint arthritic changes. In this study, 76 rat paws were used (actual number of rats not given), compared with 60 control paws, and given an injection of adjuvant (mycobacterium) into the knee joint. Prior to the injection the animals were divided into several groups and underwent a variety of procedures to attenuate the resulting experimental arthritis to determine which mechanism contributed most to these changes. The procedures included; administration of the neurotoxin capsaicin to neonatal rats (which destroys the dorsal root ganglion and thus eliminates the central and peripheral branches of the primary afferent nerves) (Gamse et al, 1981), sympathectomy with guanethidine or reserpine (destroys sympathetic fibres), and surgical deafferentation of the hind limb (which destroys central afferents but leaves the peripheral branches intact).

Following the interventions, rats in the experimental groups were examined and compared to a control group for signs of tenderness, experimental arthritis (x-ray used) and plasma extravasation/oedema (by measuring the amount of swelling produced with callipers). X-ray for arthritic changes was interpreted using a blinded examiner, and a grading system on a 0-3 scale of severity. No evidence of reliability analysis or interpretation criteria was discussed and therefore the results must be interpreted with this in mind. The results of the study showed that there was no single class of nerve fibre responsible for neurogenic inflammation in experimental arthritis, with large and small diameter afferents, sympathetic efferents and central spinal circuits all contributing to joint inflammation and plasma extravasation in rats.
Sympathectomy with guanethidine or reserpine was shown to be the most profound way of attenuating signs of experimental arthritis and plasma extravasation, and therefore the authors suggested that the sympathetic nervous system is a significant mediator in the development of plasma extravasation. (However it must be acknowledged that these changes are primarily related to experimental arthritis, and though this may be relevant for the present research study, it may not be relevant for all trophic change plasma extravasation such as that from visceral pathologies).

One study has also investigated the underlying mechanism of vasomotor changes including plasma extravasation and axon flare in human subjects with a past history of complex regional pain syndrome (CRPS). In a controlled study, Leis et al, (2004) investigated whether electrical stimulation of C fibres resulted in plasma extravasation and circulatory change on the unaffected side of 12 patients (9 upper and 3 lower limbs used) in comparison to 12 control group subjects. Following the intervention, researchers found that there was an increase in the flare response (vasodilation) in the affected and unaffected limb (detected by laser Doppler flowmetry) suggesting that the mechanism underpinning vasomotor changes, even in the contra-lateral limb may be connected with C fibre stimulation. However though there was an increase in blood flow, plasma extravasation (measured by blue dye and photometric analysis) was only found in the affected (not unaffected) limb, which led to conclusions that in pathology such as complex regional pain syndrome, plasma extravasation (but not axon flare) is mediated by a local neurogenic mechanism. Interestingly these findings are somewhat contradicted by previous work of Levine et al, (1985c). In this study the researchers demonstrated a central mechanism for spatially remote plasma extravasation following an experiment in which electrical stimulation of rat cutaneous afferents increased vascular permeability in the contra-lateral limb. Though Leis et al, (2004) had found only local mechanisms important in mediation of plasma extravasation, this work thus suggests that central or spinal mechanisms may also contribute.

In a recent review article, Levine et al, (2006) also identified that several factors may influence the control of the inflammatory and plasma extravasation response, which may influence the existence of trophic changes in different populations. For example
it has also been shown that stress and pain have a negative feedback effect on the ongoing inflammatory and plasma extravasation response (Khasar et al, 2005), and that co-existing inflammation in another part of the hind paw has a negative feedback effect on plasma extravasation (Green et al, 1995), [again dependent on the sympathetic terminals (Green et al, 1997)]. These findings suggest that populations with different types of inflammatory or painful pathologies may have different levels of vasomotor changes. Green et al, (2005) also identified differences in plasma extravasation in male and female rats suggesting that trophic changes may vary depending on the gender of the test groups.

2.4.2 Mechanism of Sensory Trophic Changes

As described in section 2.1, mechanical hyperalgesia is another symptom which may be categorized as a trophic change. Hyperalgesia to mechanical stimuli has been reported to accompany many conditions such as fibromyalgia (Staud et al, 2001), visceral inflammatory conditions (Frokjaer et al, 2005) complex regional pain syndrome (Leis et al, 2004) and osteoarthritis (Bajaj et al, 2001). It is reported to have primary and secondary components, with primary hyperalgesia defined as that which occurs at the site of tissue damage, while secondary hyperalgesia is that which occurs in the uninjured skin surrounding the injury (Lewis 1942). The mechanisms for the development of primary and secondary hyperalgesia are different. Primary hyperalgesia is thought to be due to a peripheral neural mechanism, where as secondary hyperalgesia is thought to be underpinned by a central neural mechanism-central sensitisation (Meyer et al, 1994), and it has been suggested that central sensitisation may be the mechanism which underpins hyperalgesic trophic changes (Giamberardino et al, 2005).

Central sensitisation is the term used to describe an increase in the excitability of spinal cord neurones (Woolf 1994), which has been shown experimentally by activating cutaneous and muscular, C fibre afferents (Wall and Woolf 1984; Woolf and Wall 1986). These afferents produce slow excitatory synaptic potentials which summate resulting in the unmasking of a receptor (called the NMDA receptor) which is normally blocked until certain conditions are satisfied (Dickenson 1999). The NMDA receptor is unique in that opening is dependent on membrane voltage as well as the chemical transmitter (Mayer et al, 1984), and once these conditions are met,
the NMDA receptor is exposed and can combine with transmitter substances which results in the dorsal horn cells becoming hypersensitive to incoming noxious information, (Dickenson and Sullivan, 1987; Dickenson and Besson, 1997; Dickinson et al 1991; Woolf and Thompson, 1991; Price et al, 1994). The unmasking of the NMDA receptor allows the post-synaptic cell to produce much larger responses to a normal input, and to express previously weak or relatively ineffective inputs. This can result in altered, prolonged, enhanced (hyperalgesia) or referred pain symptoms (Woolf 1994; Johnson, 1997).

The mechanism for the development of central sensitisation has been studied by several authors in both animals and in humans. Woolf and Thomson (1991) investigated the mechanism by blocking the NMDA receptor in the dorsal horn with NMDA antagonists in in-vitro preparations. Others investigated the mechanism by blocking the temporal summation evoked by electrical stimulation of C fibre afferents in in-vivo preparations without reducing the responses of other fibres such as A-delta fibres (Dickenson and Sullivan 1987; Dickenson et al, 1991).

Price et al, (1994), investigated the mechanism by studying the effects of NMDA blockade in human subjects exposed to experimentally induced pain which had been mediated by C fibre stimulation (commonly called second pain to distinguish its mechanism from that of fast immediate pain thought to be initiated by A-delta activation) (Price et al, 1977). Price et al, (1994) conducted a small controlled experiment using 6 normal male volunteer subjects who were exposed to noxious heat and noxious electrical stimuli, however 2 of the subjects were authors of the paper which may suggest some bias. The NMDA receptor antagonist was given orally in several different dose forms (including a control dose) and on several different days in what is described but not evaluated as ‘quasi-random’ order. 3 doses were given on a double blind basis but whether the authors were also given double blind doses is not accounted for. The visual analogue scale was used as an outcome measure and it was shown that the NMDA receptor antagonist reduced temporal summation of electrically and thermally evoked second pain in a dose dependent manner in humans. The effects of the NMDA receptor were selective as the experiment showed that the A-delta fibres responsible for ‘first pain’ had not been affected (which mirrors previous animal study findings).
Central sensitization has not yet been demonstrated to exist for long periods of time in experimental conditions, and therefore it is thought that other mechanisms may also influence the development of hyperalgesia such as A-beta fibre sprouting (Nakatsuka et al, 1999). In a controlled animal study (number of rats not given), inflammation in the hind paw was experimentally created with injection of mycobacterium, which produced a persistent peripheral inflammation characterised by oedema (measured by callipers), and mechanical hyperalgesia measured by von Frey hairs. Following inflammation, the dorsal root ganglia of the experimental group were isolated and compared to the dorsal root ganglia in control rats. On analysis, a change in synaptic responses was observed with a decrease in A-delta monosynaptic inputs into the substantia gelatinosa, and an increase in A-beta monosynaptic afferents (33%). Conclusions from this work suggest that re-organisation of the dorsal horn may also be a factor in the development of hyperalgesia, particularly in cases of inflammatory pathology.

2.4.3 Mechanism of Motor Trophic Changes

Motor trophic changes are the least well studied of the 3 sub-groups of trophic changes discussed, and mechanisms underpinning muscle spasm or motor changes are not well understood. Following their research Gunn and Milbrandt (1978) hypothesised that denervation supersensitivity could explain the existence of motor and vasomotor trophic changes such as muscle spasm or subcutaneous oedema. Denervation supersensitivity is characterised by the denervated structure becoming more sensitive to circulating chemicals such as acetyelecholine or noradrenalin. Increased sensitivity has been shown to occur due to an increase in receptor sites in the denervated structure (Axelsson and Thelseff 1959). This physiological phenomenon has been observed in many animal studies, in both smooth and skeletal muscle, with receptor sites which are normally only found at the end plate, spreading across whole the muscle fibre, leading to an increase in the muscular response (Axelsson and Thelseff 1959; McConnell and Simpson 1976; Merlie et al, 1984; Cangiano 1985).

However despite numerous animal studies demonstrating denervation supersensitivity over the last 50 years, few human studies were found which have
measured the number of receptors following denervation. One small, non-randomized and non-blinded study measured the number of alpha receptors in 8 patients with sympathetic denervation (compared to 5 control), and found an increase in the number of receptors (Davies et al., 1982). However unfortunately the findings were not correlated to trophic change symptoms such as blood flow or spasm and therefore this theory remains unsubstantiated as a mechanism for the development of motor or vasomotor trophic changes. No other mechanism for the development of muscle spasm or motor trophic changes has been proposed.

One further complication with regards to motor trophic changes is that reviews of the wider literature have shown that questions have been raised about whether muscle spasm exists at all. In 1966, De Vries suggested that pain led to the development of muscle spasm, and outlined a phenomenon called the pain-spasm-pain cycle. Since then several authors have tried to investigate the existence of muscle spasm primarily through surface and needle electromyography, however conclusions as to whether to, or how to, measure muscle spasm, are still somewhat unclear. The difficulties with the measurement of motor trophic changes and muscle spasm will be discussed further in the method section 3.4.3 page...

2.5 Reversal or Attenuation of Trophic Changes
The review so far has focussed on the identification of the existence of trophic changes (for use as indicators of pathology) rather than on the effects of interventions or treatments on their existence. One study, (which has only been considered in abstract form as it is published in Italian), has however investigated the effects of topically applied heparin-glucuronylglucosaminoglycane on trophic changes, in a double blind placebo-controlled trial in 20 female subjects with painful, osteoarthritis of the knee (n=10 in control group, n=10 in experimental group) (Dragani et al., 1992). (Heparin-glucuronylglucosaminoglycane is a chondroprotective drug with anti-inflammatory properties used in osteroarthritis). Subcutaneous and muscular pain thresholds were assessed (by electrical stimulation), along with subcutaneous and muscle tissue thickness (assessed by ultrasound). Measurements were taken at baseline then one, two, and three weeks after treatment with the drug or placebo. Subcutaneous and muscular pain thresholds were shown to be increased as early as 1 week after treatment, subcutaneous tissue thickness was significantly decreased two
weeks after treatment and in the same period a statistically significant increase in the thickness of the vastus medialis muscle was also noted. No such changes occurred in the placebo-controlled group. In the abstract the authors suggest that the peripheral control of inflammation and the resultant reduction in pain may be a possible underpinning mechanism for these changes.

The evidence of Wesselmann and Lai (1997) linking vasomotor trophic changes and inflammation, and the study by Nakatsuka et al. (1999) which linked persistent dorsal horn changes following inflammatory pain and hyperalgesia, both show a link between trophic changes and inflammation. It is possible that a reduction in inflammation may well lead to reduced trophic changes, however apart from Dragani et al. (1992) no studies have investigated the effects of commonly used anti-inflammatory agents such as cortico-steroids or non steroidal anti-inflammatory drugs on trophic changes in humans. It is possible that trophic changes could not only provide diagnostic information but could also be useful indicators of inflammatory recovery. Therefore as will be identified below the second part of this experiment aims to investigate whether trophic changes are affected by administration of corticosteroid.

**2.6 Summary and Aim of the Research**

In summary, this chapter has reviewed the previous studies which pertain to the measurement of trophic changes, with studies in visceral, musculoskeletal and radicular pathology. In the main it has been shown that the quality of the studies, particularly in the musculoskeletal field, is poor. Despite claims that trophic changes are sensitive indicators of pathology, it has been shown that none of the studies have investigated sensitivity or specificity and thus these claims cannot be substantiated. Furthermore links to pathology are also unclear, experimental evidence has shown a link between vasomotor trophic changes and inflammation, which has been shown to be underpinned by all classes of afferent neurones particularly sympathetic, whereas general pain research has shown a link between hyperalgesia, central sensitisation, increased C fibre activity and dorsal horn changes. Finally it has been shown that investigations into treatment effects on trophic changes have so far been very limited. The reduction of hyperalgesia and subcutaneous thickness has been shown with topical application of heparin-glucuronylglucosaminoglycane, however no other
studies into the effects of pain relieving or anti-inflammatory medication have been conducted.

These findings have demonstrated that evidence of the existence and sensitivity of trophic changes in the neuromusculoskeletal field is lacking. If these changes are to be useful as indicators of pathology, pain or inflammation, they need to be able to be detected in clinical practice so that if they are shown to be sensitive they can be used widely. The lack of investigation into the effects of treatments such as anti-inflammatory or analgesic medicines on trophic changes demonstrates another area worthy of investigation as these findings may provide information regarding recovery.

As the literature has shown that there has been little investigation in the neuromusculoskeletal field, this research will focus on changes in subjects with upper limb and cervical pathology as these have not been investigated in any trophic change study. As cervical radiculopathy and frozen shoulder are conditions which have been noted as being significantly painful (Codman 1934; Middleditch and Jarman 1984; Bunker 1998), relatively common (Wainner and Gill 2000; Ostor et al, 2005), and difficult to diagnose (Date and Gray 1996), these conditions will be selected for study. Both C5 cervical radiculopathy and frozen shoulder refer into the C5 segment, and therefore subjects with these two conditions will be investigated. The changes to be investigated will be those that have been identified as part of the family of trophic changes discussed at the beginning of this chapter and thus include one change from each vasomotor, sensory and motor sub group.

The study aims to:
1. Determine whether clinical tests of vasomotor, sensory and motor trophic changes were sensitive indicators of frozen shoulder and cervical radicular pathology.

2. Determine the effects of cortico-steroid injection on trophic changes in frozen shoulder.
Research Questions
1. Are clinical measures of trophic changes sensitive indicators of frozen shoulder or cervical sensory radiculopathy?

2. Can cortico-steroid shoulder joint injection reduce trophic changes in frozen shoulder detected by clinical tests?

Research Hypotheses
1. There will be a significant difference between trophic changes detected in frozen shoulder and cervical radiculopathy when compared to a control group (vasomotor changes and sensory changes will be increased on the affected side, motor changes will be reduced on the affected side).

2. Trophic changes will be sensitive indicators of frozen shoulder pathology but not cervical radicular pathology.

3. There will be a significant difference in trophic changes in subjects with frozen shoulder following an injection of cortico-steroid into the shoulder joint (vasomotor and sensory changes will be reduced, and motor changes will be increased on the affected side following injection).

2.7 Intended Outcomes of the Research
It is hoped that the information gained from this study will add to the body of knowledge concerning the existence of trophic changes in neuromusculoskeletal pathology and whether these changes are affected by the use of anti-inflammatory medication. This information may add to the knowledge concerning the types of pathology in which trophic changes are found.

It is hoped that the study will provide information concerning whether trophic changes can be detected by simple tests which can be used widely in clinical practice and whether these changes are sensitive indicators of the pathology investigated such that they may assist with clinical diagnosis of shoulder and cervical dysfunction.
Table 2: The Quality of Studies which have Investigated Trophic Changes. The JADAD quality measurement tool has been used.

<table>
<thead>
<tr>
<th>Study</th>
<th>Quality Measurement with JADAD Scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giamberardino et al, (2005)</td>
<td>Non randomized, Non blinded, No explanation of dropouts</td>
<td>0/5</td>
</tr>
<tr>
<td>Wesselmann and Lai (1997)</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Vecchiet et al, (1990)</td>
<td>Non randomized, Non Blinded, No explanation of drop outs</td>
<td>0/5</td>
</tr>
<tr>
<td>Galletti et al, (1990)</td>
<td>Non randomized, Non Blinded, No explanation of drop outs</td>
<td>0/5</td>
</tr>
<tr>
<td>Gunn and Milbrandt (1978)</td>
<td>Randomized (procedure not described), Non blinded, No explanation of dropouts</td>
<td>1/5</td>
</tr>
</tbody>
</table>

Table 3: The Descriptors used in the JADAD Scale for Quality Assessment

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Yes=1 No= 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Was the study randomized</td>
<td></td>
</tr>
<tr>
<td>2. Was randomization described and appropriate</td>
<td></td>
</tr>
<tr>
<td>3. Was the study double blinded</td>
<td></td>
</tr>
<tr>
<td>4. Was Blinding described and appropriate</td>
<td></td>
</tr>
<tr>
<td>5. Was there a description of drop-outs?</td>
<td></td>
</tr>
<tr>
<td>Maximum total score</td>
<td>5</td>
</tr>
</tbody>
</table>
CHAPTER 3

METHOD

Introduction

This was a non-randomized controlled study which took place in Eastern Birmingham Primary Care Trust (with pilot work conducted in South Birmingham and Bristol South and West Primary Care Trusts). It was carried out in 2 experiments, the first aimed to investigate the diagnostic sensitivity of trophic changes which can be used in clinical practice, in cervical sensory radiculopathy and frozen shoulder. The second study aimed to investigate the effect of corticosteroid on trophic changes in subjects with frozen shoulder, 4 weeks following intra-articular shoulder injection.

The method chapter is organised such that the context and background to the research is outlined in section 3.1. The participants used in study 1, the inclusion and exclusion criteria and the ethics procedure are then described in section 3.2. Section 3.3 covers an in depth analysis and justification of the alternative methods for each of the 3 outcomes to be investigated. Section 3.4 describes the equipment selected for this study which includes the modified matchstick test, pressure pain rating with the numerical rating scale and surface electromyography. These methods were used to investigate vasomotor, sensory and motor trophic changes respectively. The pilot study work which led to the development of these methods and the reliability analysis of each outcome is also described. The procedure for the main experiment is detailed in section 3.5, the methods for each outcome are identical to those used in the reliability testing and are included in this section only, to avoid repetition. The subject recruitment, ethics process and study procedure for study 2 is described in section 3.6 and the data and statistical analysis for both studies is discussed in section 3.7.

3.1 The Research Context

As discussed in the literature review, trophic changes have been investigated in visceral, osteoarthritic and radicular pathology, however the existence and sensitivity of trophic changes in the upper limb and cervical spine has not been studied. The shoulder and cervical spine were chosen for investigation as it has been identified
that these conditions can be difficult to differentially diagnose (Date and Gray 1996). The incidence of cervical radiculopathy and frozen shoulder have been estimated to be around 3.3 cases (Wainner and Gill 2000) and 1.425 cases (Ostor et al, 2005) per 1000 respectively which is much lower than back pain (estimated at 44 cases per 1000, Kopec et al, 2004) but of greater incidence than diseases such as rheumatoid arthritis (estimated at 0.31 cases per 1000, Hanova et al, 2006). Thus though the incidence of cervical radiculopathy and frozen shoulder is not as great as other musculoskeletal pathologies, these conditions still make up a significant number of conditions seen by musculoskeletal specialists and investigation in this area is therefore justified.

If trophic changes were found to be sensitive indicators of pathology it is important they could be used widely in clinical practice. Therefore the methods employed in this study needed to be portable, simple to use requiring minimal training, and where possible be of low cost so that they could be taken up easily by clinicians. The literature review demonstrated that previous studies which have investigated trophic changes have measured them in the area to which pain refers. Therefore in this study it was deemed appropriate to measure trophic changes in the area to which frozen shoulder and cervical radiculopathy refer pain. C5 sensory radiculopathy and frozen shoulder both refer pain into the C5 dermatome, therefore this area was selected in which to measure trophic changes (thus only C5 cervical radiculopathy patients were used).

The second part of the study aimed to investigate whether trophic changes were affected by cortico-steroid injection. The experimental evidence suggests that the existence of trophic changes is related to inflammation and it is possible that if trophic changes are shown to be altered by steroid medication, they could not only provide diagnostic information, but could also be useful indicators of recovery. As frozen shoulder is a condition of inflammatory aetiology often treated by cortico-steroid injection this group was chosen for this study.

3.2 Research Participants, Recruitment, Consent and Ethics

Ethical approval was granted by the West Birmingham Local Research Ethics Committee (pilot study Ethics approval granted by the South West Local Research
Ethics Committee). All subjects gave informed consent (see information leaflets and the consent form used in appendix A1 pg...). The research participants were drawn from General Practice referrals to a musculoskeletal Physiotherapy Department. For experiment 1, subjects were recruited into 2 experimental groups, group 1 –the cervical radiculopathy group, and group 2 –the frozen shoulder group. Control subjects were recruited and matched for age and gender. For experiment 2 subjects were recruited from the pool of participants in experiment 1 with frozen shoulder and compared to the control group. Recruitment of subjects was not randomized because difficulties in obtaining the required sample size prevented this method (though it is acknowledged that this would have been superior). However subjects were recruited consecutively from referrals from a wide range of GP practices (90 in total) without prior selection. Prior to the main experiment, reliability of the equipment for each outcome used was tested with 20 subjects from the control group.

3.2.1 Sample Size and Power Analysis

Previous unpublished data (from PhD pilot work 2005) had shown that the scores for most outcomes and groups tested were not of a normal distribution. The power and sample size calculations for this study were based on the assumption that non parametric statistics would be used in the analysis because the data was unlikely to be normally distributed (given previous pilot results), and the majority of data was of an ordinal nature. The sample size calculations for this study were carried out by the Heart of England NHS Trust Statistician, R Holder. They were specifically tailored for a non parametric analysis using NQUERY (version 5.0), a specialist software for sample size calculations. The method used was based on that recommended by Noether (1987) for common non-parametric sample size determination.

For experiment 1 the calculations showed that using a 5% significance test with an effect size of 1 (exact calculation 0.93), a sample size of 31 would be sufficiently large to ensure that there was a 90% probability (power) of rejecting a false null hypothesis, (i.e. that there would be an 90% probability of correctly detecting those cases whose result is significant).

For experiment 2, the calculations showed that using a 5% significance test with an effect size of 2, a sample size of 17 would be sufficiently large to ensure that there
was an 80% probability of rejecting a false null hypothesis (using a Wilcoxon Test for analysis).

Based on these findings a total 93 subjects were recruited into study 1, n=30 for the control group, n=31 for the cervical radiculopathy group and n=32 for the frozen shoulder group. Subjects were also matched to the control group for age and gender, and the number of subjects per gender per group is shown in the table 4. In experiment 2, 17 frozen shoulder subjects were recruited for injection and compared to 30 control subjects. 10 further subjects with frozen shoulder who declined injection were recruited as an extra control (named the non injection group). The number of male and female subjects in the injection and non injection groups in experiment 2 is also shown in table 4. 5 subjects dropped out of experiment 2. Specific reasons were not given.

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td>13</td>
<td>17</td>
<td>30</td>
</tr>
<tr>
<td>Cervical Radiculopathy Group</td>
<td>14</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Frozen Shoulder Group</td>
<td>14</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Injection Group</td>
<td>7</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Non Injection Group</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

### 3.2.2 Inclusion Criteria

A summary of the inclusion/exclusion criteria for all groups can be seen in table 6.

**a) Cervical Radiculopathy Group**

The inclusion criteria for the cervical radiculopathy group had to be developed for this study because no definitive diagnostic criteria exists (Carette and Fehlings 2005; Wainner and Gill 2000; Radhakrishnan et al, 1994; Dillin et al, 1986). Experimental studies which document the clinical signs of radiculopathy are scarce, and evidence tends to be drawn from clinical experience or personal opinion (Radhakrishnan et al, 1994).
Therefore a pilot study was used to determine the most common symptoms in patients referred with C5 cervical sensory radiculopathy. Physiotherapy referrals from 10 general practitioners were examined over a 3 month period. The first 10 referrals with diagnostic labels of 'C5 cervical nerve compression', 'C5 trapped nerve', 'C5 brachial nerve root irritation', 'C5 cervical radiculopathy', C5 cervical spondylosis, were identified consecutively from the referral centre and marked so that extra details could be obtained during their first assessment. Each patient was given an appointment with the study operator, and the presence of common signs and symptoms which have been associated with cervical radiculopathy (listed in table 5) were documented. It is important to note that these signs and symptoms have not been determined experimentally, rather over time, these signs and symptoms have been suggested to be indicative of cervical radiculopathy and have become accepted by clinicians.

Table 5: Common Signs and Symptoms Associated with Cervical Radiculopathy

<table>
<thead>
<tr>
<th></th>
<th>Common Signs and Symptoms of Cervical Radiculopathy</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pain referral pattern in the affected dermatome/myotome</td>
<td>(Kellgren 1939; Cyriax 1983)</td>
</tr>
<tr>
<td>2</td>
<td>Pain elicited by cervical movements of side flexion or rotation</td>
<td>(Wainner et al, 2003)</td>
</tr>
<tr>
<td>3</td>
<td>Sensory changes of parasthesia and anaesthesia</td>
<td>(Hardy and Plank 1982)</td>
</tr>
<tr>
<td>4</td>
<td>Reflex loss and myotome weakness</td>
<td>(Dyck and Thomas 1982)</td>
</tr>
<tr>
<td>5</td>
<td>Presence of pain on palpation of the affected spinal segment</td>
<td>(Maitland 1986)</td>
</tr>
</tbody>
</table>

The results from the pilot study were compiled and tabulated (see appendix A1, tables A1.1-A1.3). In summary, all subjects had pain in the C5 dermatome, 5 out of 10 had cervical pain on rotation towards the affected side, and two had pain when side flexing away, consistent with Wainner et al. (2003). None of the patients examined in the pilot study had reflex loss or discernable myotome weakness, and 1
subject had parasthesia and anaesthesia. Only 1 subject had pain on palpation of the C5 cervical segment alone. (9 subjects had pain on palpation of all segments).

The inclusion criteria was therefore based on the findings of the pilot study and is shown below, subjects had to have all 3 symptoms.

- Pain initiated or aggravated by cervical rotation towards and/or cervical side flexion away from the affected side (Wainner et al, 2003)
- Referred pain into the C5 dermatome, which had originated in the cervical spine (Kellgren 1939; Cyriax 1983)
- Pain as a consequence of palpation of the cervical spine inter-vertebral joints (Maitland 1986).

As the other sensory and motor signs were not commonly found they were not included in the inclusion criteria.

b) Frozen Shoulder Group

Frozen shoulder is another condition for which a clear diagnostic criteria does not exist. Frozen shoulder is a term which describes a shoulder condition of unknown aetiology, which is characterized by a number of shoulder symptoms first described by Codman (1934). These descriptions arose from clinical observation and they have not been demonstrated experimentally, nor has sensitivity analysis been conducted. However they are widely used in physiotherapeutic and orthopaedic medicine and they form the basis of descriptions used by other authors such as (Cyriax 1983). The inclusion criteria for frozen shoulder (based on Codman 1934) is listed below, subjects should have all of the signs and symptoms:

- Gradual onset of ‘trying’ pain
- Shoulder pain referring into the deltoid with little local tenderness
- Inability to sleep on the affected side
- Painful and incomplete elevation and external rotation
- Passive and active restriction of movement

A more recent addition to the criteria came from Cyriax (1983) (again from clinical observation rather than experimental work). Cyriax (1983) stated that movement
restriction in a capsular pattern also exists in frozen shoulder not just loss of lateral rotation and elevation. However as there have been questions raised over the reliability of the capsular pattern (Rundquist et al. 2003), this has not been included in the criteria. In the original frozen shoulder criteria (Codman 1934), atrophy of the spinati was also suggested to be a sign of frozen shoulder. However as Bunker (1998) has questioned the existence of this sign in frozen shoulder it has also been omitted from the criteria.

Control Group
Subjects in the control group were matched in age and gender to the experimental groups (see further rationale for matching in section 3.4.2 pg.).

3.2.3 Exclusion Criteria for all Groups
- Subjects with a history systemic joint disease (such as rheumatoid arthritis or ankylosing spondylitis) were excluded because systemic arthritic conditions may cause swelling which could lead to false positive results in the modified matchstick test.

- Subjects with recent traumatic neck injury or shoulder injury (particularly soft tissue trauma) in the last 12 months were excluded because resultant local swelling could lead to an increased number of false positive results in the modified matchstick test.

- Subjects with co-existing shoulder or upper limb pathology were excluded from the cervical and control groups and subjects with co-existing cervical pathology were excluded from the shoulder and control groups.

- For all groups, subjects were excluded if they were under 18 years old or pregnant (due to consent issues and systemic changes respectively).

- Subjects who demonstrated significant red flag pathology (such as unexplained weight loss over 5% of body weight, signs of systemic infection,
drop attacks, speech and swallowing problems, significant dizziness) were excluded from all groups and managed appropriately.

**Table 6: Inclusion and Exclusion Criteria for All Groups**

This table summarises the inclusion and exclusion criteria for all groups

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria All Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cervical Radicular Group</strong></td>
<td></td>
</tr>
<tr>
<td>1. Pain initiated or aggravated by cervical rotation towards and/or cervical side flexion away from the affected side</td>
<td></td>
</tr>
<tr>
<td>2. Referred pain into the C5 dermatome, which had originated in the cervical spine</td>
<td></td>
</tr>
<tr>
<td>3. Pain as a consequence of palpation of the cervical spine inter-vertebral joints</td>
<td></td>
</tr>
<tr>
<td><strong>Frozen Shoulder Group</strong></td>
<td></td>
</tr>
<tr>
<td>1. Gradual onset of ‘trying’ pain</td>
<td></td>
</tr>
<tr>
<td>2. Shoulder pain referring into the deltoid with little local tenderness</td>
<td></td>
</tr>
<tr>
<td>3. Inability to sleep on the affected side</td>
<td></td>
</tr>
<tr>
<td>4. Painful and incomplete elevation and external rotation</td>
<td></td>
</tr>
<tr>
<td>5. Passive and active restriction of movement</td>
<td></td>
</tr>
<tr>
<td><strong>Control Group</strong></td>
<td></td>
</tr>
<tr>
<td>Subjects with no shoulder or cervical pathology were recruited into the control group matched in age and gender to the experimental groups</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Consideration of Alternative Methodology

As 3 separate outcomes were measured in this study (i.e. vasomotor, sensory and motor) this section is split into 3 parts which identify the alternative methodologies which were considered for use in this study.

3.3.1 Methods to Investigate Vasomotor Changes

As identified in the literature review, in previous trophic change studies, vasomotor changes were investigated indirectly by measurement of the flare and plasma extravasation response, as well as by measuring subcutaneous oedema and alterations of skin texture. Despite these tests being cited in several papers, reliability has not been investigated. The use of plasma extravasation methodology may also require that clinicians gain advanced skills for administration of blue dye which reduces the suitability of this method for widespread use in clinical practice. The invasiveness of dye injection and the associated risks such as bleeding or infection, also raise the risk of this method beyond its diagnostic benefit in musculoskeletal practice and therefore it was considered unsuitable for this study.

In the general literature a variety of methods and equipment have been used to determine vasomotor changes, however, a gold standard test for use in clinical conditions has not been identified so far. One of the most reliable and valid methods that has been used to quantitatively measure vasomotor function is laser Doppler flowmetry (LDF) (Caspary et al, 1996; Bircher et al, 1993; Nilsson et al, 1980). The underlying principle is based on the change in frequency which occurs in light beams when they are directed on to moving red blood cells in comparison to the unshifted frequency which occurs when the beam is directed towards static tissue. Nilsson et al, (1980) investigated the validity of LDF by measuring its performance using a fluid model in which the red cell velocity, concentration and oxygen content could be controlled. They found that the signal output measured, increased proportionally to the red cell volume and flow velocity indicating its validity to measure change in blood flow. Reliability measurements of LDF were not clearly reported in the study and therefore assurance regarding reliability of this tool could not be made from this early work. Consistent blood flow changes in response to temperature changes were reported, but it is unclear from the method or results, how many measurements were taken during this part of the study.
On further analysis of the literature, very few clinical studies have tested the reliability of laser Doppler flow, though a variety have used LDF to measure blood flow. For example Sumikura et al. (2003) used LDF to measure the correlation between neurogenic inflammation and hyperalgesia, Karason and Drysdale (2003) used LDF in a small non-randomized study measuring dermatomal blood flow changes before and after high velocity, low amplitude, spinal manipulation, and Lofgren et al. (2001) measured lumbar skin blood flow changes before and after posterior or anterior cervical spinal decompression. However none of these studies reported reliability testing of the equipment used.

Though less specific to the research of this study, short term reliability analysis was reported by Iwao et al. (1993) who investigated LDF of gastric mucosal blood flow in 32 subjects (12 control, 20 with liver cirrhosis). Four measurements were recorded in 10 minute intervals by 2 blinded observers. The intra-class correlation coefficient was used to assess observer agreement showing intra and inter-observer agreement to be 0.87 and 0.86 respectively, demonstrating a high to excellent reliability for the 2 examiners (using the Landis and Koch (1977) scale, see appendix A1.3 pg ...). The coefficient of variation was more variable with average and maximum values of 12% and 35% respectively for examiner 1, with similar levels being reported for the second examiner. Despite the relatively high levels of reliability, the authors concluded that ‘although the reproducibility of laser Doppler flowmetry was clinically acceptable, it appeared to be a subjective experimental measurement tool in this area’ and thus it seems that reliability in each specific situation should be tested. Unfortunately though LDF is one of the only tools reviewed for which reliability and validity has been shown, the use of this tool was prohibited in this study by the Electrical Service Department of the NHS Trust involved, on the grounds of ‘concerns over equipment maintenance, insurance and safety’ and therefore other methods had to be considered.

Thermography is also a method of indirectly measuring vasomotor changes by the temperature response that results from changes in blood flow. In a literature review, Plaugher (1992), concluded that generally studies investigating the reliability of thermography were scarce and often poorly conducted, which questions the
appropriateness of thermography as an outcome measure for this study. However a more recent study by Owens et al. (2004) assessed the intra and inter-observer reliability of thermography with 2 examiners in 30 asymptomatic subjects in a non-randomized and non-blinded study, and showed high levels of reliability for thermography. Unfortunately the lack of blinding reduces the value of these results, and it appears that further reliability analysis would be useful before conclusions regarding reliability can be firmly made. The Electrical Service Department was also contacted with regards to the use of thermography for a reliability pilot study, however again this was refused on the grounds of maintenance, insurance and safety.

The fact that both LDF and thermography were prohibited in this study, and the finding that other methods previously used lacked validity, reliability, and suitability for use in a clinical study, demonstrated that there was a need for the development of a new method of measuring vasomotor changes, which was suitable for clinical practice. Most previously used tests of vasomotor activity such as skin observation were difficult to modify in conjunction with valid or reliable measurement tools and were thus rejected. However the matchstick test used by Gunn and Milbrandt (1978) to measure subcutaneous oedema (indirectly through the delivery of compression to the skin) was considered highly suitable to adaptation so that it could be used in combination with algometry or similar valid pressure measurement. This ‘modified matchstick test’ was considered ideal for this study because it had the advantage of portability and simplicity, and could be conducted easily in a variety of clinical environments with little training required for use or interpretation. The test development and reliability analysis can be seen in the next section 3.4.

3.3.2 Methods to Investigate Sensory Trophic Changes

As identified in Chapter 2, the only sensory trophic change to be investigated in studies specifically investigating trophic changes was hyperalgesia. The hyperalgesic response to manual palpation (Giamberardino et al. 2005; Gunn and Milbrandt, 1978), and to electrical stimulation (Giamberardino et al. 2005) have both been reported. Unfortunately, as with many of the vasomotor tests used, manual palpation lacks standardization and known force measurement. On searching the general literature to determine reliable and valid measures of hyperalgesia testing, pressure algometry and electric stimulation were the most commonly cited methods,
and both are said to be valid (Fischer 1987a; Sang et al, 2003). However it must be noted that the measurement of hyperalgesia with either electrical stimulation or pressure algometry is dependent on the patient’s subjective experience which is in turn influenced by the cultural, cognitive and emotional perspectives of those being tested (Kosek et al, 1993; Janal et al, 1991).

Electrical stimulation has been shown to be a reliable tool to measure pain threshold, though many less reliability studies have been conducted than in pressure algometry. Sang et al, (2003) investigated the stability and reliability of electrical stimulation using monopolar, constant-current rectangular pulses, delivered on 3 separate occasions to 5 equi-spaced sites on the anterior aspect of the left forearm along a transverse line, 5cm distal to the cubital crease. The results showed that no significant differences were recorded on repeated tests or at different sites demonstrating reliability of repeated measures and consistency in pain reporting at different sites. These results show that electrical stimulation could be used to determine hyperalgesia in a clinical setting such as in this study, however it has the disadvantage that it requires more staff training than pressure algometry, as well as the fact that some of the associated equipment (such as oscilloscope to determine wave shape) is also less portable and thus less satisfactory for clinical studies. Pressure algometry has also been shown to be a reliable and valid tool to measure pressure pain (Fischer 1987a). As it is more simple to use and more portable than electrical stimulation it was considered more suitable for the clinical environment. It was thus selected to determine sensory trophic changes in this study. The equipment used and the reliability analysis are discussed in section 3.4.2 pg...

3.3.3 Methods to Investigate Motor Trophic Changes

The literature review identified that muscle spasm has been the only motor trophic change previously investigated (Gunn and Milbrandt 1978; Giamberardino et al, 2005), however there is no consensus regarding the measurement of muscle spasm and even its existence is questioned. One in-depth review paper was found which attempted to define muscle spasm, highlighting the ambiguities between the terms muscle tension, muscle spasm and muscle tone (Simons and Mense 1998). The authors suggested that muscle spasm was defined as the ‘electromyographic activity of the muscle that is not under voluntary control and not dependent on posture’,
though they did not substantiate this definition with experimental evidence of electromyography (EMG) readings in subjects with muscle spasm. Thus according to this definition, muscle spasm is represented by the level of electromyographic activity within the muscle that is not under voluntary control, and as such ‘could be measured by the level of EMG activity’ implying that EMG should be measured at rest and without postural effort.

However earlier work by Jones et al, (1987) contradicts the suggestions made by Simons and Mense (1998). In their small, non-randomized, non-blinded, non-normalized experimental study (n=7), EMG and muscle stiffness of a painful bicep muscle were investigated following repeated eccentric contraction. They found that after the intervention, significant muscle stiffness occurred, but EMG levels measured at rest were electrically silent, suggesting that muscle spasm did not correlate with electrical activity at rest.

When reviewing the methods of other studies which have claimed to measure muscle spasm, both EMG at rest and during activity has been measured. For example Larsson et al, (1999) investigated ‘muscle spasm’ in a non-randomized, non-blinded, non-normalized study in 76 subjects, with surface EMG from the trapezius muscle, measured at rest and during muscle contraction following incrementally increasing static loads. In this study, measurements at rest did not reveal electrical silence as in the study by Jones et al, (1987), but they did appear to be very low, with no significant differences reported until higher levels of contraction were employed (exact values at rest not reported). In contrast using a randomized, non-normalized, double blind crossover design study (n=20) to determine the effects of muscle relaxants on muscle spasm, Bajaj et al, (2003) measured electrical activity with surface EMG during a maximum voluntary contraction rather than measuring electrical activity at rest. Though the results of this study are not applicable to this work, the method employed suggests that measuring changes in electrical activity during muscle contraction is more appropriate than measuring electrical activity at rest. Thus in summary, studies aiming to measure muscle spasm have either found no significant muscle spasm when measuring electrical activity at rest (Larsson et al, 1999; Jones et al, 1987) or have not measured muscle activity at rest (Bajaj et al, 2003).
The disparity between these experimental findings, and the theoretical definition of Simons and Mense (1998), suggests that use of the term muscle spasm is misleading, and it was considered more appropriate to use the term which represents the outcome being measured (i.e. electrical activity) rather than the term muscle spasm. Changes in electrical activity are representative of changes in the recruitment of motor units, which is one way of measuring changes in motor activity, (though the cause of changes in electrical activity cannot be clearly attributed and may include influence from peripheral, spinal or cerebral areas). Other methods of measuring motor activity may include strength evaluation with the oxford scale, dynamometry, or timed measurement of functional tasks. The use of the oxford scale was considered unsuitable for this study due to subjectivity and lack of validity. Unfortunately shoulder dynamometry equipment tends to be large to ensure thoracic stabilisation, and was therefore was not suitable for use in a clinical outpatient setting because of its lack of portability, (the cost was also prohibitive for this study). Small hand held dynamometers are portable and low cost, however their use around the shoulder was considered inappropriate, due to the lack of stabilisation. Time measured functional tasks were also considered inappropriate for this study as many patients would have significant pain on movement and therefore a test of relatively short duration was considered particularly important. Overall the measurement of electrical activity during muscular contraction was considered to be the most appropriate measure of motor trophic changes.

On searching the literature electromyography appears to be the primary measure of muscular electrical activity and has been considered a valid measure of electrical activity for many years, other methods of measuring electrical activity include motor evoked potentials, H Reflexes and F Waves. Motor evoked potentials (MEPs) and H reflexes are primarily measures of the velocity of motor nerve conduction rather than motor unit recruitment. MEPs are responses that can be recorded from the muscle after electrical or magnetic stimulation of the central nervous system or the proximal nerve root, and they primarily provide information about the conduction velocity of central or spinal motor pathways (Pascual-Leone et al, 2002; Wilbourn and Aminoff 1998). MEPs require a controlled environment as well as operator skill and specialist interpretation, such that MEPs were considered unsuitable for use as a clinical test to be employed in musculoskeletal clinics. The H reflex is also a
measure of nerve conduction and is indicated primarily in investigations of the spinal reflex loop (Clark et al, 2006; Fisher 2002; Pierrot-Deseilligny and Mazenet 2000; Burke et al, 1985; Troni et al 1983). Interestingly, although H reflexes are stable in adulthood, they are only commonly present in the soleus and forearm flexor muscles (Fisher 2002; Clark et al, 2006). Therefore the H reflex was not appropriate for this experiment where the aim of the investigation was to study the muscles innervated by the 5th cervical roots. Experimental evidence from Shimsheimer et al, (1985) adds weight to the statement made by Fisher (2002), where H reflexes were measured in 32 patients with C5 – C8 nerve root injury, confirmed by myelography, and compared to 143 control subjects in a non-randomised and non-blinded study. The findings showed that in those patients with C5 or C8 nerve root injury, the H reflex could not be detected, where as in C6 and C7 root injury, H reflexes were shown, though the lack of blinding prejudices these results.

The F wave like EMG, is a measure of the motor neurone output from the spinal cord, however it is only representative of a small number of motor units, usually less than 5% of the associated compound motor unit action potential (Yates and Brown, 1979). The F wave is produced when a supramaximal stimulus, delivered to the peripheral motor nerve produces an antidromic volley of nerve impulses which travel back to the spinal motoneurones and induce re-excitation of the axon causing a late excitation of the muscle known as an F wave (Pascual-Leone et al, 2002). These late responses have small amplitudes as they are produced by discharge from a small number of motor units, and are considered to be inherently variable (Fisher et al, 1994; Mesrati and Vecchierini 2004) (it is recommended that for accurate measurement, a series of 20 or more stimuli are required to yield approximately 16-20 F waves) (Fisher et al, 1994) which means they are less useful for clinical practice. Though F waves may yield some information regarding the electrical signal in the muscle, they do not appear to have been used for the assessment of background electrical activity in kinesiological studies or studies of muscle spasm.

Thus in summary surface EMG was considered to be the most suitable method for this study. The equipment used and reliability analysis is described in section 3.4.3, page....
3.4 Equipment

As the aim of this study was to determine the diagnostic sensitivity of trophic changes with methods that could be used in clinical practice, all instrumentation needed to be appropriate for the clinical environment. The equipment used and the reliability studies for each outcome measure are described below.

3.4.1 Modified Matchstick Test

The matchstick test used by Gunn and Milbrandt (1978) is a test of subcutaneous oedema and entails delivering a compression force to the skin using a blunt instrument (similar to, but not defined as a matchstick). The presence of residual compression indicates the presence of subcutaneous oedema. As discussed in the literature review, previously compression force had been delivered manually and therefore test modification was required to develop a valid test where a known force could be applied. To deliver the compression force to the skin a cylindrical plastic tube similar to an acupuncture guiding tube, was selected because it was blunt, could provide the appropriate spread of force without discomfort and was plastic such that it could be cleaned between patients. The tube was inflexible, 50mm in length, 3.5mm in diameter, with a rim of 1mm thickness (see figure 1). Other similar instruments such as plastic syringes may also be suitable. As pressure algometry has been shown to be a valid and reliable tool in both clinical and laboratory environments (Fischer 1987a), this was considered most suitable for delivering a standard compression force, via the plastic tube to the skin rather than using manual pressure. A non digital FDN 10 algometer (Wagner Instruments USA) was used.

Figure 1: Cylindrical Compression Tube for Modified Matchstick Test
A pilot study was conducted to determine:

a) the appropriate pressure required to create compression in the subcutaneous tissues
b) the length of time required to determine the presence of abnormal residual compression and,
c) the criteria for interpretation.

The pilot study (see Appendix A1.2 pg. for details) was undertaken on the assumption that the force had to be great enough to create skin compression which lasted for a few minutes, but not too great such that the force may damage the skin or take too long to return to normal levels, (as increased time for test completion would increase the risk of the test loosing its usefulness in busy clinical practice). Force less than that required for pressure pain measurement was used because pressure was exerted through a small, stiff tube which increases the pressure load onto the skin. Therefore in the pilot study, forces of 2.5, 5, 7.5 and 10N were trialed (see results in appendix A1.2, table A1.4, page). The results showed that with a plastic tube of 50mm length and 3.5mm diameter, a force of 5N was most suitable (forces of 2.5N did not leave a consistent compression and those over 5N were sometimes painful). The results of the pilot study monitoring the length of time for residual skin compression to return to normal showed that skin was recovered at 5 minutes in control subjects (See results in Appendix A1.2, table A1.5 page...). However as this was extended beyond 5 minutes in 2 subjects it was considered appropriate to monitor the skin at both 5 and 10 minutes.

Gunn and Milbrandt (1978) had not identified the criteria by which skin would be judged to be ‘recovered’ or still ‘indented’. As no previous criteria had been proposed, an arbitrary scoring system was developed based on ease of identification of the remaining indentation. If the indentation was fully visible it was given a compression score of 1, and if the indentation was not visible at all it was given a score of 0. Where there was partial recovery, a score of 1 was given if the indentation ring was 75% or more complete, partial recovery of less than 75% was scored as 0.

**Reliability of the Modified Matchstick Test and Measurement Error**

To determine the level of intra-observer reliability of the modified matchstick test, 20
control subjects were consecutively selected. On first assessment subjects were screened using the inclusion and exclusion criteria described above for the control group, and informed consent was gained. Subjects were tested initially and then the test was repeated 4 weeks later. The procedure was the same as that used in the main study described in section 3.5 page....

The difference between the number of compression scores for each side (left side subtracted from right side) was calculated for each test. The reliability of the data was analysed by comparing the level of agreement between the difference scores obtained at the 2 time periods. As the data was of an ordinal nature, the kappa coefficient was used (Sim and Wright 2000). A kappa value of 0.79 was obtained for repeated testing at 5 minutes, and 0.61 at 10 minutes. The standards set by Landis and Koch (1977) indicate that results between 0.61 and 0.80 are considered to have ‘substantial’ levels of agreement which provides support for the use of the test in this study. Thus the results showed that in conjunction with a valid tool such as pressure algometry, the modified matchstick test was shown to be reliable.

According to De Mast and Van Wieringen (2004) ‘measurement precision is interpreted as reliability by the social sciences and can be viewed as the degree of variation, or equivalently, as the correlation among multiple measurements’. For ordinal measurements quantification of measurement error or precision can be found by the correlation between pairs of readings with the kappa correlation coefficient (Bland 2000; De Mast and Van Wieringen 2004). For interval or ratio data measurement error may be determined by the intraclass correlation coefficient or by the within subjects standard deviation as seen later in section 3.4.3 (Bland 2000). For the modified matchstick test the kappa coefficient has been calculated as discussed above, which has shown that there was less measurement error at 5 minutes than at 10 minutes.

3.4.2 Pressure Pain Rating
Sensory changes were determined with a non digital FDN 50 Algometer (Wagner Instruments USA) used in conjunction with the numerical rating scale. On analysis of the variety of methods to measure pressure pain the use of a pain rating scale was considered most appropriate for this study. Pressure pain thresholds were discounted
as they can sometimes be difficult to determine due to difficulties finding the exact point when a subject first perceives a stimulus (Fischer 1986). They can also take time to complete, and require a significant concentration from the patient, usually away from other stimulus.

On analysis of pain scales previously used Gagliese et al, (2005) compared the validity of a variety of pain scales including the visual analogue scale (VAS), the numerical rating scale (NRS), and the verbal descriptor scale (VDS) (which utilizes descriptions of pain e.g. 5=worst pain, 4=severe pain etc) in 504 post-operative patients spanning a wide range of adult ages. The numerical rating scale had the lowest error rates and patients reported that this scale most accurately represented their pain. The VAS on the other hand was associated with higher error rates, high non score data, low face validity, and was not recommended for use in the elderly post-operative patient. In a study of 175 patients (age range 25-94), Herr et al, (2004) found that all pain scales (VAS, VRS, VDS) were valid measures of pain, but also identified that again patients found that the VRS represented their pain intensity most accurately, followed by the verbal descriptor scale.

In support of these findings Ferraz et al, (1990) evaluated the reliability of the VAS, NRS and VRS in illiterate and literate patients with chronic rheumatoid arthritis (total n=91; illiterate=25, literate=66). Scales were presented to patients in random order, twice, before consultation with their doctor. The intra-class correlation coefficient was calculated for literate and illiterate patients (see table 7 below) showing that the numerical rating scale achieved the highest reliability rating in both groups of patients.

<table>
<thead>
<tr>
<th>Pain Scale</th>
<th>ICC for Literate Patients</th>
<th>ICC for Illiterate Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>0.937</td>
<td>0.712</td>
</tr>
<tr>
<td>NRS</td>
<td>0.963</td>
<td>0.947</td>
</tr>
<tr>
<td>VRS</td>
<td>0.901</td>
<td>0.820</td>
</tr>
</tbody>
</table>

Table 7: Intra-class Correlation Coefficients for Illiterate and Literate Patients using a variety of Pain Rating Scales
In contrast reliability of the VAS and the NRS was investigated by Good et al, (2001) in a randomized controlled trial, with results showing that the VAS was slightly more reliable than the NRS. Patients were tested on 2 separate days after surgery (day 1 and 2), and on each of these days, pain assessment was measured twice, with a 15 minute space between each measurement to test reliability. The results showed that the VAS scored slightly higher than the NRS (ICC ranged from 0.73-0.82 for VAS and 0.72-0.78 for NRS). In summary the numerical rating scale consistently appears to be more valid and reliable than the other scales, with the exception of the work by Good et al, (2001) where the VAS achieves slightly higher reliability scores. The numerical rating scale also has the advantage of being ideal for patients to rate pain when their upper limbs are under test and thus was considered ideal to use in combination with pressure algometry.

The level of force used was determined by the consideration of work in previous studies. Mean pressure pain measurements (in asymptomatic subjects) of 36.25N have previously been recorded by Chesterton et al, (2003) using an algometer of 1.1cm tip diameter. However because the algometer used in this study was non digital, it was not possible to accurately and consistently measure a value of 36.25N without prolonging the pressure pain experience. This finding, in conjunction with the fact that the algometer tip used in this study was slightly smaller at 1cm diameter, resulted in a slightly reduced compression force to 35N.

Short term reliability of pressure has been demonstrated by Chesterton et al, (2003) where repeated pressure pain measurement was performed in a large, blinded study using 2 groups, 1 group of 240 subjects, and 1 group of 30 subjects who were randomly selected from the large group of 240 subjects. In the first study using the larger group, the initial measurement was taken and then repeated 15-20 minutes later, where as in the second study, initial algometer readings were taken from 14 points over the body, then repeated 6 times at 10 minute intervals. The results for both studies showed that there were no significant differences between the initial readings and those taken on repeated sessions (study 1 P=0.892; study 2 P= 0.280).

However Kosek et al, (1993) found longer term reliability (up to 13 weeks) to be poor, in their study of 12 healthy female volunteers where they measured pressure.
pain thresholds in over 30 points, in different tissues, in randomized order (mainly over the trunk). Three sets of measurements were taken, the first and second measurements were separated by 1 week, and then the third set was taken 10-13 weeks later. Their results also showed that there was no significant difference between measurements taken initially and at week 1, but 10-13 weeks later, the mean thresholds were significantly different to the previous 2 readings (P<0.001), indicating that in the long term, pain thresholds were not reliable. However the study also showed that in normal subjects, there were no significant differences between each side tested, or between the dominant and non-dominant side demonstrating that differences which occur between sides, are likely to be associated with hyperalgesic responses.

Mid term reliability was investigated by Ohrbach and Gale (1989) in a small, non-randomized study of 10 asymptomatic subjects (5 male, 5 female). Measurements at 2 sites over the temporalis and masseter muscles were taken at weekly intervals over 4 weeks and then at a fifth session at 8 weeks. The subjects and the sites tested were randomized at each session. Over both sites there were no significant differences found over the first 4 weeks or at the fifth session at week 8 (P=0.828). Intra-class correlations varied for all comparisons made but overall the results showed that there was good to high reliability for most measurements. Thus for pressure algometry short and medium term reliability has been shown (up to 8 weeks) but questions still remain over long term reliability. These findings support the methodology in this study for trophic changes to be measured at week 4. Reliability analysis for this study was conducted as previous studies had not been conducted in the deltoid area (see below).

Despite reliability it has been suggested that both age (Lee et al, 1994) and gender (Chesterton et al, 2003) may confound the results of pressure pain threshold analysis. In their study conclusions, Lee et al, (1994) proposed that age affects the pressure pain threshold, however the statistical analysis in the paper does not support this suggestion. In the study discussed above Chesterton et al, (2003) found that pressure pain thresholds at the dorsal interossei were significantly lower in females than males (P<0.0005), though many other studies have failed to show significant gender differences (Lee et al 1994; Fillingim et al 1999; Berkley 1997). It was suggested by
Chesterton et al, (2003), that many of the studies which have not shown a gender difference, have not used a large enough sample size, (though Lee et al, (1994), used a sample of 207, but no power analysis was given). The finding of a significant gender difference when analyzing pressure pain in the hand, (Chesterton et al, 2003) must also be considered in light of the trend which has shown a greater divergence between male and female pressure pain in highly innervated areas, (like the hand) (Fillingim et al, 1999). Therefore gender differences may be relevant for some studies but not necessarily for this study which aimed to investigate hyperalgesia at the shoulder. However at present, with no clear consensus on age and gender differences, it was considered appropriate to match experimental and control groups on age and gender, thus reducing the effect of these confounding variables.

**Reliability of Pressure Pain Rating and Measurement Error**

The reliability of pressure algometry (FDN 50-Wagner Instruments USA) in combination with the numerical rating scale has not been conducted in the deltoid area and therefore reliability testing was conducted. Reliability was tested before proceeding with the main study with 20 control subjects, at baseline and 4 weeks later (see section 3.5 for a detailed description of procedure).

The difference of the NRS scores for each side were calculated initially and then for the values taken 4 weeks later. The level of agreement between these 2 sets of NRS scores was analyzed using the Kappa coefficient as recommended for ordinal and nominal data (Sim and Wright 2000), as the ratio properties of these subjective pain rating scales have been questioned. The results of analysis showed that there was an agreement of 0.93, which corresponds to almost perfect agreement on the Landis and Koch (1977) scale (see appendix A1.3 page…. for scale). The high level of reliability of this valid measurement tool justifies the use of this method as a measure of hyperalgesia (and thus sensory trophic changes) in this study.

The same considerations concerning measurement error discussed in 3.4.1 applied to pressure pain rating. Quantification of measurement error and reliability was conducted with the kappa coefficient for ordinal data. The results above suggest that the pressure pain rating was the most reliable outcome used in this study with the least measurement error.
3.4.3 Surface Electromyography

Surface electromyography (sEMG) is widely used in the musculoskeletal field for the measurement of electrical activity (Gaudreault et al. 2005; Pascual-Leone et al. 2002; Soderberg and Cook 1984). The electrical signal emanating from the muscle, detected by electromyography, ‘is the algebraic summation of motor unit action potentials (MUAPs) from all active motor units, within the pick up area of the electrode’ (Basmajian and Deluca 1987). Several factors can affect the data obtained such as the type of electrode used (surface or needle), the type of contraction (static or dynamic), the normalization procedure, the placement of the electrode and its location in reference to the motor point, and the recording, analysis and interpretation of the signal (Basmajian and Deluca 1987). Surface EMG is indicated when detection of electrical activity from numerous individual motor units is required and for relatively simple assessments of the electrical activity in superficial muscles. Needle EMG is indicated for analysis of a single, or a small number of motor units and is comparatively invasive requiring some technical skill (Kamen 2004). The advantages of easy use, low training requirements, low cost, portability, non-invasive technique, and the indications for use in superficial muscle analysis demonstrate that surface EMG was more appropriate than needle EMG for this study. The two important parameters of the EMG signal are the frequency and the amplitude (Kamen 2004; Basmajian and Deluca 1987). The signal amplitude reflects muscle activation (both the number of active motor units activated and the firing rate) (Beck et al. 2005; Kamen 2004). The frequency of the signal is also affected by these factors, but primarily reflects the average conduction fibre velocity (Basmajian and Deluca 1987; Lindstrom and Magnusson 1977). Although both the amplitude and the frequency of the signal may reveal information about the electrical activity of the muscle in both experimental groups, the aim of this study was primarily to determine data pertaining to the level of muscle activation (number of motor units) rather than conduction fibre velocity, and therefore measurement of the amplitude parameter was considered the most suitable.

The Pathway MR 20 dual channel, portable surface EMG unit (Prometheus Group, USA), (Range = 1-800 microvolt, Band pass filter = 20-500 Hz) was used with self adhesive, surface active electrodes with a built in signal amplifier (high input resistance of 10 gigohms to reduce the sensitivity to noise ratio) (Turker 1993;
Basmajian and Deluca 1987). Each electrode had 3 contact surfaces, 2 for signal
detection (inter-electrode distance 10mm), and the third being a built in reference
electrode. As the machine was a portable battery operated unit, no earth electrode
was required. The Pathway MR 20 automatically samples and analyses the
amplitude signal. This built in feature was considered important for this study to
facilitate its use in clinical practice.

The amplitude signal was automatically sampled at a rate of 1250Hz (as required by
Niquist equation) (twice the upper limit of the band pass filter). Once sampled, the
signal amplitude was automatically analyzed by root mean square (RMS). A root
mean square circuit is reported to provide a nearly instantaneous output of the power
of the EMG signal and is considered to have a sounder mathematical basis than many
other methods of processing (Soderberg and Cook, 1984; Basmajian and Deluca
1987), however other techniques are still widely used. In line with the standards for
electromyographic reporting (Merletti et al, 1999), and guidance from Soderberg and
Knutson (2000), the root mean square should be reported for a particular time period,
over which the RMS is calculated, (no minimum or maximum time periods are
stipulated). On analysis of the literature many previous studies (e.g. Roe et al, 2006)
have commonly used RMS amplitude values calculated for ‘epochs’ of 0.1s (100
milliseconds). The MR 20 specification includes a built in the time period for RMS
analysis of 0.1 s.

On analysis of the general kinesiological studies which have used surface EMG in
the shoulder region, it appears that the reliability is variable and conclusions
regarding the reliability of specific techniques or test positions are difficult to draw
because of the large amount of methodological variation pertaining to electrode
placement, muscle tested, task investigated, data obtained and equipment used. As a
general rule intra-day reliability has been shown to be more reliable than inter-day
reliability, and experiments using isometric contractions are generally more reliable
than isotonic contractions. As the aim of this study was to investigate trophic
changes in the C5 dermatome, studies which have investigated the reliability of
surface EMG around the shoulder, were used where possible from which to draw
conclusions.
Roe et al. (2006) examined the reliability of peak amplitude surface EMG (root mean square-rms) in 26 subjects with and without neck and shoulder pain (18 asymptomatic, 8 with shoulder and neck pain), over a 3 year period. Subjects performed 3 maximal voluntary contractions (held for 4 seconds) and 1 sustained sub-maximal isometric contraction of the deltoid and trapezius muscles, with the shoulder joint positioned at 45 degrees of abduction to facilitate peak force generation. The subject group was not randomized but was drawn from a large working population with a variety of age ranges. (Initially 104 subjects were recruited but following criteria exclusions and dropouts, 26 remained). For maximal contractions of the deltoid muscle, the intra-class correlation coefficients for intra-subject variability over 3 years ranged from 0.67-0.89 showing moderate to high reliability. Intra-subject variability over 1 day was much less, with intra-class correlation coefficients of 0.85-0.95 showing high levels of reliability. The coefficient of variation (CV) over 3 years for maximal contraction shoulder abduction was 1-37% and on repeated tests within the same day the CV was 1-34% showing similar values. The CV for sub-maximal contractions of shoulder abduction ranged from 2-65% showing more variation than the maximal voluntary contraction.

Other studies have reported less favourable reliability statistics, though direct comparisons are difficult as studies have used different parameters. For example in a study conducted by Minning et al. (2007) differences in shoulder muscle fatigue were investigated in the deltoid muscle (and other shoulder muscles), by surface EMG frequency analysis rather than amplitude analysis. 16 asymptomatic subjects performed an isometric contraction, whilst holding a weight of 60% of their MVC, at 90 degrees of shoulder elevation. The results demonstrated good intra-day test reliability (intra-class correlation ranged from 0.75-0.83), however inter-day test reliability ranged from very poor to good (0.03 - 0.76) depending on the muscle tested.

Nordander et al. (2004) investigated the reliability of peak amplitude (rms) surface EMG from the infraspinatus muscle, and also found relatively poor reliability (though the study was very small). EMG analysis of specific work tasks was undertaken with normalization to maximum voluntary contraction, in 6 healthy female volunteers. Intra-class correlation coefficients were not calculated, but the
between days and between subjects coefficient of variation was shown to be quite large at 15% and 57% respectively. In summary, the method and positions used in the study by Roe et al, (2006) demonstrated the most reliable short and long term values, and were thus adopted where possible for this study. As there were some variations, such as the equipment used, reliability testing was conducted.

Reliability of Surface EMG and Measurement Error
The procedure for reliability testing was the same as the procedure for the main experiment (see section 3.5 page. for further details). As with reliability testing for the other outcomes, 20 control subjects were consecutively selected from the physiotherapy referrals using the criteria as outlined in section 3.2. In brief, the root mean square peak amplitude signal was recorded from each deltoid muscle during the MVC. The difference between the MVC contraction for each side was calculated and then reliability analysis between baseline and measurement at 4 weeks was conducted. As the data was normally distributed (see appendix A1.5, figures A1.1 and A1.2 page 113-114) and was of an interval/ratio nature, an intra-class correlation coefficient to determine level of agreement between the 2 time periods was calculated (Sim and Wright 2000). It has been recommended that the ICC used for analysis should reflect the situation in which future analysis is likely to take place (Sim and Wright 2000). Thus an ICC (2,1) model was used which identifies that raters would be assigned to subjects for re-measurement, rather than a different set of raters being used for each measurement which is most likely to reflect clinical usage. The MVC reliability demonstrated moderate to poor agreement with an ICC value of 0.6. Though the level of reliability was moderate it was felt that this method would still be useful to give an indication of the existence of motor trophic changes and their diagnostic sensitivity. However it was acknowledged that an ICC of 0.6 was on the lower limit of acceptable reliability and this is further considered in the Discussion chapter. A normalized EMG test as well as a maximum voluntary contraction had originally been conducted (see appendix A1.4 page 110 for details on the uses of normalization and the procedure employed in this study). However the intra-class correlation coefficient of the normalized EMG values between the 2 test points was poor (ICC=0.25), and thus the normalized procedure was not considered to be reliable enough for use in the main study.
The technical information for the Pathway MR 20 reports that it has an accuracy of 2% +/- 2 microvolts (for values of less than 500 mv), however measurement precision calculated specifically on the subjects in this study showed much less precision. As discussed previously measurement error can be calculated by correlation of two sets of measurement or by the within subjects standard deviation. As the EMG data was normally distributed and was interval in nature, the within subjects standard deviation was calculated (see table A1.7 appendix A1.6 page 115) and found to be 47.54mv. Following the British Standards Institution (1979) guidance, measurement precision may be quoted as being within 2 standard deviations, therefore for the peak amplitude measured with surface EMG during the maximum voluntary contraction, measurement precision was 95.08mv. As the mean of the first set of values for the control group was -30.9mv, this shows that surface EMG in this study lacks precision and appears to be related to large measurement error, thus the results must be interpreted with this in mind. As with other studies the between subject variance when quoted within 2 standard deviations was also shown to be large at 122.08mv.

3.5 Experimental Procedure – Study 1
3.5.1 Modified Matchstick Test
Trophic changes were measured in the C5 dermatome for all outcomes as this is the site to which frozen shoulder and C5 radiculopathy refer pain (Kellgren 1939). Subjects were seated in a relaxed position with their hands resting on the mid thigh. Compression was delivered to the skin 1 cm above the deltid tuberosity by placing the rim of the small hollow plastic guide tube (3.5mm diameter, 50mm in length, rim 1mm thickness), against the skin horizontally, and then placing the rubber tipped 10N algometer (Wagner Instruments USA) against the free end of the plastic tube. A force of 5N was delivered in the horizontal plane from the algometer to the skin via the tube. This was repeated 5 times such that after the procedure 5 compression rings (of 1mm thickness) were evident on the skin, (see figure 2). The procedure was repeated on the opposite side, (both arms were tested but the order of testing for each arm was randomized). Following the compression on both sides, a stopwatch was started and the skin at each compression site was photographed at 5 and 10 minutes following the procedure post compression.
Figure 2: Example of Skin Compression Following the Modified Matchstick Test

Skin lesions of 5-10mm in diameter require photography of a focus distance of approximately 5cm (Medical Photography Guidelines, Bristol Royal Infirmary). Therefore the skin was photographed with a Nikon digital camera, (model coolpix 880), 3.34 mega pixels at distance of 5cm from the compression site. Each photograph was assessed for clarity at the time of the experiment and then saved for interpretation and analysis. If the clarity was poor the photograph was repeated immediately. After the procedure the skin photographs were reviewed and the number of residual compression scores remaining at the 5 and 10 minute measurement point were counted and recorded for each side. The data analysis section, 3.7 describes how this data was reduced and analysed.

3.5.2 Pressure Pain Rating

The area around the deltoid motor point was chosen as the site for hyperalgesia testing because the motor point was used as a site to determine hyperalgesia in the previous study by Gunn and Milbrandt (1978). Motor points have been suggested to be more hyperalgesic than other areas of the muscle, though no experimental data supports this suggestion.
Subjects were seated in an upright position on an adjustable plinth, with hips and knees at 90 degrees and feet placed in neutral on the floor. The area of the skin at the motor point of the middle fibres the deltoid muscle was surface marked (the motor point is said to be found at the point between the lateral aspect of the acromion and the head of the humerus with the arm placed at 90 degrees of abduction) (Forster and Palastanga 1985). The hyperalgesic response was then measured at this site by placing the algometer tip onto the skin surface, and then applying a constant force of 35N.

Subjects were asked to rate the level of discomfort experienced during force delivery, using the numerical rating scale to determine the level of pain/discomfort experienced. Before the test, subjects were given an explanation of the numerical rating scale, to ensure they were familiar with the method of rating pain. Subjects were asked to verbally rate the level of their perceived pain intensity on a numerical scale from 0 to 10, with the zero representing one extreme (e.g. no pain) and the 10 representing the other extreme (e.g. “the worst pain possible”) as used by Randall et al, (2004).

3.5.3 Surface EMG

Subject Position
Subjects were seated in an upright position on an adjustable plinth, with hips and knees at 90 degrees and feet placed in neutral on the floor as used by Roe et al, (2006). The shoulder under test was positioned at 45 degrees of glenohumeral abduction in the scapula plane (elbow and wrist joint neutral). Other studies have used positions varying from 10 degrees (McLean 2005), 20 degrees (Brown et al, 2007) and 90 degrees (Minning et al, 2007) of abduction. However the 45 degree mid position is highlighted by Kendall et al, (1983) as the position which promotes maximum force production and was thus considered ideal for testing the maximum voluntary contraction.

Electrode Placement
Prior to placing the electrodes, the skin was cleaned with a mediswab alcohol wipe to reduce skin impedance (Kamen 2004). It is recommended that the surface electrodes
are placed away from the motor point of the muscle because this area produces the most variable EMG signal (Kamen 2004). As discussed earlier the motor point of the middle fibres of deltoid has been identified as the point between the lateral aspect of the acromion and the head of the humerus with the arm placed at 90 degrees of abduction (Forster and Palastanga 1985). The electrodes were therefore placed away from this point, midway, on a line between the deltoid tuberosity and the mid point of the lateral aspect of the acromion. They were placed in parallel with the muscle fibres to ensure a consistent signal, as it has been shown that when the electrode is not placed in parallel with the muscle fibre, the signal may be reduced by as much as 50% (Kamen 2004).

**Maximal Voluntary Contraction**

Following positioning, subjects were asked to perform 3 static maximum voluntary contractions of the deltoid muscle against a manual resistance delivered to the lower part of the humerus just above the elbow. Each deltoid was tested in random order. A contraction time of 4 seconds and an inter-trial rest period of 2 minutes were used as in the study by Roe et al (2006), with verbal encouragement to facilitate the maximum voluntary contraction. No standard time length for holding the maximum voluntary contraction has been identified in the literature, however it is advised that the time period over which the contraction is held should not exceed the time that maximum effort can be exerted such that the muscle becomes fatigued (Soderberg and Knutson, 2000). The 4 second contraction time used was considered long enough to gain a MVC, but short enough to reduce the risk of fatigue. Other studies have used contraction times from 400 milliseconds (Brown et al, 2007), to 1 second (Brindle et al, 2006). The peak amplitude during each maximum voluntary contraction was recorded with the Pathway MR20 portable surface EMG unit as outlined in section 3.4, and the root mean square was automatically calculated. The highest value of 3 maximum voluntary contractions was used which is the procedure used in the study by Morris et al, (1998). Other studies have averaged the MVC results but as the aim was to gain the value for the maximum voluntary contraction, this method was deemed to be the most appropriate.

Prior to the procedure subjects were given the opportunity to practice before any data was collected. 3 practice sessions were carried out as it has been estimated that
without training, the MVC could be as much as 20-30% less than that obtained after appropriate training (Merletti et al, 1999). Yang and Winter (1983) recommend that several repeated MVC contractions also improves the reliability of readings from maximal and sub-maximal contractions and those studies using 3 repeated MVC contractions have shown reliable results (Roe et al, 2006; McLean 2005). Other studies (Morris et al, 1998; Brindle et al, 2006) have used 1 or 2 repeated MVC contractions, but no reliability data was available from these studies to determine whether this method was also acceptable. Once the procedure had been completed the data was analysed as discussed in section 3.7.

3.6 Experiment 2
The aim of experiment 2 was to determine whether cortico-steroid shoulder injection affected existing trophic changes in frozen shoulder.

3.6.1 Ethics, Consent and Research Participants
The same ethical and consent procedures applied for this part of the study. In experiment 2, subjects recruited from the frozen shoulder group were subject to further investigation (the same inclusion and exclusion criteria were used). From the 32 subjects with frozen shoulder initially recruited in study 1, 17 subjects (7 male, 10 female) who consented to an injection of corticosteroid were consecutively selected and matched to 30 control subjects (13 male and 17 female). Subjects who did not consent to an injection but who consented to take part in the study as a further control were also recruited and underwent the same procedure as the control (n=10).

3.6.2 Procedure Experiment 2
All subjects were exposed to the baseline measurements of the modified matchstick test, pressure pain rating and surface EMG (rms) during maximum voluntary contraction as described above in the procedure for experiment 1. Following baseline measurements, subjects who had consented received an injection of corticosteroid (Kenalog-dose 30mg) using a posterior approach with an aseptic technique, into their affected shoulder joint, in line with the Association of Chartered Physiotherapists in Orthopaedic Medicine, Injection Therapy Guidelines. Each patient was positioned in long sitting and the posterior angle of the acromion was identified. The skin was marked, cleaned with a steret and allowed to dry. The
injection was delivered using a fresh, sterile 21 gauge needle just below the angle of the acromion and inserted until the needle tip touched the intra-articular cartilage. The fluid was then delivered in a bolus and the needle removed and safely discarded (Saunders 2002).

Control subjects and those with a frozen shoulder who had agreed to be part of the study but did not wish to receive and injection (from here on called the non injection group) had baseline measurements only and no intervention. All tests including the modified matchstick test, pressure algometry and surface EMG were conducted again 4 weeks after baseline measurements and injection. Again the procedure is the same as that described for experiment 1.

3.7 Data Analysis

3.7.1 Data Analysis for Experiment 1

Data Reduction
Following the procedure the first step for all outcomes was to calculate the difference between the scores for the affected and unaffected sides. The calculation to determine the difference between the affected and unaffected side was based on the hypothesis which stated that vasomotor and sensory trophic changes would be greater, therefore the score for the unaffected side was subtracted from the affected side. In the case of the control group, the difference values were calculated by matching to the experimental groups, therefore the values for the control group are slightly different depending on whether the group has been matched to the cervical radicular or frozen shoulder group. Alternatives for the calculation of the control group differences were considered, including arbitrarily subtracting all left sides from right sides, calculating the first half of the group as left from right and the second half as right from left and vice versa. However the matching procedure chosen was considered to have the least error variance (Holder 2007-statistician advice).

The decision to match the control group to each experimental group was made because it was important to analyse each experimental group in comparison to its control rather than make comparisons across 3 groups where one part of the analysis
would be between 2 experimental groups. Comparisons between 2 experimental groups would not be made in clinical practice.

**Modified Matchstick Test**
Following the procedure, residual skin compression at 5 and 10 minutes was measured in each deltoid muscle. A range of scores for each arm from 0 to 5 could be recorded. The difference between the scores for the affected and unaffected side were calculated such that for each subject a score that ranged from -5 to +5 was obtained.

**Pressure Pain rating**
Following the procedure each subject reported their pain score between 0 to 10 using the numerical rating scale. The difference between the affected and unaffected sides was again calculated and thus for each subject a score which ranged from -10 to +10 was obtained.

**Surface EMG**
For the EMG scores, it had initially been envisaged that the difference between the normalized values would be used, however, as the EMG reliability study showed the reliability of the normalized values was poor (ICC=0.25), the difference between the peak EMG values during maximum voluntary contraction were used as these had shown much higher levels of reliability (ICC=0.6).

**3.7.2 Data Analysis for Experiment 2**
Data for experiment 2 was managed in the same way as experiment 1. As baseline and at 4 weeks, for each outcome measure, the data was reduced as described above, for each of the 3 groups.

**3.7.3 Statistical Data Analysis**
The data from both experiments was analysed statistically using SPSS for windows, version 11, SPSS Inc. Normal distributions were calculated (see appendix..) and then the data was analysed with the appropriate test depending on the type of data and the distribution obtained for each outcome (see each outcome for specific details).
**Experiment 1**

**Modified Matchstick Test and Pressure Pain Rating**

For both of these outcomes significant differences between the groups were calculated with the Mann-Whitney U Test, a nonparametric test suitable for independent samples (Pallant 2005; Sim and Wright 2000). This was used because the data from either outcome was not normally distributed (see appendix page...), subjects were not randomly selected and data was not of an ordinal nature (Sim and Wright 2000; Hicks 1988; Pallant 2005). Comparisons between each experimental group and the control group were made because the main aim was to determine whether significant differences between each affected group and the control group existed, rather than a general comparison between all groups.

**Surface EMG**

The histograms..... in the appendix... (pg... figures...) and the Kolmogorov Smirnov significance values show that EMG values obtained from difference calculations between each side were not normally distributed in either of the matched control groups or in the cervical radiculopathy group. However the Kolmogorov Smirnov significance value (which indicates normal distribution if greater than 0.05) was 0.186 for the frozen shoulder group showing that this was the only set of data obtained which followed a normal distribution. As only one measurement across all groups was normally distributed, and the data was not randomly selected, the Mann Whitney U Test was again used.

**3.7.4 Sensitivity Data Analysis**

The sensitivity analysis between the control group and each experimental group was then undertaken. The sensitivity of a diagnostic test is defined as the extent to which it identifies patients who have the disease for which the test is trying to determine (Sim and Wright 2000), where as the specificity is the extent to which the diagnostic test excludes those without the disease (Bland 2000). Sensitivity and specificity are usually in an inverse relationship and as the test increases in sensitivity, specificity decreases and vice versa.

In determining whether the trophic changes were sensitive indicators of cervical radicular or frozen shoulder pathology, sensitivity calculations outlined by Bland...
(2000) were employed (see appendix page ..). Sensitivity calculations were conducted using the baseline that those in the experimental groups were disease positive as detected by the inclusion criteria outlined in section 3.2.2 as no gold standard diagnostic criteria for frozen shoulder or cervical radiculopathy exists. As recommended by Ajetunmobi (2002), all subjects were exposed to both the original method of diagnosis as well as the new trophic change tests. Also in both experimental groups, the subjects recruited were representative of subjects with all stages of each condition and no pre-selection had been employed.

As the aim of this study was to determine whether a clinical trophic changes could be sensitive indicators of cervical radicular or frozen shoulder pathology, it was considered important to choose a cut off value for sensitivity which could be identified easily by clinicians in practice, for all 3 outcomes measured (Stewart 2002). For the modified matchstick test the cut off value chosen was +2 on a scale of −5 to +5. A positive value was used as this reflects the hypothesis that trophic changes would be greater on the affected side. A cut off value of +2 was considered to be appropriate for the modified matchstick test as it was felt that it could be easily identified. Unfortunately as no previous sensitivity studies in this field had been carried out, this value was somewhat arbitrary. Higher values were considered but it was felt that these may be excessively high and may exclude some cases at the second measurement point at 10 minutes.

For the NRS score following algometry, a cut off point of +2 was also used (i.e. a difference between affected and unaffected sides of +2 on a −10 to +10 scale). This was used because a difference in pain score of +2 points is often considered to be clinically relevant following treatment, though clearly clinically relevant pain scores vary between conditions and clinicians in different situations. The literature was searched to determine whether data could be found to support an appropriate pain scale cut off point. However no data could be found to guide this decision.

It is well known that the maximum voluntary contraction varies widely between individuals (Winter 1991) therefore the cut off value was calculated as a ratio rather than an absolute value. The ratio between the 2 sides was calculated by dividing the affected side score by the unaffected score.
The cut off value for the EMG data was calculated by transforming the difference between the affected and unaffected sides into a ratio. This was done by the following calculation: 

\[
\frac{\text{Affected Side EMG Score} - 1}{\text{Unaffected Side EMG Score}}
\]

This calculation was used as it was easy to convert this value into a percentage for use in clinical practice by multiplying the ratio by 100 (see appendix A2…for further details).

As the hypothesis stated that the maximum voluntary contraction would be reduced on the affected side in comparison to the unaffected side, ratio values of less than 1 were considered in determination of the sensitivity value. Calculations with a ratio value of 0.5 and 0.75 can be seen in the appendix-pg…..for both cervical radiculopathy and frozen shoulder. It was felt that as EMG varies widely between individuals a clear cut off value was required for clinical use, there the cut off of 0.5 was thought to be more clinically appropriate than 0.75.

**3.7.5 Statistical Analysis for Experiment 2**

For experiment 2, data was analysed statistically with a Wilcoxon Signed Rank Test, a non parametric test suitable for paired samples, because subjects were not randomly selected and with the exception surface EMG for the injection and non injection groups, the data was not normally distributed (see Kolmogorov Smirnov significance values and the distribution histograms for all outcomes page…). The data from the modified matchstick test and the pressure pain rating was also ordinal in nature data and therefore non parametric analysis was also most appropriate.

**Summary**

This chapter has described the participants, equipment and procedures used in the study as well as the methods to analyse the data. The results will be described in the next chapter.
CHAPTER 4

RESULTS

Introduction
As stated in Chapter 1, experiment 1 examined the sensitivity of vasomotor, sensory and motor trophic changes in cervical radiculopathy and frozen shoulder and experiment 2 examined the effects of corticosteroid injection on these trophic changes.

The subject characteristics for the participants in each experiment are presented below in section 4.1 and 4.2 respectively. In each experiment vasomotor, sensory and motor trophic changes were measured by the modified matchstick test, pressure pain rating and surface EMG. For experiment 1, the results of these tests are reported under the heading of each trophic change in sections 4.1.2, 4.1.3, and 4.1.4 respectively. The results of the sensitivity analysis are reported in section 4.1.5 and the results for experiment 2 are shown in section 4.2. The implications of the results are briefly discussed in this section and further discussed in Chapter 5 (pg...) and the data analysis methods used can be seen in the previous chapter on page ...

4.1 Results for Experiment 1
Study Aim: The aim of experiment 1 was to determine whether clinical tests of vasomotor, sensory and motor trophic changes were sensitive indicators of frozen shoulder and cervical radicular pathology.

The research hypotheses stated that there would be a significant difference between trophic changes detected in cervical radiculopathy and frozen shoulder when compared to a control group, but that these differences would only be sensitive indicators of pathology in the frozen shoulder group, hypothesized because of the correlation between trophic changes and inflammation. In order to answer the study question, differences between the outcomes investigated in each of the experimental groups were compared to the control group, and then sensitivity analysis was performed.
Overall the results show that the trophic changes are not sensitive indicators of pathology in cervical sensory radiculopathy or frozen shoulder. Significant differences between the frozen shoulder and the control groups did exist for all trophic changes measured (except the modified matchstick test at 10 minutes), but these do not appear to be clinically relevant.

### 4.1.1 Subject Characteristics

The number of subjects recruited in experiment 1 is shown in table 8 below along with the mean ages. The mean ages demonstrate that the control group was well matched to both experimental groups particularly the cervical radiculopathy group. The standard deviation also shows that there was less age variance in the frozen shoulder group, which supports suggestions made by Cyriax (1983) that age range for frozen shoulder falls between 40 and 60 years.

A one-way ANOVA was conducted to determine whether there were significant differences between age across the 3 groups in experiment 1 but none were shown, (P=0.136). A Kruskall-Wallis test was also conducted which showed that there were no significant gender differences across the 3 groups in experiment 1 (P=0.989). A non-parametric test was used because the data was nominal.

**Table 8: Mean Age and Gender of Subjects Recruited for Experiment 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Mean Age (Years)</th>
<th>Age Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td>13</td>
<td>17</td>
<td>30</td>
<td>50.63</td>
<td>15.575</td>
</tr>
<tr>
<td>Cervical Radiculopathy Group</td>
<td>14</td>
<td>17</td>
<td>31</td>
<td>50.81</td>
<td>15.079</td>
</tr>
<tr>
<td>Frozen Shoulder Group</td>
<td>14</td>
<td>18</td>
<td>32</td>
<td>56.75</td>
<td>9.762</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>52</td>
<td>93</td>
<td>52.80</td>
<td>13.821</td>
</tr>
</tbody>
</table>

### 4.1.2 Vasomotor Trophic Changes

The modified matchstick test was used to investigate vasomotor changes by measuring the existence of subcutaneous oedema, which was represented by the
presence of residual skin compression at 5 and 10 minutes. Figures... in Appendix A2 page... demonstrate the frequency of residual compression scores following the modified matchstick test and show that none of the data was not normally distributed for all 3 groups. It was therefore inappropriate to describe the data using mean or standard deviation statistics as these methods are reserved for data that are measured on at least an interval scale, which exhibit a symmetrical distribution (Sim and Wright 2000). It is recommended that ordinal, non normally distributed data is represented by the median and interquartile range (IQR), and these values for the modified matchstick test for all groups (experimental and matched control) can be seen in appendix ..box plots...... figures......, and in table.......pg..???.

Figure 3 shows the median value and interquartile range for the modified matchstick test at 5 minutes for the frozen shoulder group and the relevant matched control group. The black line in the centre of the box plot shows the median value, the beige box shows the interquartile range (between the 25th and 75th percentile) demonstrating where 50% of the scores lie. The whiskers extending from the box demonstrate the minimum and maximum values (starred values represent outliers). At the 5 minute measurement point, the interquartile range for the control group show less variability than the frozen shoulder group, however there is no difference between the median values. The interquartile range for the frozen shoulder group continues to show wider score variability at the 10 minute measurement point, where as the control and cervical radiculopathy groups do not (see figures .pg...appendix A2). The results of significance testing for the modified matchstick test at 5 and 10 minutes for the experimental groups and the matched control groups are shown in table 9, the only significant result occurs between the control and the frozen shoulder group at 5 minutes P<0.05. These findings suggest that subcutaneous oedema may be present in the frozen shoulder group.
Figure 3: Box Plot showing the Interquartile range, median, minimum and maximum values for the frozen shoulder group and the control group for the modified matchstick test at 5 minutes. (Control Group N=30; Frozen Shoulder Group N=32; Statistical Significance P=0.033)

Table 9: Significance and Z values for All Groups for the Modified Matchstick Test

<table>
<thead>
<tr>
<th>Modified Matchstick Test (MMST)</th>
<th>Z Value</th>
<th>Significance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group Vs Cervical Radiculopathy 5 minutes</td>
<td>-1.425</td>
<td>P=0.154</td>
</tr>
<tr>
<td>Control Group Vs Cervical Radiculopathy 10 minutes</td>
<td>-1.250</td>
<td>P=0.211</td>
</tr>
<tr>
<td>Control Group Vs Frozen Shoulder 5 minutes</td>
<td>-2.134</td>
<td>P=0.033</td>
</tr>
<tr>
<td>Control Group Vs Frozen Shoulder 10 minutes</td>
<td>-0.794</td>
<td>P=0.427</td>
</tr>
</tbody>
</table>

4.1.3 Sensory Trophic Changes
Sensory trophic changes were investigated by measuring hyperalgesic responses to pressure. Pressure was delivered to the motor point in each deltoid muscle with an
algometer and the hyperalgesic response was measured on a 0-10 numerical rating scale (NRS). The difference between each side was calculated and the resultant NRS score obtained thus ranged –10 to +10 for each subject. Interquartile ranges and median values were again used to represent the data because the data was considered to be of an ordinal nature and the NRS scores were not normally distributed (see Appendix A2 pg ..figure..). The control group interquartile ranges showed low score variation (see table ...pg for median and IQR values and box plots pg....), where as the experimental groups (particularly the cervical radiculopathy group) showed more variation.

The results of significance testing for the each experimental group and the matched control groups are shown in table 10. The results show that there is a significant difference in the pain score reported between the cervical radiculopathy and frozen shoulder group in comparison to the matched control groups (P< 0.05 in both groups), with the pain scores higher on the affected side, demonstrating hyperalgesia in both experimental groups.

Table 10: Significance and Z values for All Groups for Pressure Pain Rating

<table>
<thead>
<tr>
<th>Numerical Rating Scale</th>
<th>Z Value</th>
<th>Significance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group Vs Cervical Radiculopathy</td>
<td>-3.687</td>
<td>P=0.000</td>
</tr>
<tr>
<td>Control Group Vs Frozen Shoulder</td>
<td>-2.971</td>
<td>P=0.003</td>
</tr>
</tbody>
</table>

4.1.4 Motor Trophic Changes
Motor trophic changes were investigated by measuring the difference in the maximum voluntary contraction between each side with surface EMG (peak amplitude parameter). Median and interquartile ranges were again used (see figures...pages ...Appendix A2) as only one set of EMG data from the frozen shoulder group was normally distributed (see appendix A2... pg...figs... and the Kolmogorov Smirnov significance values pg ..). (N.B. Mean, Standard Deviation and Standard error can be found in appendix....for information purposes only). Generally the interquartile range for the matched control groups and the cervical radiculopathy groups were similar (with values of 113mv, 107mv and 109mv respectively) showing relatively large score variation. However the IQR for the
frozen shoulder group showed much less variability at 69mv. The median value for the frozen shoulder group is -51.50mv which, when compared to the matched control group value of -5.50mv, indicates that electrical activity is less in the frozen shoulder group when compared to the control group. The results of significance testing between groups can be seen in table 11 and the difference between the control and the frozen shoulder group is statistically significant (P<0.05). No difference between the control and the cervical radiculopathy group exists which suggests that motor changes are present in the frozen shoulder group alone.

Table 11: Significance and Z values for All Groups for Surface EMG

<table>
<thead>
<tr>
<th>MVC EMG</th>
<th>Z value</th>
<th>Significance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Vs Cervical Radiculopathy</td>
<td>-0.866</td>
<td>P=0.387</td>
</tr>
<tr>
<td>Control Vs Frozen Shoulder</td>
<td>-2.705</td>
<td>P=0.007</td>
</tr>
</tbody>
</table>

Summary

In summary there was a significant difference between the affected and unaffected sides in the frozen shoulder group in all outcomes when compared to the control group except for the modified matchstick test at 10 minutes. This suggests that vasomotor, sensory and motor trophic changes were present in the frozen shoulder group in the form of subcutaneous oedema, hyperalgesia and reduced electrical activity. It appears that in the frozen shoulder group, subcutaneous oedema can be detected when measured 5 minutes following compression, but is no longer detectable at 10 minutes. One interpretation may be that the existence of subcutaneous oedema is mild in frozen shoulder which may be why it is only detectable at 5 minutes post compression. The results also suggest that in cervical radiculopathy the only trophic change present is hyperalgesia.

4.1.5 Sensitivity Analysis

To determine whether the significant differences obtained were sensitive indicators of pathology, sensitivity analysis was performed. Sensitivity values for all outcomes can be seen in table 10. As discussed in the data analysis section pg., the cut off point for the modified matchstick test and pressure pain rating was +2, based on the hypothesis that trophic changes would be greater in the affected side. This value was
considered to be the lowest cut off which could be used and thus no further analysis is shown.

For the EMG outcome, the hypothesis stated that the maximum voluntary contraction would be reduced on the affected side in comparison to the unaffected side in the experimental groups. Calculations with cut off values of 0.5 and 0.75 were conducted (see appendix-pg.….for both cervical radiculopathy and frozen shoulder). The results in table 11… show that using a ratio cut off value of 0.5, the sensitivity in cervical radiculopathy was 0.16 and in frozen shoulder was 0.25. If a higher ratio cut off value of 0.75 was used, the sensitivity increased to 0.42 in cervical radiculopathy, and 0.59 in frozen shoulder.

**Table 12: Sensitivity Calculations for each Outcome in Cervical Radiculopathy and Frozen Shoulder.** (Modified Matchstick Test=MMST; Numerical Rating Scale =NRS; Electromyography=EMG)

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Sensitivity in Cervical Radiculopathy</th>
<th>Test Sensitivity in Frozen Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMST 5 minutes</td>
<td>0.06</td>
<td>0.31</td>
</tr>
<tr>
<td>MMST 10 minutes</td>
<td>0.16</td>
<td>0.28</td>
</tr>
<tr>
<td>NRS</td>
<td>0.39</td>
<td>0.41</td>
</tr>
<tr>
<td>EMG Sensitivity (cut off 0.5)</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>EMG Sensitivity (cut off 0.75)</td>
<td>0.42</td>
<td>0.59</td>
</tr>
</tbody>
</table>

The hypothesis in section 2.6 stated that trophic changes would be sensitive indicators of frozen shoulder pathology but not of cervical sensory radiculopathy. However the results above show that none of the tests in either condition are sensitive indicators of pathology.

(For information purposes, appendix… pg… also shows the specificity calculations for the 3 tests. These demonstrate that although sensitivity is low, specificity is high, however as this test is not likely to be used in general musculoskeletal screening to exclude those without the disease these values are not relevant).
4.2 Results for Experiment 2

Study Aim: The aim of experiment 2 was to determine the effects of cortico-steroid injection on trophic changes in frozen shoulder.

The hypothesis for experiment 2 stated that there would be a reduction in vasomotor and sensory trophic changes and an increase in motor changes in subjects with frozen shoulder following injection. To determine whether these changes had occurred in subjects with frozen shoulder the differences between the affected and unaffected shoulders were calculated, before and 4 weeks after injection for each trophic change investigated. The difference between the base line and the 4 week measurements were also calculated for the control group and for the subjects in the frozen shoulder group who decided not to have an injection (the non injection group).

4.2.1 Subject Characteristics

The number of subjects recruited in experiment 2 is shown in table 13 below along with the mean ages. A one-way ANOVA was conducted to determine whether there were significant differences between age across the 3 groups in but none were shown (P=0.085). A Kruskall-Wallis test was conducted which showed that there were no significant gender differences across the 3 groups (P=0.904), again a non-parametric test was used because the data was nominal.

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Mean Age (Years)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Group</td>
<td>7</td>
<td>10</td>
<td>17</td>
<td>58.12</td>
<td>8.470</td>
</tr>
<tr>
<td>Non-injection Group</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>59.00</td>
<td>10.220</td>
</tr>
<tr>
<td>Control Group</td>
<td>13</td>
<td>17</td>
<td>30</td>
<td>50.63</td>
<td>15.575</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>32</td>
<td>57</td>
<td>54.33</td>
<td>13.359</td>
</tr>
</tbody>
</table>

4.2.2 Vasomotor, Sensory and Motor Tropic Changes, Results for Experiment 2

The median and interquartile ranges were again used to demonstrate the findings because the data was not normally distributed (except for the EMG values). These can be found in table... in appendix A2... pg...and shown in figure...pg... As may be expected the interquartile range for the modified matchstick test and the numerical
rating scale showed low variability (IQR=0) in the control group, but again the injection and non-injection groups showed more score variance. Again the EMG scores on maximum voluntary contraction pg...showed generally high variability through out all groups see figure...pg...

Observation of the baseline median EMG values in all 3 groups shows that the measurements were all negative. Taking into account how the difference scores were calculated (i.e. affected side minus unaffected side) this indicates that at baseline the maximum voluntary contraction on the unaffected side was consistently greater than on the affected side resulting in a negative finding. After the 4 week period, the median value for both the injection group and the non injection group had changed from negative to positive indicating that the affected side maximum voluntary contraction had become greater than the unaffected side (injection group median change from -48.00 to 12.00mv; non-injection group median change from -64 to 2.00mv). The median value for the control group had also changed from -5.50 to -2.00mv, which showed a similar trend but remained negative indicating that the unaffected side maximum contraction was still greater.

A Wilcoxon Signed Rank Test was used to determine whether the differences between measurements at baseline and 4 weeks after injection, were significant for each trophic change. Comparisons between baseline measurements and those taken at 4 weeks were also performed for the non-injection and the control group to determine whether significant differences were unique to the injection group alone. Table 14 shows that there were no significant differences in vasomotor and sensory trophic changes between the baseline measurements and those taken at week 4, as measured by the modified matchstick test or pressure pain rating in any of the groups. However the difference in motor trophic changes as measured by EMG was statistically significant between baseline and week 4 in the injection group (P=0.001). Interestingly, the difference between the baseline and week 4 was also significantly different in the control group (P=0.045) (but there were no significant differences in the non-injection group see table 14). To ensure that these differences were not related to the unequal size of the sample (i.e. n=17 in the injection group, n=30 in the control group) a Wilcoxon test was conducted on the results obtained from the first 17 control subjects. The results can be seen in appendix.. pg.. and
showed that this control group also demonstrated a significant difference between the baseline and the 4 week measurement point (P=0.033). Though the injection group results follow the hypothesis that motor trophic changes increase following injection, the finding that this also occurs in the control group demonstrates that this finding cannot be relied upon and lacks clinical significance. In summary, the conclusion drawn is that there is no clinically significant difference between trophic changes before and after cortico-steroid injection.

Table 14: The results of significance testing between initial scores and those taken 1 month later for all groups in experiment 2. (Modified Matchstick Test=MMST; Numerical Rating Scale =NRS; Electromyography=EMG)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Control Group</th>
<th>Non Injection Group</th>
<th>Injection Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z Value</td>
<td>P Value</td>
<td>Z Value</td>
</tr>
<tr>
<td>MMST 5 minutes</td>
<td>-0.317</td>
<td>0.751</td>
<td>-0.106</td>
</tr>
<tr>
<td>MMST 10 minutes</td>
<td>-0.816</td>
<td>0.414</td>
<td>-1.069</td>
</tr>
<tr>
<td>NRS</td>
<td>-1.530</td>
<td>0.596</td>
<td>-1.841</td>
</tr>
<tr>
<td>EMG</td>
<td>-1.2006</td>
<td>0.045</td>
<td>-1.070</td>
</tr>
</tbody>
</table>

Results Summary
Thus overall it appears that trophic changes are not sensitive indicators of pathology and are not altered by anti-inflammatory medication. The implications of these findings are discussed further in Chapter 5.
CHAPTER 5

DISCUSSION AND CONCLUSIONS

Introduction
This final chapter is divided into two parts, evaluating the results of experiment 1 and 2 respectively. The aim of each study is be re-stated, the methodology is be briefly outlined to add clarity and the results are discussed in detail. Finally the chapter ends with conclusions and recommendations for further study.

5.1 Overview of Experiment 1
The aim of study 1 was to determine whether clinical tests of vasomotor, sensory or motor trophic changes were sensitive indicators of cervical radiculopathy or frozen shoulder.

Experiment 1 was a non-randomized, controlled study with 93 subjects, (control n=30, cervical radiculopathy n=31, frozen shoulder n=32). Trophic changes were measured in the C5 segment (specifically over the lateral aspect of the shoulder), the area to which pain normally refers in C5 radiculopathy and frozen shoulder. Measurements were taken from each shoulder and the difference between the affected and unaffected side was calculated for each outcome tested. Clinical tests were used to ensure that if trophic changes were found to be sensitive indicators of pathology, they would be low cost, easy to perform and would thus be able to have a high impact to a wide range of practitioners.

Vasomotor trophic changes were investigated indirectly by measuring the presence of subcutaneous oedema in the C5 segment with the modified matchstick test (a method which involved placing a cylindrical tube against the skin and exerting a known force to the free end with an algometer, resulting in skin compression). Residual skin indentations were measured at 5 and 10 minutes following compression of 5N, at a site in each deltoid muscle, 1cm above the deltoid tuberosity. This newly modified method showed substantial levels of agreement (as defined by Landis and Koch (1977) for Kappa comparisons) between baseline and
measurements at 4 weeks, (level of agreement at 5 minutes $k=0.79$; at 10 minutes $k=0.61$) thus demonstrating good to high reliability (see method pg.).

Sensory trophic changes were measured with the numerical rating scale following algometer pressure of 35N, within the C5 segment at the site of the motor point in each deltoid muscle. Reliability of this technique was demonstrated by comparison of the levels of agreement between measurements taken at baseline and at 4 weeks and again substantial levels of agreement were shown ($k=0.93$) (Landis and Koch 1977).

Motor trophic changes were measured using surface electromyography in the C5 segment (deltoid muscle). The root mean square peak amplitude parameter of the maximum voluntary contraction was used. Both the maximum voluntary contraction (MVC) and a normalized value following low effort muscle activity (abduction 1kg) were trialled, however as reliability values were particularly low for the normalized value, (intra-class correlation coefficient = 0.25) this was excluded from the main experiment and the MVC method demonstrating moderate reliability was used (intracllass correlation coefficient = 0.60).

5.2 Discussion of the Results of Experiment 1
The results showed that in subjects with cervical radiculopathy, sensory trophic changes were the only findings shown to be significantly different to the control group ($P=0.000$). However in the frozen shoulder group, the results showed that vasomotor changes measured with the modified matchstick test at 5 minutes, sensory changes tested by pressure pain rating and motor changes tested with EMG of the maximum voluntary contraction were all significantly different when compared to the control group ($P=0.033$, $P=0.003$ and $P=0.007$ respectively). Despite the statistically significant difference between the control and the experimental groups, these differences were not clinically relevant. This was further shown by the sensitivity analysis which demonstrated that trophic changes were not sensitive indicators of pathology in either group. Sensitivity analysis using a cut off value of +2 for vasomotor changes at 5 minutes showed values of 0.06 and 0.31 for the cervical radiculopathy and frozen shoulder groups respectively, sensitivity analysis at 10 minutes was similarly low. A lower cut off value would have yielded higher
sensitivity values but this was not considered clinically useful and thus the cut off value was kept at +2.

The sensitivity of pressure pain rating was slightly higher at 0.39 and 0.41 for cervical radiculopathy and frozen shoulder respectively. Though the sensitivity was slightly higher for sensory trophic changes, these values were not considered to be clinically useful to assist diagnosis. The cut off value of +2 was again considered to be clinically appropriate, though it is acknowledged that this value is based on clinical experience. A literature search to determine the appropriate level for the pain score ‘cut off’ revealed that the clinical significance of pain scales such as the NRS or VAS has not yet been studied widely. Ernst et al, (1998) considered the clinical significance of pain scores following administration of cortico-steroid medication for the management of pain following herpes zoster, and concluded that the clinical significance of a reduced pain scores, has yet to be determined. Thus a cut off value of less than +2 was not considered to be clinically relevant and therefore no further analysis was undertaken.

Sensitivity analysis of EMG from maximum voluntary contraction was conducted using a ratio between affected and unaffected side rather than an absolute value (see method pg... for details). The cut of value which was considered to be most clinically relevant again revealed poor sensitivity values of 0.16 and 0.25 for the cervical radiculopathy and frozen shoulder groups respectively. Raising the cut of value did yield significantly more sensitive results (see sensitivity table 12, pg..), however this would also have raised the likelihood false positives and reduced the clinical relevance, therefore the lower cut off value was maintained. It was acknowledged in the section 3.4 that the reliability of surface EMG in this study was on the lower limit of acceptable reliability. If these results had been shown to be sensitive indicators of pathology then the usefulness of findings produced would have to be considered in light of the fact that the EMG test was only moderately reliable. However as the results were not shown to be sensitive, further discussion is not required.
Although studies to date such as Giamberardino et al, (2005), Wesselman and Lai (1997), Galletti et al, (1990) and Gunn and Milbrandt (1978), have stated that trophic changes can be used as indicators of pathology in visceral, musculoskeletal and radicular pathology, the results of this study suggest that vasomotor changes tested by measuring subcutaneous oedema, sensory changes tested by pressure pain rating and motor changes tested with surface EMG during maximum voluntary contraction are not sensitive indicators of neuromusculoskeletal pathology such as cervical radiculopathy and frozen shoulder.

In Chapter 2 page., the study by Leis et al, (2004) was discussed which hypothesized that flare response and plasma extravasation may have different mechanisms. This hypothesis arose following the finding that skin blood flow measurements indicating flare response were found in complex regional pain syndrome patients, but that plasma extravasation was not. It is therefore possible that other trophic changes may be sensitive indicators of pathology and thus generalised statements cannot be made regarding the sensitivity of all trophic changes.

5.3 Limitations of Experiment 1

The use of convenience or consecutive rather than random sampling may mean that the sample recruited was not truly representative of the range of subjects with cervical radiculopathy or frozen shoulder. Randomization would have been superior, but difficulties in obtaining the required sample size prevented this method. The lack of blinding was also a limitation of this study and could have led to the introduction of assessment bias (Bland 2000), particularly when determining the outcome of the modified matchstick test. Unfortunately because of the constraints of the study, (financial and time), the risk of assessment bias could not be excluded. It has been suggested that non-blinded examiners may bias the results positively or, in an attempt to compensate may in fact, bias the results negatively, thus both of these scenarios must be considered with respect to the results of this study.

As discussed in the data analysis section, when determining the difference between the affected and unaffected side, the control group was matched to the experimental group. A variety of arbitrary calculations for the control group were considered such as subtracting the left side from the right side in the first 50% of subjects and then
reversing this for the second 50% and vice versa. All of the calculations revealed the same significant results (i.e. different z and p values, but the same significant or non significant outcome). The only change occurred when all left sides were taken from all right sides in the control group. This calculation revealed no significant differences between groups in all outcomes except for the modified matchstick test at 5 minutes for the frozen shoulder group, which was significant when this process was used. However, as outlined in the data analysis section, exact matching to the affected group was recommended by the consulting statistician (Holder 2007) to reduce the effects of error variance, and thus this procedure was maintained.

Finally an increase in the amount of pressure used in the modified matchstick test may have resulted in more significant values particularly for the sensitivity analysis. However when testing for subcutaneous oedema with the modified matchstick test, the amount of pressure used had to be kept to a relatively low level to ensure that skin was not broken during pressure by the cylindrical plastic tube. Though higher pressure may have been useful it was not considered appropriate as the aim was to develop a clinical test to be used with a variety of patients some of whom would not tolerate this pressure due to increases in pain and some of whom may have frail skin which could be damaged by the test.

In summary significant differences in vasomotor, sensory and motor trophic changes between the control and the frozen shoulder group were found, but in the cervical radiculopathy group only sensory changes were significantly different. However none of these changes were sensitive indicators of pathology and are thus not clinically relevant.

5.4 Overview of Experiment 2
The aim of experiment 2 was to determine whether trophic changes were significantly different after corticosteroid injection into the shoulder joint in subjects with frozen shoulder.

17 subjects with frozen shoulder were recruited for shoulder joint injection from the pool of 32 subjects in study 1. 10 subjects were also recruited as a further control from study 1 who did not consent to injection but who agreed to undergo tests at
baseline and 4 weeks later (non injection group). Comparisons of both groups were made to the control group (n=30). All subjects were subjected to the same tests used in experiment 1. The injection group then underwent a shoulder joint injection and then all groups were subject to measurements again at 4 weeks.

5.5 Discussion of the Results of Experiment 2

The results show that there were no significant differences between baseline measurements and those taken at 4 weeks for the modified matchstick test and pressure pain rating, which suggests that injection has no effect on vasomotor and sensory trophic changes. However the finding that EMG scores are significantly different in both the injection group and the control group (P= 0.001 and 0.045 respectively) suggests that these results cannot be relied upon as a basis from which to draw conclusions regarding the effects of cortico-steroid on motor changes. The finding that motor trophic changes were significantly different in the control group was unexpected as analysis of the control group when testing reliability, comparing the baseline measurements with those at 4 weeks, with a paired samples T Test, had shown no significant difference between the 2 time periods P=0.091 (pg…appendix). However in the control group analysis, calculations had been conducted by arbitrarily taking all left side values from right side values and thus calculations were slightly different from those conducted when the control group was matched to the experimental groups. In summary the results of experiment 2 suggest that cortico-steroid injection has no effect on trophic changes.

5.6 Limitations of Experiment 2

As with study 1, the lack of randomization and blinding were significant limiting factors in this study. The power calculations for study 2 showed that 17 subjects per group were required however due to drop outs the non injection group was reduced to 10 subjects which increased the risk of a type 2 error (i.e. concluding that there was no difference between groups when they are in fact different) (Pallant 2001).

Finally if the results had shown that there were significant differences between baseline and week 4 measurements after injection, the inclusion of formal methods to monitor correlations between trophic changes, general pain levels and functional recovery may have been useful.
5.7 Conclusions and Recommendations

Experiment 1 aimed to determine whether trophic changes were sensitive indicators of neuromusculoskeletal pathology in cervical sensory radiculopathy and frozen shoulder. Though significant differences were shown to exist between the experimental and the control groups, these differences were not shown to be sensitive indicators of pathology in frozen shoulder or cervical sensory radiculopathy. The results of this study contradict the suggestions made by other authors in the field that trophic changes could be useful in the diagnostic process. Further work to investigate the sensitivity of other trophic changes such as plasma extravasation may be useful to determine whether certain changes are more sensitive than others.

The aim of experiment 2 was to determine whether cortico-steroid injection had an effect on the existence of trophic changes, particularly to determine whether vasomotor and sensory trophic changes were reduced and motor changes were increased after injection. The results from the first experiment showed that there was a significant difference between the control and the frozen shoulder group in 3 out of 4 of the trophic changes investigated, however generally the results of experiment 2 do not reveal a significant change after injection. A significant difference in motor trophic changes was found in the injection group, however as significant differences in the control group between baseline and measurement at 4 weeks were also found these findings were not considered to be clinically relevant. Overall it does not appear that the trophic changes investigated in this study are significantly changed by administration of corticosteroid, which also suggests that trophic changes do not appear to be useful as a sign of recovery. Further studies to determine whether trophic changes are reduced following injection in the long term may be useful, as well as other studies investigating other anti-inflammatory medication.
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APPENDIX A1

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APPENDIX A1

A1.1 Pilot Study Cervical Spine Inclusion Criteria
The pilot study was conducted to determine the inclusion criteria for cervical spine radiculopathy. A variety of signs and symptoms were assessed for subjects referred with C5 Cervical Radiculopathy and the results are listed below for the 10 subjects screened in table A1.1 to table A1.3

Table: A1.1 Pain Location, Pain Score and Shoulder Pathology for Cervical Radicular pilot study group

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Pain Location</th>
<th>NRS Score</th>
<th>Passive Movements</th>
<th>Resisted Movements</th>
<th>Shoulder Pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C5</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>C5</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>C5</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Diffuse</td>
<td>3</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>C5</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>C5</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>C5</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>C5</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>C5</td>
<td>9</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>C5</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Table: A1.2 Pain on Movements of Cervical spine and Joint Palpation for Cervical Radicular Pilot Study Group

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Pain on Rotation towards affected side</th>
<th>Pain on side flexion away from affected side</th>
<th>Pain began in neck</th>
<th>Pain began in arm</th>
<th>Pain on palpation of multiple C spine jts</th>
<th>Pain on palpation of C5 jts only</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>
Table: A1.3 Sensory/motor disturbance from Cervical Radicular pilot study group

<table>
<thead>
<tr>
<th>Subject number</th>
<th>Reflex loss</th>
<th>Myotome weakness</th>
<th>Parasthesia</th>
<th>Anaesthesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>10</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>
A1.2 Modified Matchstick Test Pilot Study Procedure and Data

The pilot study was conducted to determine the most appropriate compression force required to test for subcutaneous oedema and the time it took for the skin compression to return to normal.

Procedure

5 volunteers subjects with no history of cervical or shoulder pathology were randomly selected from 30 staff working in an NHS outpatient department. Subjects were positioned in a relaxed, supported, seated position with feet placed on the floor, knees and hips at 90 degrees. The skin overlying the deltoid muscle, 1cm proximal to the deltoid tuberosity was identified and the plastic guide tube was placed vertically on the skin. Compression was applied to the skin with an algometer (Wagner Instruments, USA), via the free end of the plastic guide tube in increments of 2.5N, 5N, 7.5N and 10N. The algometer was fitted with a rubber stop to prevent sliding between the algometer and the compression tube. To determine the normative data for the length of time for which compression should be observed, the subjects were again exposed to skin compression (3 hours later) and the time taken for skin recovery was observed following compression with force levels of 5N.

Results

The results for the ideal compression force are shown in table A1.4. In summary force over 5N tended to be considered painful by some volunteer subjects, because of the small surface area of the guide tube, even though it was blunt. In contrast a force of 2.5N did not leave a consistent skin indentation, therefore a force of 5N was deemed most suitable for this study. Timing the skin recovery from compression can be seen in table A1.5. The average time for skin indentation following compression via algometry of 5N was 4.9 minutes (4.8 minutes for the right and 5 minutes for the left side). Therefore it was determined that in the main experiment indentation marks would be observed at 5 minutes following the test. As 2 subjects also had evidence of residual skin indentation at 6 minutes, it was decided that a final cut off point at 10 minutes would be used to determine subjects with marked oedema.
Table A1.4 The Results of the Pilot Study to determine optimum level of compression force for the modified matchstick test.

Boxes which state ‘unable to complete’ indicated where the test was too painful to proceed.

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Subject 1 (minutes)</th>
<th>Subject 2 (minutes)</th>
<th>Subject 3 (minutes)</th>
<th>Subject 4 (minutes)</th>
<th>Subject 5 (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5N</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5.0N</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>7.5N</td>
<td>15</td>
<td>Unable to complete</td>
<td>Unable to complete</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>10N</td>
<td>Unable to complete</td>
<td>Unable to complete</td>
<td>Unable to complete</td>
<td>Unable to complete</td>
<td>Unable to complete</td>
</tr>
</tbody>
</table>

Table A1.5 The Results of the Pilot Study to determine the time taken for skin compression to return to normal following the modified match stick test.

<table>
<thead>
<tr>
<th>Subject number</th>
<th>Right Deltoid Compression (minutes)</th>
<th>Left Deltoid Compression (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>4.8</td>
<td>5</td>
</tr>
</tbody>
</table>
A1.3 Standards for Agreement

**Strength of Agreement using the Kappa Coefficient**

Landis and Koch (1977)

<table>
<thead>
<tr>
<th>Kappa Coefficient</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Poor</td>
</tr>
<tr>
<td>0.01-0.20</td>
<td>Slight</td>
</tr>
<tr>
<td>0.21-0.40</td>
<td>Fair</td>
</tr>
<tr>
<td>0.41-0.60</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.61-0.80</td>
<td>Substantial</td>
</tr>
<tr>
<td>0.81-1.0</td>
<td>Almost Perfect</td>
</tr>
</tbody>
</table>

**Strength of Agreement using the Intraclass Correlation Coefficient**

Portney and Watkins (1993)

Below 0.75 poor to moderate reliability
0.75 to 0.90 good to excellent reliability
A1.4: Normalization and Procedure for Surface EMG Data Collection

Normalization

To enable comparisons of electrical activity to be made between different individuals or different studies, a normalization procedure is commonly employed (Winter 1991). The procedure should involve taking a reference value (such as the maximum voluntary contraction) and then expressing the test EMG value as a percentage of this value. Raw or processed versions of data can be used for normalization (Soderberg and Knutson 2000). A variety of normalization procedures have been used but there is still debate about the most appropriate and effective normalization procedure, with the rationale for the procedure being reported as ‘often based on logic or opinion’ (Soderberg and Knutson 2000). Four normalization procedures have been described in the literature which include the:

a) Isometric Maximum Voluntary Contraction (MVC) (Yang and Winter 1984)
b) Sub-maximal Voluntary Contraction (Yang and Winter 1983)
c) Peak EMG value obtained during a dynamic activity (Knutson and Richards 1979) and
d) Mean EMG value obtained during a dynamic activity (Winter and Yack, 1987).

Studies have shown wide ranging levels of reliability for all normalization techniques, despite studies having similar levels of methodological quality. MVC and sub-maximal normalization methods were compared (Roe et al, 2006) showing that MVC normalization was significantly more reliable than sub-maximal normalization (intra-class correlation coefficient for intra-day reliability for 3 MVC measurements was 0.92, coefficient of variation of 13%), whereas sub-maximal normalization showed very poor repeatability (ICC values of 0.15 and a coefficient of variation of 29%). In contrast, Yang and Winter (1983) considered the reliability of MVC versus sub-maximal normalization and found that sub-maximal values were more reliable than MVC. The intra-class correlation coefficients across a 3 day period ranged from 0.59-0.81 for the MVC; 0.81-0.93 for 50% MVC and 0.87-0.95 for 30% MVC, demonstrating the most reliability over 3 days for the 30% MVC contraction.
Knutson et al, (1994) compared the MVC, peak dynamic and mean dynamic normalization methods using the gastrocnemius muscle in a study of 20 subjects with ‘anterior cruciate deficient’ knees and 20 control subjects, showing that MVC normalization was most reliable in comparison to the mean or peak dynamic method. However in contrast, Morris et al, (1998) investigated the reliability of 3 normalization procedures (MVC, peak dynamic and mean dynamic), in the rotator cuff muscles, using needle EMG in a small controlled study (n=5). The results showed that the MVC procedure had higher levels of variation on repeated testing (overall coefficient of variation (CV) =53%), in comparison to the peak (CV =8%), or mean dynamic methods (CV =12%).

In light of variations in the literature, Soderberg and Knutson (2000) have recommended that MVC should be used for the normalization procedure until further literature supporting the optimum procedure for sub-maximal normalization is available. They also make a strong case that as the majority of studies have used the MVC normalization procedure, the results of work from MVC studies can be more easily compared. Following these recommendations a normalization procedure with the maximum voluntary contraction model, was employed. Reliability analysis was conducted with 20 control subjects, measuring at baseline and at 4 weeks (see procedure below). However, statistical analysis demonstrated that the intra-class correlation coefficient was very low at 0.25, and thus this procedure was not considered to be reliable enough to use in the main study.

**Normalization Procedure Used**

**Subject Position**

Subjects were seated in an upright position on an adjustable plinth, with hips and knees at 90 degrees and feet placed in neutral on the floor as used by Roe et al, (2006). The shoulder under test was positioned at 45 degrees of glenohumeral abduction in the scapula plane (elbow and wrist joint neutral).

**Electrode Placement**

Prior to placing the electrodes, the skin was cleaned with a mediswab alcohol wipe to reduce skin impedance (Kamen 2004). One electrode was placed on each deltoid
muscle midway between the greater tuberosity and the deltoid tuberosity, parallel with the muscle fibres to ensure a consistent signal.

Prior to the procedure subjects were given the opportunity to practice before any data was collected. Following the maximum voluntary contraction data collection, subjects rested for a 5 minute period. A 1kg wrist weight (Reebok, USA) was attached to the subject’s wrist (a 1kg weight was also used by Nordander et al, 2004). Subjects were asked to raise the arm to 45 degrees of abduction, with the palm of the hand facing towards the floor, and were then asked to hold this position for 4 seconds. Each subject was initially asked to practise this procedure twice, prior to data collection. Following rehearsal, each subject was then asked to perform the test procedure 3 times with a 30 second rest period between each contraction. The EMG amplitude was recorded and the average of the 3 values was then calculated.
A1.5 Distribution of Scores for the Surface EMG Reliability Tests

This section shows the Kolmogorov-Smirnov Test results and the distribution of scores for surface EMG Baseline and 4 week Measurements for 20 Control Subjects. Kolmogorov-Smirnov values greater than 0.05 indicate a normal distribution and those less than 0.05 indicate a non-normal distribution of scores. The scores for the MVC EMG measurements at baseline and week 4 are both greater than 0.05, and are thus normally distributed which is reflected in the histograms in figures A1.1 and A1.2.

Table A1.6 Results of the Kolmogorov-Smirnov Test for Surface EMG at Baseline and 4 week for 20 control subjects

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Statistic</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMG MVC at Baseline</td>
<td>.186</td>
<td>.069</td>
</tr>
<tr>
<td>EMG MVC at 4 weeks</td>
<td>.108</td>
<td>.200</td>
</tr>
</tbody>
</table>

Figure A1.1 Distribution of Scores for Surface EMG Reliability Test, Baseline values for 20 control subjects
Figure A1.2 Distribution of Scores for Surface EMG Reliability Test, 4 week values for 20 control subjects

Mean = -5.45
Std. Dev. = 36.491
N = 20

Histogram

Repeat test difference MVC

Frequency

-100 -50 0 50 100

Mean = -5.45
Std. Dev. = 36.491
N = 20
A1.6 Measurement Error

Surface EMG (rms)

Table A1.7 The results of One Way ANOVA to determine within subjects standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within Groups</td>
<td>45206.500</td>
<td>20</td>
<td>2260.325</td>
</tr>
</tbody>
</table>

N.B. The standard deviation is the square root of the residual within groups mean square, i.e. square root of 2260.325 = 47.54. Measurement error is 2x47.54, which is 95.08mv

The between subject variance was calculated by the statistician using the following calculation:

1466+2260=3726
Square root of 3726=61.04mv

Reported within 2 standard deviations this is 2x61.04=122.08mv.
A1.7 Patient Information Leaflets and Consent Forms

Date 28.2.06: Version 5

Information About the Study For Volunteers

1) Study Title
Investigation of trophic changes (skin changes) in C4/5 cervical dysfunction (neck pain) and frozen shoulder.

2) Invitation Paragraph
You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you.

3) What is the purpose of this study?
This research study which began in 2000 involves collecting information and testing patients with neck and shoulder problems to help improve diagnosis and treatment. It is due to finish in 2005. Neck pain and frozen shoulder are common complaints that affect patients attending for physiotherapy and can be very difficult to diagnose and treat. This study looks at investigating simple changes that occur to the skin thickness and muscle tone to see if these simple changes can be used to aid diagnosis rather than sending patients for more complex tests.

4) Why have I been chosen?
Patients who have a frozen shoulder or who have neck pain that sends pain into the shoulder area will be asked to take part in the study. There will also be a group of volunteers who have no neck and shoulder problems and you are invited to be one of these volunteers. The study aims to test 25 patients.

5) Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to
take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

6) **What will happen if I have to take part?**

If you agree to take part you will be asked to participate in the 3 tests listed below:

a) **Test 1**

Sitting whilst the therapist palpates the muscle to see if tender knots are present in the middle of the muscle.

b) **Test 2**

Sitting whilst the therapist applies a firm pressure to the skin around the shoulder to look for very subtle areas of swelling and thickening within the skin. The skin indentation which occurs after pressure will be photographed.

c) **Test 3**

The therapist will place small electrodes on the surface of the skin to look for tightness in the muscles around the neck and shoulder whilst asking you to tense your muscles. These electrodes are connected to a small machine called an EMG which shows changes in the muscle function. The test is completely **harmless** and **painless**.

d) You will be asked to be tested 2 times. This will occur at the initial session and 1 month following the first session.

7) **What do I have to do?**

There are no restrictions to your lifestyle. The tests will be completed when you attend your normal treatment sessions.

8) **What is the drug or procedure that is being tested?**

There is no drug being tested.

9) **What are the alternatives for diagnosis and treatment**

Not applicable for volunteers.

10) **What are the side effects of any treatment received when taking part?**

There are no side effects. Some of the palpation tests may cause discomfort.
11) What are the possible disadvantages and risks of taking part?
There are no risks to taking part.

12) What are the possible benefits of taking part?
There is no benefit to you when taking part in the trial.

13) What if new information becomes available?
Not applicable for volunteers.

14) What happens when the research study stops?
Not applicable for volunteers.

15) What if something goes wrong?
All the tests are non invasive and non harmful. In the unlikely event of data being collected incorrectly then it may have to be repeated with your permission. If any other problems occur you may request that the tests are stopped immediately. If you are worried about the tests you may talk to me at any time.

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone’s negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms should be available to you.

16) Will my taking part in this study be kept confidential?
The results of the tests will be anonymous and during the study the results will be kept in a secure area, in line with data protection. The results of the study will be used to further the understanding of treating neck pain and frozen shoulder. The information should be collected and compiled by 2007. Any photographs taken will be destroyed once the data collection is transferred and completed.

17) What will happen to the results of the research study?
Eventually once compiled the results will be published in a medical journal and presented at medical conferences and seminars. Publication of results may include a description of symptoms found, however all information will be anonymous.

18) Who is organising and funding the research?
The study is being organised by myself with the assistance of Eastern Birmingham Primary Care Trust.

19) Who has reviewed this study?
This study has been reviewed by West Birmingham Local Research Ethics Committee and the South West Local Research Ethics Committee (in the South West of England).

20) Contact name and number
Stephanie Griffiths MSc., MCSP., FSOM. 0121 415 8594
You can also leave a message at the School of Health Sciences (Physiotherapy), University of Birmingham, Edgbaston, Birmingham, B15 2TT. 0121 414 6893
Or Partners in Health Centre, Yardley Green Road, Birmingham 0121 465 2680

Thank you very much for taking part in the study and helping to improve the diagnosis and treatment of neck pain and frozen shoulder.
Information For Frozen Shoulder Patients About the Study

1) Study Title
Investigation of trophic changes (skin changes) in C4/5 cervical dysfunction (neck pain) and frozen shoulder.

2) Invitation Paragraph
You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you.

3) What is the purpose of this study?
This research study which began in 2000 involves collecting information and testing patients with neck and shoulder problems to help improve diagnosis and treatment. It is due to finish in 2007. Neck pain and frozen shoulder are common complaints that affect patients attending for physiotherapy and can be very difficult to diagnose and treat. This study looks at investigating simple changes that occur to the skin thickness and muscle tone to see if these simple changes can be used to aid diagnosis rather than sending patients for more complex tests.

4) Why have I been chosen?
Patients who have a frozen shoulder or who have neck pain that sends pain into the shoulder area will be asked to take part in the study. There will also be a group of volunteers who have no neck and shoulder problems. The study aims to test 25 patients.

5) Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a
reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

6) What will happen if I have to take part?
If you agree to take part you will be asked to participate in the 3 tests listed below:

a) Test 1
Sitting whilst the therapist palpates the muscle to see if tender knots are present in the middle of the muscle.

b) Test 2
Sitting whilst the therapist applies a firm pressure to the skin to look for very subtle areas of swelling and thickening within the skin around the shoulder and spine including pressing the skin for indentation. The skin changes will be photographed.

c) Test 3
The therapist will place small electrodes on the surface of the skin to look for tightness in the muscles around the neck and shoulder whilst asking you to tense your muscles. These electrodes are connected to a small machine called an EMG which shows changes in the muscle function. The test is completely harmless and painless.

d) You will also be asked some general questions about your symptoms. The tests last for about 30-40 minutes and will be performed 2 times once before your injection, as well as 1 month after your injection. They do not affect your normal treatment in any way

7) What do I have to do?
There are no restrictions to your lifestyle. The tests will be completed when you attend your normal treatment sessions.

8) What is the drug or procedure that is being tested?
The drug used in your treatment is a steroid. Please make sure you read the information leaflet you were given when you decided to opt for that treatment.

9) What are the alternatives for diagnosis and treatment
Of the group of patients with frozen shoulder, a steroid injection is given to help the frozen shoulder recover quicker. If injection is not chosen for any other reason, physiotherapy will continue just as normal.

10) **What are the side effects of any treatment received when taking part?**
There are no side effects to the research tests but you may experience slight discomfort. The injection leaflet explains the side effects to the steroid injection.

11) **What are the possible disadvantages and risks of taking part?**
There are some risks to having a steroid injection and there are consequences of the local anaesthetic it is mixed with. Please see accompanying information if injection is part of your treatment. There are no risks from the study procedures.

12) **What are the possible benefits of taking part?**
There is no clinical benefit to you when taking part in the trial. However the chance to improve diagnosis for future treatment may have benefits to you if your symptoms recur.

13) **What if new information becomes available?**
Sometimes during the course of a research project, new information becomes available about the treatment/drug that is being studied. If this happens, your researcher will tell you about it and discuss with you whether you want to continue in the study. If you decide to withdraw your researcher will make arrangements for your care to continue. If you decide to continue in the study you will be asked to sign an updated consent form.

14) **What happens when the research study stops?**
When the research stops your treatment will continue with your doctor or therapist.

15) **What if something goes wrong?**
All the tests extra to the normal treatment are non invasive and non harmful. In the unlikely event of data being collected incorrectly then it may have to be repeated with your permission. If any other problems occur you may request that the tests are
stopped immediately. If you are worried about the tests you may talk to me at any time.

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone’s negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms should be available to you.

16) Will my taking part in this study be kept confidential?
All your physiotherapy records will be kept confidentially as usual, they are not needed for the study and so will not be accessed by anyone at any time before, during or after the study except when they are needed by the physiotherapist regarding your normal treatment. The results of the tests will be anonymous and during the study the results will be kept in a secure area, inline with data protection. The results of the study will be used to further the understanding of treating neck pain and frozen shoulder. The information should be collected and compiled by 2007. Any photographs taken will be destroyed once the data collection is transferred and completed.

17) What will happen to the results of the research study?
Eventually once compiled the results will be published in a medical journal and presented at medical conferences and seminars. Publication of results may include a description of symptoms found, however all information will be anonymous.

18) Who is organising and funding the research?
The study is being organised by myself with the assistance of Eastern Birmingham Primary Care Trust.

19) Who has reviewed this study?
This study has been reviewed by West Birmingham Local Research Ethics Committee and the South West Local Research Ethics Committee (in the South West of England).
20) Contact name and number
Stephanie Griffiths MSc., MCSP., FSOM.  0121 415 8594
You can also leave a message at the School of Health Sciences (Physiotherapy),
University of Birmingham, Edgbaston, Birmingham, B15 2TT.
0121 414 6893

**Or Partners in Health Centre, Yardley Green Road, Birmingham 0121 465 2680**

Thank you very much for taking part in the study and helping to improve the
diagnosis and treatment of neck pain and frozen shoulder.
Information About the Study For Patients With Neck Pain

1) Study Title
Investigation of trophic changes (skin changes) in C4/5 cervical dysfunction (neck pain) and frozen shoulder.

2) Invitation Paragraph
You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you.

3) What is the purpose of this study?
This research study which began in 2000 involves collecting information and testing patients with neck and shoulder problems to help improve diagnosis and treatment. It is due to finish in 2005. Neck pain and frozen shoulder are common complaints that affect patients attending for physiotherapy and can be very difficult to diagnose and treat. This study looks at investigating simple changes that occur to the skin thickness and muscle tone to see if these simple changes can be used to aid diagnosis rather than sending patients for more complex tests.

4) Why have I been chosen?
Patients who have a frozen shoulder or who have neck pain that sends pain into the shoulder area will be asked to take part in the study. You have been asked because you have a neck problem. There will also be a group of volunteers who have no neck or shoulder problems.

5) Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a
reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

6) What will happen if I have to take part?
If you agree to take part you will be asked to participate in the 3 tests listed below:

a) Test 1
Sitting whilst the therapist palpates the muscle to see if tender knots are present in the middle of the muscle.

b) Test 2
Sitting whilst the therapist applies a firm pressure to the skin to look for very subtle areas of swelling and thickening within the skin around the shoulder including pressing the skin for indentation. The skin indentation which occurs after pressure will be photographed.

c) Test 3
The therapist will place small electrodes on the surface of the skin to look for tightness in the muscles around the neck and shoulder whilst asking you to tense your muscles. These electrodes are connected to a small machine called an EMG which shows changes in the muscle function. The test is completely harmless and painless. They do not affect your normal treatment in any way.

7) What do I have to do?
There are no restrictions to your lifestyle. The tests will be completed when you attend your normal treatment sessions.

8) What is the drug or procedure that is being tested?
There is no drug involved in your tests.

9) What are the alternatives for diagnosis and treatment
If you do not wish to take part physiotherapy will continue just as normal.

10) What are the side effects of any treatment received when taking part?
There are no side effects to the research tests but you may experience slight discomfort.
11) What are the possible disadvantages and risks of taking part?
There are no risks to taking part.

12) What are the possible benefits of taking part?
There is no clinical benefit to you when taking part in the trial. However the chance
to improve diagnosis for future treatment may have benefits to you if your symptoms recur.

13) What if new information becomes available?
Sometimes during the course of a research project, new information becomes
available about the treatment/drug that is being studied. If this happens, your
researcher will tell you about it and discuss with you whether you want to continue in
the study. If you decide to withdraw your researcher will make arrangements for
your care to continue. If you decide to continue in the study you will be asked to
sign an updated consent form.

14) What happens when the research study stops?
When the research stops your treatment will continue with your therapist.

15) What if something goes wrong?
All the tests extra to the normal treatment are non invasive and non harmful. In the
unlikely event of data being collected incorrectly then it may have to be repeated
with your permission. If any other problems occur you may request that the tests are
stopped immediately. If you are worried about the tests you may talk to me at any
time.

If you are harmed by taking part in this research project, there are no special
compensation arrangements. If you are harmed due to someone’s negligence, then
you may have grounds for a legal action but you may have to pay for it. Regardless
of this, if you wish to complain, or have any concerns about any aspect of the way
you have been approached or treated during the course of this study, the normal
National Health Service complaints mechanisms should be available to you.

16) Will my taking part in this study be kept confidential?
All your physiotherapy records will be kept confidentially as usual, they are not needed for the study and so will not be accessed by anyone at any time before, during or after the study except when they are needed by the physiotherapist regarding your normal treatment. The results of the tests will be anonymous and during the study the results will be kept in a secure area, inline with data protection. The results of the study will be used to further the understanding of treating neck pain and frozen shoulder. The information should be collected and compiled by 2007. Any photographs taken will be destroyed once the data collection is transferred and completed.

17) What will happen to the results of the research study?
Eventually once compiled the results will be published in a medical journal and presented at medical conferences and seminars. Publication of results may include a description of symptoms found, however all information will be anonymous.

18) Who is organising and funding the research?
The study is being organised by myself with the assistance of Eastern Birmingham Primary Care Trust.

19) Who has reviewed this study?
This study has been reviewed by West Birmingham Local Research Ethics Committee and the South West Local Research Ethics Committee (in the South West of England).

20) Contact name and number
Stephanie Griffiths MSc., MCSP., FSOM.  0121 415 8594
You can also leave a message at the School of Health Sciences (Physiotherapy), University of Birmingham, Edgbaston, Birmingham, B15 2TT.
0121 414 6893

Or Partners in Health Centre, Yardley Green Road, Birmingham 0121 465 2680
Thank you very much for taking part in the study and helping to improve the diagnosis and treatment of neck pain and frozen shoulder.
CONSENT FORM

Title of Project: Investigation of trophic changes (skin changes) in C4/5 cervical dysfunction (neck pain and Frozen shoulder)

Name of Researcher: Stephanie Griffiths

Please initial box

1. I confirm that I have read and understand the information sheet dated .............................. (version ............) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

3. I understand that sections of any of my medical notes may be looked at by S Griffiths where it is relevant to my taking part in research. I give permission for S Griffiths to have access to my records.

4. I agree to take part in the above study.

Name of Patient Date Signature

Name of Person taking consent Date Signature (if different from researcher)

Researcher Date Signature

1 for patient; 1 for researcher; 1 to be kept with hospital notes
APPENDIX A2

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A2.2 Experiment 1 Histograms for all Outcomes...............................
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A2.5 Interquartile Ranges and Median Values for Experiment 1...
A2.6 Interquartile Ranges and Median Values for Experiment 2...
A2.7 Sensitivity Calculations......................................................
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APPENDIX A2

A2.1 Experiment 1 Kolmogorov Smirnov Significance Values

The information below relates to the results of experiment 1. Following analysis of the normal distribution, table A2.1 below shows the Kolmogorov Smirnov Significance Values for each group for each outcome tested. Results greater than 0.05 indicate a normal distribution and those less than 0.05 indicate a non normal distribution of scores. Thus the results show that with the exception of surface EMG for the frozen shoulder group, (P=0.186), the scores are not normally distributed. The histogram graphs below also show that the distribution of scores are generally not symmetrical showing a skewed distribution to the left or right.

Table A2.1 Kolmogorov Smirnov Significance Values

(MMST= Modified Matchstick Test, NRS= Numerical Rating Scale, EMG= Surface Electromyography of the Maximum Voluntary Contraction)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Control Matched with Cervical Radiculopathy</th>
<th>Control Matched with Frozen Shoulder</th>
<th>Cervical Radiculopathy Group</th>
<th>Frozen Shoulder Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMST 5 mins</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>MMST 10 mins</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>NRS</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>EMG</td>
<td>0.006</td>
<td>0.032</td>
<td>0.004</td>
<td>0.186</td>
</tr>
</tbody>
</table>
A2.2 Experiment 1 Histograms for all Outcomes

Histograms for all the outcomes tested in experiment 1 are listed below (figures A2.1-A2.16) in the following order:

- Modified Matchstick Test at 5 minutes for all Groups
- Modified Matchstick Test at 10 minutes for all Groups
- Numerical Rating Scale for all Group
- Surface EMG MVC Scores for all Groups

Distribution of Scores for Modified Matchstick Test at 5 and 10 minutes Post Compression for All Groups for Experiment 1

Figure A2.1 Histogram of frequency scores for the modified matchstick test at 5 minutes for the control group matched with the cervical spine group
Figure A2.2 Histogram of the frequency scores for the Modified Matchstick Test at 5 minutes for the cervical radiculopathy group

![Histogram](image1)

- Mean = 0.1
- Std Dev = 1.136
- N = 31

Figure A2.3 Histogram showing the frequency scores for the modified matchstick Test at 5 minutes for the control group matched with the frozen shoulder

![Histogram](image2)

- Mean = -0.1
- Std Dev = 1.162
- N = 30
Figure A2.4 Histogram showing the frequency scores for the modified matchstick test at 5 minutes for the frozen shoulder group.

Figure A2.5 Histogram of Control Group matched with Cervical Spine Group for modified matchstick test at 10 minutes.
Figure A2.6 Histogram showing frequency of Modified Matchstick Test scores at 10 minutes for the Cervical Radiculopathy Group

![Histogram](image1)

Mean = 0.26
Std. Dev. = 1.75
N = 31

Modified Matchstick Test Score 10 minutes Post Compression

Figure A2.7 Histogram showing Frequency Scores for the Modified Matchstick Test at 10 minutes for the Control Group Matched with the Frozen Shoulder Group

![Histogram](image2)

Mean = 0.13
Std. Dev. = 0.73
N = 30

Modified Matchstick Test Score at 10 minutes
Figure A2.8 Histogram showing Frequency Scores for the Modified Matchstick Test at 10 minutes for the Frozen Shoulder Group.

Histogram

Modified Matchstick Test Frozen Shoulder Group

- Frequency
- Modified Matchstick Test Score at 5 minutes

Mean = 0.59
Std Dev = 1.701
N = 32
Distribution of Numerical Rating Scale Scores For All Groups For Experiment 1 (Figures A2.9-A2.12)

Figure A2.9 Histogram showing Frequency of Numerical Rating Scale Scores for Control Group matched with Cervical Spine Group

Histogram

Frequency Scores for NRS Control Group matched with Cervical Radiculopathy

NRS Score

Mean = 0.23
StDev = 0.99
N = 30

Figure A2.10 Histogram showing Frequency of Numerical Rating Scale Scores for Cervical Spine Group

Histogram

Frequency Scores for NRS for Cervical Radiculopathy Group

Mean = 1.74
StDev = 2.221
N = 21
Figure A2.11 Histogram showing the frequency of NRS Scores for the Control Group matched with the Frozen Shoulder Group

Figure A2.12 Histogram showing the frequency of NRS Scores for the Frozen Shoulder Group
Distribution of Scores for Surface EMG Maximum Voluntary Contraction for Experiment 1 for All Groups (A2.13-A2.16)

Figure A2.13 Histogram showing the Frequency of surface EMG MVC Scores for Control Group Matched with Cervical Spine

Figure A2.14 Histogram Showing Frequency of Surface EMG MVC Scores for the Cervical Radiculopathy Group
Figure A2.15 Histogram showing the Frequency of Surface EMG MVC Scores for the Control Group Matched with Frozen Shoulder Group

Histogram

Mean = 12.27
Std. Dev. = 105.874
N = 30

Figure A2.16 Histogram showing frequency of surface EMG MVC scores for the Frozen Shoulder Group

Histogram

Mean = -46.56
Std. Dev. = 80.981
N = 32
A2.3 Experiment 2 Kolmogorov Smirnov Significance Values

Table A2.2 below shows the Kolmogorov Smirnov Significance Values for each group for each outcome tested. All values less than 0.05 show that the data is not normally distributed. The EMG values for the injection group and non injection group at baseline measurement for the MVC EMG outcome are normally distributed, as are all EMG values at 4 weeks. The histogram plots shown below for each outcome also reflect these findings. (NB MMST=Modified Matchstick Test, NRS=Numerical Rating Scale, EMG=Surface EMG).

Table A2.2 Kolmogorov Smirnov Significance Values

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Injection</th>
<th>Non Injection</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMST 5 minutes Baseline</td>
<td>0.019</td>
<td>0.044</td>
<td>0.000</td>
</tr>
<tr>
<td>MMST 5 minutes 4 weeks</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>MMST 10 minutes Baseline</td>
<td>0.025</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>MMST 10 minutes 4 weeks</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>NRS Baseline</td>
<td>0.006</td>
<td>0.008</td>
<td>0.000</td>
</tr>
<tr>
<td>NRS 4 weeks</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>MVC EMG Baseline</td>
<td>0.186</td>
<td>0.200</td>
<td>0.005</td>
</tr>
<tr>
<td>MVC EMG 4 weeks</td>
<td>0.074</td>
<td>0.200</td>
<td>0.200</td>
</tr>
</tbody>
</table>
A2.4 Experiment 2 Histograms for all Outcomes

Histograms for all the outcomes tested in experiment 21 are listed below (figures A2.17-A2.40) in the following order:

- Modified Matchstick Test at 5 minutes at baseline and at 4 weeks for all Groups (i.e. Injection, non-injection and control groups) (figures A2.17-A2.22)
- Modified Matchstick Test at 10 minutes at baseline and at 4 weeks for all Groups (figures A2.23-A2.28)
- Numerical Rating Scale at baseline and at 4 weeks for all Groups (figures A2.29-A2.34)
- Surface EMG MVC Scores at baseline and at 4 weeks for all Groups (figures A2.37-A2.40)

Distribution of Scores for Experiment 2 for Modified Matchstick Test (MMST) at 5 minutes Post Compression for All Groups

Baseline Scores (figures A2.17-A2.19) (i.e. pre-injection week 0)
4 week Scores (figures A2.20-A2.22) (i.e. post injection week 4)

Figure A2.17 Histogram showing the Injection Group Baseline Modified Matchstick Test Scores at 5 minutes post compression
Figure A2.18 Histogram showing the Non Injection Group Baseline Modified Matchstick Test Scores at 5 minutes

Histogram for Non Injection Group

Mean = 0.2
Std. Dev. = 2.3
N = 10

Figure A2.19 Histogram showing the Control Group Baseline Modified Matchstick Test Scores at 5 minutes post compression

Histogram for Control Group

Mean = 0.4
Std. Dev. = 1.003
N = 30
Figure A2.20 Histogram showing the Injection Group Modified Matchstick Test Scores at 5 minutes post compression at 4 weeks

Figure A2.21 Histogram showing the Injection Group Modified Matchstick Test Scores at 5 minutes post compression at 4 weeks
Figure A2.22 Histogram showing the Control Group Modified Matchstick Test Scores at 5 minutes post compression at 4 weeks

Histogram for Control Group

Mean = 0.57
Std. Dev. = 1.073
N = 30

Histograms for Modified Matchstick Test Scores 10 minutes Post Compression at Baseline for All Groups

Baseline Scores (figures A2.23-A2.25)
4 week Scores (figures A2.26-A2.28)

Figure A2.23 Histogram showing the Baseline Injection Group Modified Matchstick Test Scores at 10 minutes post compression

Histogram for Injection Group

Mean = 0.75
Std. Dev. = 2.035
N = 37
Figure A2.24 Histogram showing the Baseline Non-Injection Group Modified Matchstick Test Scores at 10 minutes post compression

Figure A2.25 Histogram showing the Baseline Control Group Modified Matchstick Test Scores at 10 minutes post compression
Figure A2.26 Histogram showing the Modified Matchstick Test Scores at 10 minutes post compression for the Injection Group at 4 weeks

Figure A2.27 Histogram showing the MMST Scores at 10 minutes post compression for the Non Injection Group at 4 weeks
Figure A2.28 Histogram showing the MMST Scores at 10 minutes post compression for the Control Group at 4 weeks

Histogram for Control Group

Mean = 0.23
Std. Dev. = 0.626
N = 30

MMST 10 minutes post compression at 4 weeks

Histograms showing the frequency of NRS Scores for Experiment 2 at Baseline and 4 weeks for All Groups. Baseline Scores (figures A2.29-A2.31), Scores at 4 weeks (A2.32-A2.34)

Figure A2.29 Histogram showing Baseline NRS Scores for the Injection Group

Histogram for Injection Group

Mean = 1.35
Std. Dev. = 3.983
N = 17
Figure A2.30 Histogram showing Baseline NRS Scores for the Non-Injection Group

![Histogram](image)

Mean = 1.4
Std. Dev. = 2.547
N = 10

Baseline NRS Scores

Figure A2.31 Histogram showing Baseline NRS Scores for the Control Group

![Histogram](image)

Mean = 0.43
Std. Dev. = 0.774
N = 30

Baseline NRS Scores
Figure A2.32 Histogram showing NRS Scores for the Injection Group at 4 weeks

![Histogram for Injection Group](image)

Mean = 0.53  
Std. Dev. = 2.853  
N = 17

Figure A2.33 Histogram showing NRS Scores for the Non-Injection Group at 4 weeks

![Histogram for Non-Injection Group](image)

Mean = 0.1  
Std. Dev. = 0.994  
N = 10
Figure A2.34 Histogram showing NRS Scores for the Control Group at 4 weeks

Histogram for Control Group

Mean = 0.3
Std. Dev. = 0.596
N = 30

Histograms showing Surface EMG MVC Scores for Experiment 2 at Baseline and 4 weeks for all Groups
Baseline Scores (figures A2.35-A2.37), 4 week Scores (figure A2.38-A2.40)

Figure A2.35 Histogram showing Baseline EMG MVC Scores for the Injection Group
Figure A2.36 Histogram showing Baseline EMG MVC Scores for the Non-Injection Group

![Histogram for Non-injection Group](image)

Mean = -38  
Std Dev = 111.149  
N = 10

Baseline EMG MVC Scores

Figure A2.37 Histogram showing Baseline EMG MVC Scores for the Control Group

![Histogram for Control Group](image)

Mean = -38.4  
Std Dev = 60.301  
N = 30

Baseline EMG MVC Scores
Figure A2.38 Histogram showing EMG MVC Scores for the Injection Group at 4 weeks

Histogram

Injection Group

0 100 200 300
EMG MVC Scores 4 weeks

Mean = 48.53
Std. Dev. = 87.607
N = 17

Figure A2.39 Histogram showing EMG MVC Scores for the Non-Injection Group at 4 weeks

Histogram

for Non-Injection Group

0 -100 -200 0 100
EMG MVC Scores at 4 weeks

Mean = -6.4
Std. Dev. = 55.724
N = 10
Figure A2.40 Histogram showing EMG MVC Scores for the Control Group at 4 weeks

Histogram for Control Group

Mean = -12.27
Std Dev = 33.947
N = 30

-100 -75 -50 -25 0 25 50

EMG MVC Scores at 4 weeks
A2.5 Interquartile Ranges and Median Values for Experiment 1

As discussed in the main thesis because the data was primarily ordinal data and non normally distributed it was inappropriate to use mean and standard deviation to describe the statistics, therefore interquartile ranges and percentiles were used. The median and interquartile ranges are shown in table A2.3 and A2.4 below. Percentiles can be used when there is at least a 10 point scale (Sim and Wright 2000). In the case of the data from this study there was a range of values from −5 to + 5 when using the Modified Matchstick Test or when using the Numerical Rating Scale there was a range from −10 to +10 and thus it was possible to use percentiles to describe the data. (N.B. The positive and negative aspects of the scales do not negate each other for the purpose of using percentiles) (Holder 2007). The interquartile range (IQR) is a measure of variability, it is the range between the lower and the upper quartiles. The box plots below provide a visual representation of the data in tables A2.3 and A2.4. The median value is represented by the thick black line in the centre of the beige box, with the projections from the box reaching to the upper and lower quartiles. Starred values represent extreme data.

Table A2.3 Median Values and the Interquartile ranges for the Cervical Radiculopathy Group and the Matched Control

(MMST=Modified Matchstick Test, NRS=Numerical Rating Scale, MVC=Maximum Voluntary Contraction measured by surface EMG in millivolts, IQR=interquartile range)

<table>
<thead>
<tr>
<th>MMST 5 minutes</th>
<th>MMST 10 minutes</th>
<th>NRS (0-10)</th>
<th>MVC (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td>0.00 0</td>
<td>0.00 0</td>
<td>0.00 0</td>
</tr>
<tr>
<td></td>
<td>0.00 0</td>
<td>-10.50 113</td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>0.00 1</td>
<td>0.00 0</td>
<td>1.00 4</td>
</tr>
<tr>
<td>Radiculopathy</td>
<td>0.00 1</td>
<td>0.00 0</td>
<td>-16 109</td>
</tr>
<tr>
<td>Group</td>
<td>0.00 1</td>
<td>0.00 0</td>
<td>1.00 4</td>
</tr>
</tbody>
</table>
Table A2.4 Median Values and the Interquartile ranges for the Frozen Shoulder Group and the Matched Control

(MMST=Modified Matchstick Test, NRS=Numerical Rating Scale, MVC=Maximum Voluntary Contraction measured by surface EMG in millivolts, IQR=interquartile range)

<table>
<thead>
<tr>
<th></th>
<th>MMST 5 minutes</th>
<th>MMST 10 minutes</th>
<th>NRS (0-10)</th>
<th>MVC (mv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td>Control Group</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>Frozen Shoulder Group</td>
<td>0.00</td>
<td>2</td>
<td>0.00</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure A2.41 Box Plot showing the interquartile range for the cervical radiculopathy group and the control group for the modified matchstick test at 5 minutes.

Figure A2.42 Box Plot showing the interquartile range for the frozen shoulder group and the control group for the modified matchstick test at 5 minutes.
Figure A2.43 Box Plot showing the interquartile range for the Cervical Radiculopathy group and the Control group for the Modified Matchstick Test at 10 minutes.

Figure A2.44 Box Plot showing the interquartile range for the Frozen Shoulder Group and the Control group for the Modified Matchstick Test at 10 minutes.
Figure A2.45 Box Plot showing the interquartile range for the Cervical Radiculopathy Group and the Control Group for the Numerical Rating Scale

Figure A2.46 Box Plot showing the interquartile range for the Frozen Shoulder Group and the Control Group for the Numerical Rating Scale
Figure A2.47 Box Plot showing the interquartile range for the Cervical Radiculopathy Group and the Control Group for the EMG Maximum Voluntary Contraction

Figure A2.48 Box Plot showing the interquartile range for the Frozen Shoulder Group and the Control Group for the EMG Maximum Voluntary Contraction
<table>
<thead>
<tr>
<th>HE (mmHg)</th>
<th>MVC Endo (avg)</th>
<th>MVC Endo (avg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>105</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>110</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>115</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>120</td>
<td>89</td>
<td>89</td>
</tr>
</tbody>
</table>

**Difference in Maximum Voluntary Contraction (mV)**

![Box plot showing difference in maximum voluntary contraction (MVC)]
Section A2.6 Interquartile Ranges and Median Values for Experiment 2

The interquartile ranges and the median values are shown in table A2.6 for each group from experiment 2, for each of the 3 outcomes measured. The range of EMG scores is greater in the control and non injection group at baseline which reduces at 4 weeks. However the reverse is true for the injection group.

Table A2.6 Median values and the interquartile ranges for all 3 groups at baseline and measurements at 4 weeks

(N.B. MMST=Modified Matchstick Test, NRS=Numerical Rating Scale, MVC=Maximum Voluntary Contraction measured by surface EMG in millivolts, IQR=interquartile range).

<table>
<thead>
<tr>
<th></th>
<th>Injection Group</th>
<th>Non Injection Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
</tr>
<tr>
<td>MMST 5 minutes Baseline</td>
<td>0.00</td>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>MMST 5 minutes 4 weeks</td>
<td>0.00</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>MMST 10 minutes Baseline</td>
<td>0.00</td>
<td>3</td>
<td>0.00</td>
</tr>
<tr>
<td>MMST 10 minutes 4 weeks</td>
<td>0.00</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>NRS Baseline</td>
<td>0.00</td>
<td>4</td>
<td>0.00</td>
</tr>
<tr>
<td>NRS at 4 weeks</td>
<td>0.00</td>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>MVC EMG (mv) Baseline</td>
<td>-48.00</td>
<td>68</td>
<td>-64.00</td>
</tr>
<tr>
<td>MVC EMG (mv) at 4 weeks</td>
<td>12.00</td>
<td>95</td>
<td>2.00</td>
</tr>
</tbody>
</table>
Figure A2.49 Box Plot showing the baseline interquartile range and median values for the Modified Matchstick Test at 5 minutes for all 3 groups (Injection, Non-Injection and Control).

Figure A2.50 Box Plot showing the interquartile range and median values at 4 weeks for the Modified Matchstick Test at 5 minutes for all 3 groups (Injection, Non-Injection and Control)
Figure A2.51 Box Plot showing the baseline interquartile range and median values for the Modified Matchstick Test at 10 minutes for all 3 groups (Injection, Non-Injection and Control).

Figure A2.52 Box Plot showing the interquartile range and median values at 4 weeks for the Modified Matchstick Test at 10 minutes for all 3 groups (Injection, Non-Injection and Control)
Figure A2.53 Box Plot showing the interquartile range and median values at baseline for the Numerical Rating Scale for all 3 groups (Injection, Non-Injection and Control).

Figure A2.54 Box Plot showing the interquartile range and median values at 4 weeks for the Numerical Rating Scale for all 3 groups (Injection, Non-Injection and Control).
Figure A2.55 Box Plot showing the interquartile range and median values at baseline for the Maximum Voluntary Contraction Measured by surface EMG for all 3 groups (Injection, Non-Injection and Control).

Figure A2.56 Box Plot showing the interquartile range and median values at 4 weeks for the Maximum Voluntary Contraction Measured by surface EMG for all 3 groups (Injection, Non-Injection and Control).
Section A2.7 Sensitivity Calculations
Sensitivity Calculations are based on the following Formula (Bland 2000)

\[
\frac{\text{Number who are both disease positive and test positive}}{\text{Number who are disease positive}}
\]

Cervical Radiculopathy Group Sensitivity Calculations
Modified Matchstick Test at 5 minutes
\[
\frac{2}{31} = 0.06
\]
Modified Matchstick Test at 10 minutes
\[
\frac{5}{31} = 0.16
\]
Numerical Rating Scale with Algometry
\[
\frac{12}{31} = 0.39
\]
Maximum Voluntary Contraction Surface EMG
At 0.5 Cut off Sensitivity = \[
\frac{5}{31} = 0.16
\]
At 0.75 Cut off Sensitivity = \[
\frac{13}{31} = 0.42
\]

Frozen Shoulder Group Sensitivity Calculations
Modified Matchstick Test at 5 minutes
\[
\frac{10}{32} = 0.31
\]
Modified Matchstick Test at 10 minutes
\[
\frac{9}{32} = 0.28
\]
Numerical Rating Scale with Algometry
\[
\frac{13}{32} = 0.41
\]
Maximum Voluntary Contraction Surface EMG
At 0.5 Cut off Sensitivity = \[
\frac{8}{32} = 0.25
\]
At 0.75 Cut off Sensitivity = \[
\frac{19}{32} = 0.59
\]

A2.8 Specificity Calculations
Specificity Calculations are based on the following formula (Bland 2000)

\[
\frac{\text{Number who are both disease negative and test negative}}{\text{Number who are disease negative}}
\]
**Cervical Radiculopathy Group Specificity Calculations**

Modified Matchstick Test at 5 minutes  
29/30 = 0.96

Modified Matchstick Test at 10 minutes  
30/30 = 1

Numerical Rating Scale with Algometry  
28/30 = 0.93

MVC with Surface EMG cut off at 0.5  
27/30 = 0.90

MVC with Surface EMG cut off at 0.75  
21/30 = 0.70

**Frozen Shoulder Group Specificity Calculations**

Modified Matchstick Test at 5 minutes  
30/30 = 1

Modified Matchstick Test at 10 minutes  
29/30 = 0.96

Numerical Rating Scale with Algometry  
27/30 = 0.9

MVC with Surface EMG cut off at 0.5  
28/30 = 0.93

MVC with Surface EMG cut off at 0.75  
24/30 = 0.80
A2.9 Experiment 1 Mean, standard Deviation, Standard Error of the Mean for surface EMG

This section shows the mean, standard deviation and standard error of the mean for EMG values (for comparison purposes only). (NB Scores represent the difference between the affected and the unaffected sides.

Table A2.7 Mean, Standard Deviation and Standard Error for the Maximum Voluntary Contraction surface EMG for the Control Groups Versus the Cervical Radiculopathy and Frozen Shoulder Group

<table>
<thead>
<tr>
<th>Control Vs Cervical Radiculopathy Group</th>
<th>Control Vs Frozen Shoulder Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean EMG Control Group</td>
<td>Mean EMG Control Group</td>
</tr>
<tr>
<td>-28.00</td>
<td>12.27</td>
</tr>
<tr>
<td>Standard Deviation EMG Control Group</td>
<td>Standard Deviation EMG Control Group</td>
</tr>
<tr>
<td>102.835</td>
<td>105.974</td>
</tr>
<tr>
<td>Control Group Standard Error of the Mean</td>
<td>Control Group Standard Error of the Mean</td>
</tr>
<tr>
<td>18.775</td>
<td>19.348</td>
</tr>
<tr>
<td>Mean EMG Cervical Radiculopathy</td>
<td>Mean EMG Frozen Shoulder</td>
</tr>
<tr>
<td>-47.94</td>
<td>-46.56</td>
</tr>
<tr>
<td>Standard Deviation EMG Cervical Radiculopathy</td>
<td>Standard Deviation EMG Frozen Shoulder</td>
</tr>
<tr>
<td>94.114</td>
<td>80.981</td>
</tr>
<tr>
<td>Standard Error of the Mean Cervical Radiculopathy Group</td>
<td>Standard Error of the Mean Frozen Shoulder Group</td>
</tr>
<tr>
<td>16.903</td>
<td>14.316</td>
</tr>
</tbody>
</table>
Figure A2.61 Mean EMG Scores for the Cervical Radiculopathy Group and matched control

![Graph showing comparison between Control Group and Cervical Radiculopathy Group with error bars indicating ±2.00 SE.]

Figure A2.62 Mean EMG Scores for the Frozen Shoulder Group and matched Control

![Graph showing comparison between Control Group and Frozen Shoulder Group with error bars indicating ±2.00 SE.]

A2.10 Experiment 2 Mean, Standard Deviation and Standard Error of the Mean

The mean, standard deviation and standard error of the mean for the EMG values for experiment 2 are provided for comparison purposes only. The data is shown in table A2.10 for the control, injection and non-injection groups.

Table A2.8 Mean, Standard Deviation and Standard Error for the MVC measured with and Surface EMG for all 3 groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>Injection</th>
<th>Non Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline 4 weeks</td>
<td>Baseline 4 weeks</td>
<td>Baseline 4 weeks</td>
</tr>
<tr>
<td>Mean MVC EMG</td>
<td>12.27 3.47</td>
<td>-56.00 48.53</td>
<td>-38.00 -6.40</td>
</tr>
<tr>
<td>Standard Deviation MVC EMG</td>
<td>105.974 36.211</td>
<td>73.080 87.607</td>
<td>111.149 55.724</td>
</tr>
<tr>
<td>Standard Error MVC EMG</td>
<td>18.130 6.198</td>
<td>17.724 21.248</td>
<td>35.148 17.621</td>
</tr>
</tbody>
</table>

Figure A2.7 Mean Values for the Surface EMG maximum voluntary contraction at Baseline and at 4 weeks for the Injection, Non-injection and Control Group