

DO CLINICAL FEATURES AND MRI SUGGEST THE SAME NERVE ROOT IN ACUTE CERVICAL RADICULOPATHY?

* This study was conducted in partial fulfillment of the requirements for a master's degree at the Stellenbosch University, South Africa

ABSTRACT: *Different proposed pathophysiological mechanisms can result in variable clinical presentations of cervical radiculopathy (CR), often making it difficult to detect minor nerve root (NR) conditions. This descriptive study determined (1) the level(s) of NR involvement suggested by the distribution patterns of clinical features and detected by magnetic resonance imaging (MRI) and (2) the most common associations between the different variables in patients diagnosed with acute CR by a neurosurgeon.*

A physiotherapist blinded to the level(s) of NR involvement performed a standardized interview on 21 subjects to determine the distribution patterns of pain and paraesthesia, and a neurological examination. The Fisher exact test was used to determine associations between the different variables.

Only seven subjects presented clinically and radiologically with the same single-level NR involvement. Multiple-level presentations occurred which might be due to dermatomal overlapping, central sensitization or the possible involvement of two adjacent NR levels. Distribution patterns of motor weakness, pain and paraesthesia, and to a lesser extent sensory and reflex changes, have value in identifying the compressed NR level. For this sample the distribution patterns of radicular features identified C6 and C8 with more certainty than C7.

KEY WORDS: CERVICAL RADICULOPATHY; CLINICAL ASSESSMENT; DIAGNOSIS; NERVE ROOT LEVEL.

INTRODUCTION

The optimal, universally acceptable diagnostic criteria for cervical radiculopathy (CR) are debatable (Wainner & Gill 2000). Magnetic resonance imaging (MRI) and needle electromyography (EMG) are considered to be the most accurate means of diagnosis available. These tests are, however, very expensive, not universally available and the diagnostic accuracy thereof is not infallible (Wainner & Gill 2000). It has been demonstrated that a high percentage of subjects with structural lesions on MRI were asymptomatic (Schellhas et al

1996). According to many authors the diagnosis of CR remains largely a clinical diagnosis (Wainner & Gill 2000).

Different diagnostic tests have been purported to be useful for the clinical diagnosis of CR (Maitland 1993; Butler 2000). Clinicians rely on the distribution patterns of neurological signs and radicular symptoms like pain and paraesthesia, to determine the level of NR involvement, since these tend to have a certain predictive value (Howe et al 1977; Butler 2000). Although the interview, forms an important part of clinical decision making, very weak diagnostic value has been demonstrated. Wainner et al (2003) demonstrated that only two historical questions, one pertaining to the most bothersome area being the scapula (Sp = 0.84, Sn = 0.38, LR+ = 2.3) and the other to the influence of neck movement on the symptoms (Sp = 0.71, Sn = 0.65, LR+ = 2.23), had acceptable diagnostic value (LR > 2). The neurological examination demonstrated moderate interexaminer reliability

(Kappa between 0.16 and 0.73) and few isolated tests demonstrated acceptable diagnostic accuracy (LR+ = 2). Butler (2000) proposed that a combination of neurological signs provide a moderately accurate diagnosis, as opposed to one sign which may not offer substantial diagnostic value by itself, supporting the concept of combining tests. Wainner et al (2003) also found however that a combination of four tests was more useful in establishing a diagnosis than any single test.

The suggested areas of radicular pain representing each NR level (dermatomes) vary in the literature. Keegan & Garrett (1948) proposed that radicular symptoms such as pain are distributed in neat anatomically-fixed, non-overlapping dermatomes. However, Lundsford et al (1980) reported that only 40-60% of 295 subjects had single-level neurological signs, whereas 20-30% had multiple-level dermatomal sensory and myotomal deficits. Supporting this, Slipman et al (1998) demonstrated dermatomal over-

**Conradie M*, MScPhysio (Stell)¹,
Bester MM, MScPhysio (UWC)¹,
Crous LC, MScPhysio (Stell)¹,
Kidd M, PhD (Stell)²**

¹ Department of Physiotherapy, Faculty of Health Sciences, Stellenbosch University, PO Box 19063, Tygerberg 7505, South Africa

² Centre for Statistical Consultation, Stellenbosch University, South Africa.

CORRESPONDENCE TO:

Marlen Conradie
Department of Physiotherapy,
Faculty of Health Sciences,
Stellenbosch University, PO Box 19063,
Tygerberg 7505, South Africa
Tel: 27-21 938-9300
Fax: 27-21 931-7810
mc6@sun.ac.za (Marlen Conradie)

lapping by indicating that pain was frequently experienced in widespread, non-dermatomal areas. According to Hall & Elvey (1999) two forms of peripheral neuropathic pain have been identified following nerve injury: dysaesthetic pain and nerve trunk pain. Dysaesthetic pain results from damaged nociceptive afferent axons and is accompanied by axonal damage. In contrast nerve trunk pain results from heightened activity in chemically or mechanically sensitized nociceptive sensory fibres that innervate connective tissue of peripheral nerve trunks. This results in increased mechanosensitivity without altered conduction. It is thus possible that patients with nerve injuries can experience dysaesthetic pain or nerve trunk pain in isolation or more commonly, in combination, and this could explain the variable symptom presentation.

The purpose of this study was to determine (1) the level(s) of NR involvement suggested by the distribution patterns of the clinical features and detected by MRI and (2) the most common associations between MRI and clinical findings in patients with acute cervical radiculopathy (CR). Findings of this study can assist clinicians in their clinical reasoning by suggesting the value for the various radicular features in identifying the involved NR level(s).

METHODS

Subjects and Study design

A prospective study was performed on twenty-one consecutive patients referred by a neurosurgeon after the diagnosis of acute CR was confirmed by MRI. A sample of convenience, referred from private medical practices, was utilized.

Exclusion criteria: Chronic CR (longer than 3 months), previous cervical spinal surgery, cervical myelopathy without any radicular involvement, known malignant disease, diabetes mellitus, diagnosed inflammatory joint disease, work related compensation

claims and/or pending litigation.

Ethical clearance was obtained from the relevant Research Ethics Committee (number 2003/027/N) and all subjects provided informed consent.

Procedure

A physiotherapist blinded to the suspected level(s) of NR involvement detected by MRI, performed a standardized interview and neurological examination as described by Butler (2000) to determine the level(s) of NR involvement suggested by the distribution patterns of clinical features. Findings of the neurological examination tests were graded as either normal or altered in comparison to the opposite extremity.

Determining level(s) of NR involvement

Criteria for analyses of clinical findings. Since dermatomal maps presented in several textbooks differ slightly from each other (Maitland 1993; Patten 1995; Butler 2000), the most commonly documented areas representing each NR level were summarized. From these, the researcher compiled specific criteria (Table 1) for determining the involved NR by selecting the "signature zones" of each spinal nerve (Nitta et al 1993). To avoid dermatomal overlapping, the index and ring fingers were excluded from the criteria. The clinical findings were analysed to determine the involved NR level(s) for each radicular symptom and sign separately.

MRI findings. The radiologists' reports were accessed after completion of the clinical examination. Compression of NR's was considered if the radiologists report indicated that MRI detected definite or slight NR compression. Ashkan et al (2002) demonstrated that the sensitivity of MRI for diagnosing CR was 93%, with a positive predictive value of 91% and a negative predictive value of 25% in 48 patients who underwent MRI and neurophysiological studies preoperatively.

Instrumentation

Data were recorded on a self-designed data capturing sheet that consisted of three sections: section A - demographic data; section B - descriptors of pain and paraesthesia and section C - the neurological findings. The distribution patterns of pain, paraesthesia, and altered sensation were mapped out on separate body charts.

Statistical analysis

Descriptive and inferential statistics were used for the analysis of data. Associations between the suggested level(s) of NR involvement for different variables were assessed with the Fisher exact test. A statistical significance level of 5% was selected and all significant associations ($p < 0.05$) are indicated by * in the presented histograms.

RESULTS

The demographic information, the level(s) of NR involvement suggested by MRI, as well as clinically detected radicular features are outlined in Table 2, indicating a variable clinical presentation.

Level(s) of NR involvement

MRI

MRI detected compression of a single NR in 13 subjects and multiple NR's in 8 subjects. The majority of subjects had compression of C7, followed by C6, C8 and C5.

Clinical signs and symptoms

Neurological sign(s) were detected in 19 subjects. Not all three neurological signs occurred in all the subjects. Motor weakness was detected in 17 subjects of whom 12 subjects presented with a single-level and 5 subjects with multiple-level myotomal deficits. Reduced reflexes were detected in 14 subjects. Sensory changes occurred in 14 subjects of whom 11 had a single-level and 3 multiple-level sensory deficits.

Table 1: Criteria for determining suggested level(s) of NR involvement regarding myotomes, reflexes, pattern(s) of sensory disturbances and pain pattern(s)

(Compiled from: Keegan & Garrett 1948; Maitland 1993; Nitta et al 1993; Butler 2000).

NR	Myotome	Reflex	Only Pain	Pain, Paraesthesia, Sensory changes
C5	Shoulder abduction	Biceps		Deltoid, lateral upper, radial forearm, but not into hand
C6	Elbow Flexion	Biceps	Anterolateral upper arm (biceps)	Radial forearm, thumb
C7	Elbow Extension	Triceps	Posterolateral upper arm (triceps)	Posterior forearm, middle finger
C8	Thumb Extension	Triceps	Medial upper arm	Ulnar forearm, little finger

All 21 subjects experienced pain of whom 14 subjects reported a single-level and 7 multiple-level dermatomal pain patterns. In only 12 subjects the pain was distributed in the corresponding dermatome of compressed NR level

identified by MRI.

Pain was commonly experienced over the upper trapezius, posterior neck and medial scapular border, and was more frequently experienced over the upper- and forearm, than the distal fingers. Over-

lapping between C6 and C7 NR's regarding the index finger and C7 and C8 NR's regarding the ring fingers occurred.

Paraesthesia was reported by 17 subjects, of whom 13 had a single-level and 4 multiple-level distribution patterns.

Table 2: Demographic data for the 21 subjects and suggested level(s) of NR involvement for MRI, radicular symptoms and signs.

Demographic information					Level(s) of NR involvement suggested by:													
No	Age	Gender	Extremity	Referred Rx	MRI				Pain			Paraesthesia			Motor	Reflex	Sensory	
					C5	C6	C7	C8	UA	FA	Finger	UA	FA	Finger			LT	SP
1	49	Female	Left	Conservative	No	No	Yes	No	C7	C7	N/A	N/A	N/A	C7	C7	Triceps	N/A	N/A
2	43	Male	Right	C5/6 & C6/7	No	Yes	Yes	No	C5	N/A	N/A	N/A	C6&C7	C6&C7	C7	Triceps	C6&C7	C6&C7
3	38	Female	Right	C5/6	No	Yes	No	No	C6	C6	C6	C6	C6	C6	C6	Biceps	C6	C6
4	39	Female	Left	C6/7	No	No	Yes	No	C8	C8	C8	N/A	N/A	N/A	C7	Triceps	N/A	N/A
5	59	Female	Right	Conservative	No	Yes	Poss	Poss	N/A	C8	N/A	N/A	C8	C7&C8	N/A	N/A	C8	C8
6	55	Male	Right	Conservative	No	No	Yes	No	N/A	C7	N/A	N/A	C7	N/A	N/A	N/A	N/A	N/A
7	55	Male	Right	Conservative	No	No	Yes	Poss	C8&C7	N/A	N/A	N/A	C8	C8	C7&C8	N/A	N/A	C8
8	33	Male	Left	Conservative	No	No	Slight	No	C8	C8	N/A	N/A	N/A	N/A	C7	N/A	C8	N/A
9	42	Male	Left	C6/7	No	No	Yes	No	N/A	C6&C7	C6&C7	N/A	N/A	C6	C7	Triceps	C6	C6
10	39	Male	Left	C6/7	No	Yes	Yes	No	C5&C6	C5&C6	N/A	N/A	N/A	C6&7	C7	Triceps	C6&C7	C6&C7
11	63	Female	Right	C6/7	Yes	No	Slight	No	C5&C7	N/A	N/A	N/A	N/A	N/A	C7	Triceps	N/A	N/A
12	57	Female	Right	C7/T1	No	No	No	Slight	N/A	C7&C8	C7&C8	N/A	N/A	C8	C8	Triceps	C8	C8
13	54	Female	Left	C6/7	No	No	Yes	No	N/A	C7	C7	N/A	N/A	C7	C7	Triceps	N/A	C7
14	40	Male	Left	C6/7	No	No	Yes	Poss	N/A	C6&C7	C6&C7	N/A	N/A	C6&C7	C6&C7	Triceps	N/A	N/A
15	50	Female	Left	C5/6	No	Slight	Poss	No	C6	C6	C6	C6	C6	C6	C6&C7	Biceps	C6	C6
16	51	Male	Left	C5/6 & C6/7	No	Yes	Slight	No	C5&C6 C7	C6&C7	N/A	N/A	N/A	C6	C6&C7	N/A	C6&C7	C7
17	41	Male	Left	C6/7	No	No	Yes	No	C7	C7	N/A	N/A	C6&C7	C6&C7	C7	Triceps	N/A	N/A
18	54	Male	Right	Conservative	No	No	Slight	No	N/A	C7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	44	Female	Left	Conservative	No	No	Slight	No	C7	C7	C7	N/A	C7	C7	N/A	N/A	N/A	C7
20	59	Female	Right	C5/6	No	Yes	No	No	C6	C6	C6	N/A	C6	C6	C6&C7	Biceps	C6	C6
21	40	Female	Right	C5/6	No	Yes	No	No	C6	C6	C6	C6	C6	C6	C6	Biceps	C6	C6

Key for table 2:

UA = Upper arm; **FA** = Forearm; **Sing** = Single; **Multi** = Multiple

Single = Single-level NR involvement; **Multiple** = Multiple-level NR involvement

N/A = not applicable due to the absence of the radicular sign or symptom;

Compression of NR was divided into definite compression (**Yes**), slight compression (**Slight**), possible dynamic compression with no detectable static compression (Poss) and no compression (**No**) according to the MRI

LT = Light touch sensory testing; **SP** = Superficial pain sensory testing

Paraesthesia was always reported in the most distal parts of the dermatomes, reaching the fingers. The area/s most commonly reported representing each NR level were: thumb and index finger (C6), index, middle and ring fingers (C7), little and ring fingers (C8). Overlapping between NR levels regarding the index and ring fingers were reported.

Comparison between MRI and clinical features

Only 7 out of 21 subjects presented clinically and radiologically with the same single-level NR involvement.

ASSOCIATIONS BETWEEN MRI AND CLINICAL FEATURES

Only the results of C6, C7 and C8 NR levels are presented since the clinical features were only reported in these distribution patterns. In the histograms, the MRI 'yes' group (right) refers to the subjects in whom MRI was able to detect compression of the mentioned NR level and the MRI 'no' group (left) represents the subjects without evident compression.

Motor testing (Figure 1a-c)

Statistically significant associations were found between MRI compression and motor weakness in the corresponding myotome for C6 ($p<0.01$) and C8 ($p=0.03$), but not for C7 ($p=0.09$). More than half of the sample with detectable compression of C6, C7 and C8 presented with corresponding myotomal weakness. Motor weakness occurred in one subject without compression of C6 and C7.

Sensory testing

The C6 NR level demonstrated significant associations between MRI compression and sensory changes with both light touch (LT) ($p<0.01$) and superficial pain (SP) ($p<0.01$) sensory testing. The C8 NR level showed a significant association for SP ($p<0.01$) but not for LT testing ($p=0.08$). No significant association was found for the C7 NR level with both LT ($p=0.51$) and SP ($p=0.30$) sensory testing.

Three-quarters or more of the subjects with C6 (6 subjects) and C8 (3 subjects) compression presented with sensory changes in the corresponding dermatome. Twelve of the 17 subjects with C7 compression and all 4 subjects without C7 compression had normal SP sensation in the C7 dermatome, indicating a low incidence of altered sensation in the C7 distribution pattern. Altered SP

sensation was also noted in two subjects without C6 NR compression.

Reflex testing

Only half of the sample with NR compression had hypoactivity of the corresponding reflex, indicating a low incidence of altered reflexes. The association between the level of NR compression and hypoactivity of the corresponding reflex was significant for C6 ($p<0.01$), but not for C8 ($p=0.67$) or C7 ($p=0.33$).

Radicular pain Figure 2(a-c)

The association between the level of MRI compression and pain in the corresponding dermatomal distribution pattern was significant for C6 ($p=0.04$) and C8 ($p=0.03$), but not for C7 ($p=0.41$). Between 71% and 75% of the subjects with detectable MRI compression experienced pain in the corresponding dermatome. Pain was experienced in dermatomes without detectable compression of the corresponding NR level for C6 (3 subjects), C7 (2 subjects) and C8 (2 subjects).

Paraesthesia (Figure 3a-c)

Significant associations were found for C6 ($p<0.01$) and C8 ($p<0.01$) between MRI compression and paraesthesia in the corresponding dermatome, but not for C7 ($p=0.41$). Three-quarters or more of the subjects with either C6 (6 subjects) or C8 (3 subjects) compression experienced paraesthesia in the corresponding dermatome. A low incidence of paraesthesia (47%) in the C7 distribution pattern occurred amongst the subjects who had C7 compression. Paraesthesia was reported in the C6 (3 subjects) and C7 (1 subject) dermatomes without detectable compression of the corresponding NR level.

DISCUSSION

In this study only 7 subjects out of 21 with acute CR presented clinically and radiologically with the same single-level NR involvement.

Current results indicate that radicular pain can occur in isolation, supporting the proposal of Greening & Lynn (1998) that neuropathic pain may be due to nerve sheath inflammation when relatively minor or no axonal damage is present. This is in contrast to previous beliefs that the diagnosis of CR could only be made when the radicular pain was accompanied by evident neurological signs and that all radicular pain is due to NR compression. Furthermore all three neurological signs were not always

present simultaneously, confirming previous findings (Lundsford et al 1980; Radhakrishnan et al 1994).

These observations can be justified if neurophysiological evidence is considered (Gifford 2001). In a study by Howe et al (1977) mechanical compression of the lumbar NR elicited paraesthesia and numbness, and caused neurological signs due to altered conduction, but not pain. It is therefore possible that any one or more of the three neurological signs can be present, depending on which part of the NR complex is affected. On the other hand, radicular pain will only be experienced once the NR is subjected to intraneural inflammation (Saal 1995), due to peripheral sensitization (Greening & Lynn 1998) or central sensitization (Butler 2000; Scholtz & Woolf 2002). This could explain why only 12 of the 21 subjects reported pain in the corresponding dermatome of the compressed NR. A combination of mechanical and chemical mechanisms can cause any combination of radicular features. It is evident that radicular pain and signs should be recognized as two separate pathophysiological entities which can occur in isolation or combination, depending whether the mechanism of mechanical deformation and/or chemical irritation is responsible for the clinical presentation.

In this study, NR compression was also detected by MRI without corresponding clinical signs and symptoms and vice versa. Although MRI is the imaging method of choice in identifying structural lesions, it has been demonstrated that MRI detected compression of NR's in 20-30% of asymptomatic subjects. Schellhas et al (1996) therefore suggested that MRI used in isolation, is inadequate for the reliable identification of the source of pain. The utilization of MRI as the reference criterion, which is unable to detect intraneural inflammation, might be one of the reasons why radicular symptoms were reported in the dermatomal distribution(s) of the NR's of which compression was not detected.

Current results demonstrated that the distribution patterns of clinical features suggested multiple-level NR involvement in approximately one-third of the sample. This is in agreement with the findings of Lundsford et al (1980) and Radhakrishnan et al (1994). The occurrence of multiple-level clinical presenta-

Figure 1: Comparison between MRI findings and clinically demonstrated myotomal motor weakness for (a) C6, (b) C8 and (c) C7 NR (Fisher exact, one-tailed test and categorized histograms).

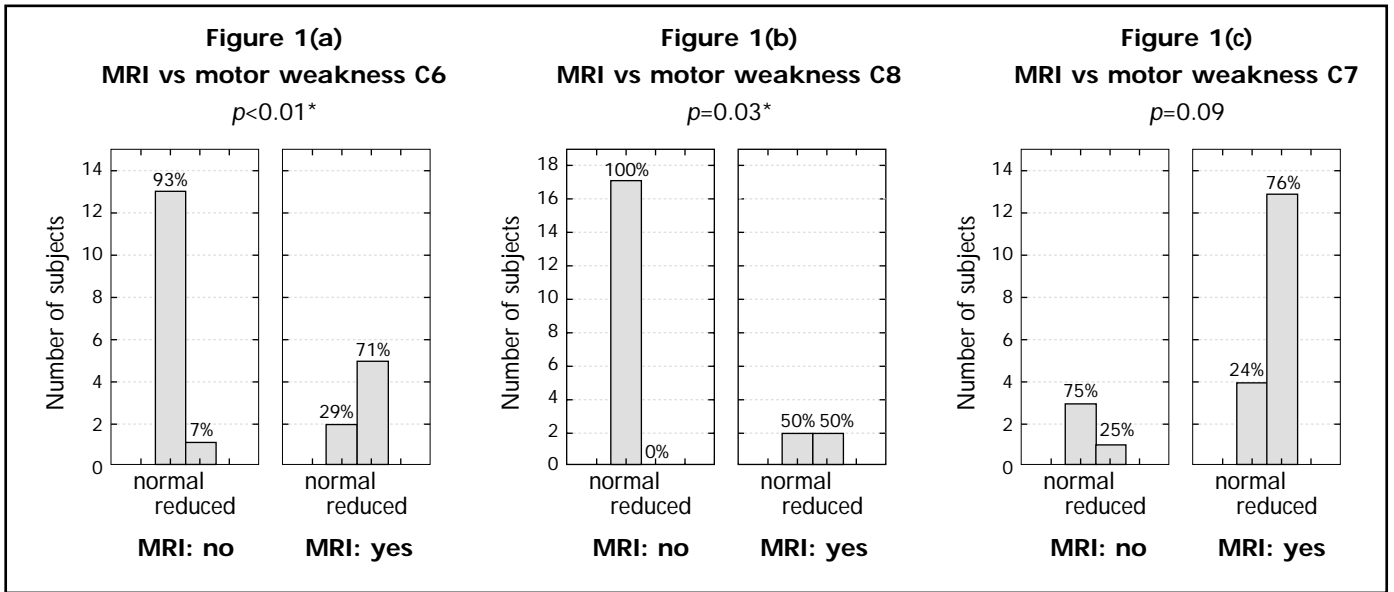


Figure 2: Comparison between MRI findings and dermatomal area(s) of radicular pain as determined during the interview for (a) C6, (b) C8 and (c) C7 NR involvement (Fisher exact, one-tailed test and categorized histograms).

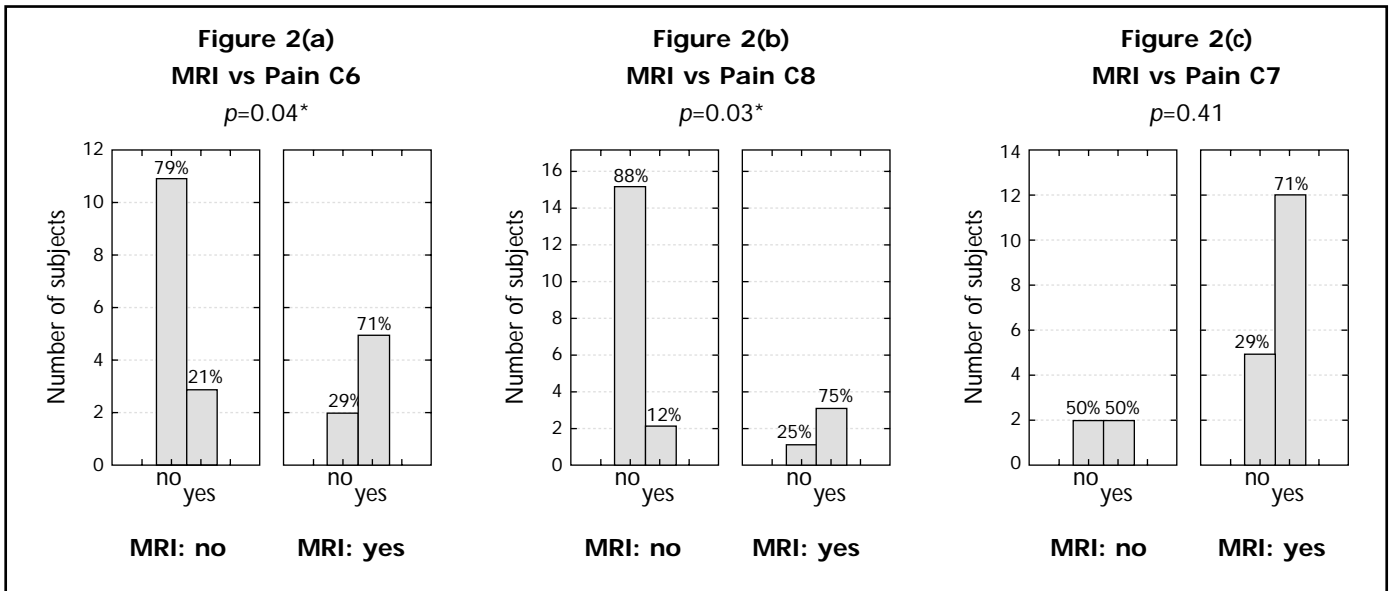
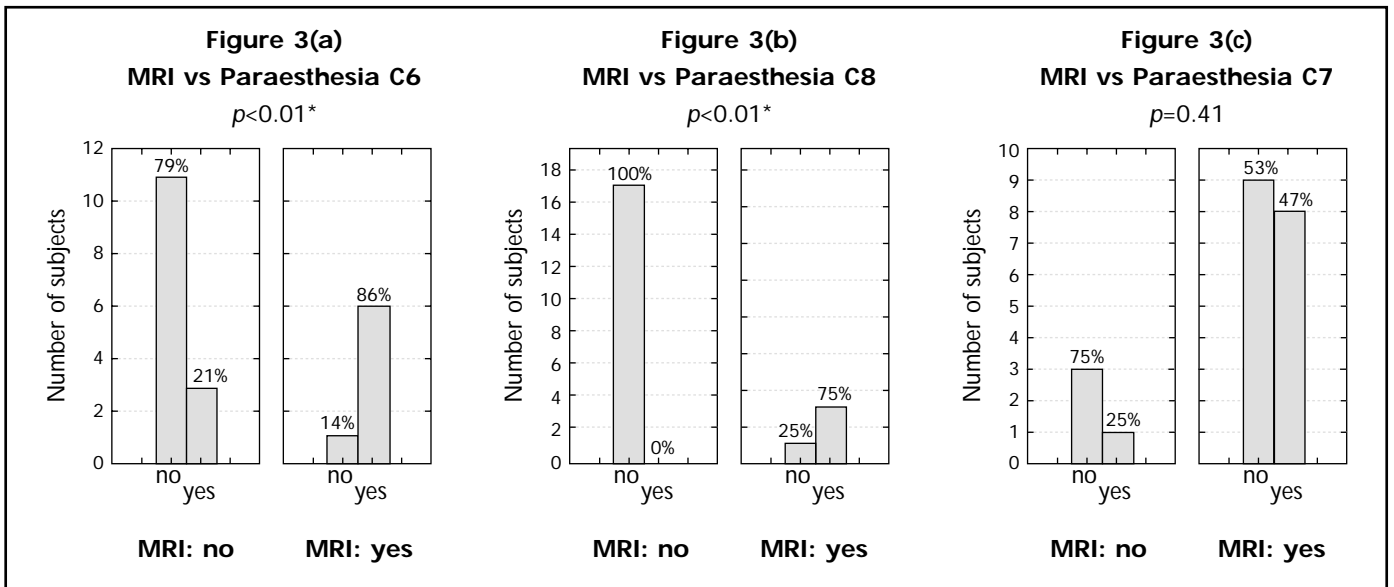


Figure 3: Comparison between MRI findings and dermatomal area(s) of paraesthesia as determined during the interview for (a) C6, (b) C8 and (c) C7 NR involvement (Fisher exact, one-tailed test and categorized histograms).



tions could be due to several factors: Slipman et al (1998) have suggested the concept of dermatomal overlapping. These investigators demonstrated that direct stimulation of NR's in patients with radicular pain caused symptoms in non-dermatomal, widespread distributions and overlapping of dermatomes, especially regarding the fingers. More recently, Butler (2000) proposed that the distribution patterns for peripheral neurogenic pain may not be clear if central sensitivity coexists. Central sensitization refers to a lowered activation threshold of the central nervous system when inputs are magnified (Winkelstein 2004).

Another possible reason for the multiple-level presentations might be the simultaneous involvement of two NR levels. The researcher propose that inflammation, surrounding the original disc herniation that compress a NR level, might spread, leading to sensitization of the adjacent level above or below. Thus, neurological signs could occur as a result of the compressed NR, whereas pain may be due to mechanosensitivity of the adjacent level, even when MRI was unable to detect compression of this level.

Current results suggest that certain radicular features when used in isolation have more value than others in identifying the involved cervical NR level detected by MRI. It is proposed from the results that motor weakness has the most value in determining the compressed NR level(s), followed by pain, paraesthesia, sensory changes and lastly altered reflexes. The observed trend that motor weakness had better predictive value than sensory changes correlates to previous recommendations. Motor findings in the upper extremity are more reliable than sensory findings, since each movement of the arm is controlled almost exclusively by a single NR. In this sample both pain and paraesthesia had value in predicting the compressed NR level(s). From the results it seems that, when present, paraesthesia provides a better indication of the compressed NR than pain which did not often extend into the fingers. Significant associations ($p < 0.05$) were found between all the variables for C6, most of the variables for C8, and none for C7 NR, indicating that for this sample the distribution patterns of radicular features identified C6, and to a lesser extent C8 NR levels with greater certainty than C7.

Consequently, current results indicate that the diagnosis of CR and the identification of the involved NR level(s) cannot be based on the distribution pattern of one isolated radicular feature. The variable clinical presentations, might explain the inability to formulate optimal, universally accepted diagnostic criteria and why very few isolated tests have demonstrated acceptable diagnostic accuracy. The researcher proposes that it is essential to combine findings from different diagnostic tests and the symptom presentation, emphasizing Maitland's recommendation of "making all the features fit" (Maitland 1993, p. 55).

Findings of this study can not be generalized due to the small sample of convenience. This small, descriptive study indicates areas for further work on NR conditions performed on larger and more representative samples. Before very specific diagnostic criteria for CR can be formulated, it will be necessary to determine the diagnostic accuracy of different combinations of clinical, radiological, imaging and surgical findings. Future research could explore the possibility of radicular pain and neurological signs being recognized as two pathophysiological entities, even distinguishing between nerve trunk pain and dysaesthetic pain. Non-invasive ultrasound imaging could be utilized for the recognition of intra-neural inflammation when assessing neuropathic pain.

CONCLUSION

Current results indicate that the clinical presentation of acute CR is variable, since multiple-level distribution patterns of clinical features occurred. The variable, multiple-level presentations may be due to dermatomal overlapping, central sensitization or the possible involvement of two adjacent NR levels. The distribution patterns of motor changes, pain and paraesthesia has value in determining the compressed NR level(s) and to a lesser extent sensory and reflex changes. Radicular features may identify C6 and C8 NR levels with more certainty than C7.

ACKNOWLEDGEMENTS

The researcher would like to thank all neurosurgeons i.e Dr CAJ Botha, NP Fisher-Jeffs & MP Small-Smith, for the referral of patients and all subjects who participated in this study.

REFERENCES

- Ashkan K, Johnston P, Moore AJ 2002 A comparison of magnetic resonance imaging and neurophysiological studies in the assessment of cervical radiculopathy. *British Journal of Neurosurgery* 16(2): 146-148
- Butler DS 2000 Manual assessment of nerve conduction In: *The sensitive nervous system*, ch 9 p 211-255. Noigroup Publications, Adelaide
- Gifford L 2001 Acute low cervical nerve root conditions: Symptom presentations and pathobiological reasoning. *Manual Therapy* 6(2): 106-115
- Greening J, Lynn B 1998 Minor peripheral nerve injuries: An underestimated pain? *Manual Therapy* 3(4):187-194
- Hall TM, Elvey RL 1999 Nerve trunk pain: Physical diagnosis and treatment. *Manual Therapy* 4(2): 63-73
- Howe JF, Loeser JD, Calvin WH 1977 Mechanosensitivity of dorsal root ganglia and chronically injured axons: A physiological basis for the radicular pain of nerve root compression. *Pain* 3: 25-41
- Keegan JJ, Garrett FD 1948 The segmental distribution of the cutaneous nerves in the limbs of man. *Anatomical Record* 102: 409-437
- Lundsford LD, Bissonette DJ, Jannetta PJ, Sheptak PE, Zorub DS 1980 Anterior surgery for cervical disc disease. Part 1: Treatment of lateral cervical disc herniation in 253 cases. *Journal of Neurosurgery* 53: 1-11
- Maitland GD 1993 *Vertebral Manipulation*, 5th edn. Butterworth-Heinemann, London
- Nitta H, Tajima T, Sugiyama H 1993 Study on dermatomes by means of selected lumbar spinal nerve block. *Spine* 10: 1782-1786
- Radhakrishnan K, Litchy WJ, O'Fallon WM, Kurland T 1994 Epidemiology of cervical radiculopathy: A population-based study from Rochester, Minnesota, 1976 through 1990. *Brain* 117: 325-335
- Saal JS 1995 The role of inflammation in lumbar pain. *Spine* 20(16): 1821-1827
- Schellhas KP, Smith MD, Gundry CR, Pollei SR 1996 Cervical discogenic pain: Prospective correlation of magnetic resonance imaging and discography in asymptomatic subjects and pain sufferers. *Spine* 21(3): 300-312
- Scholz J, Woolf CJ 2002 Can we conquer pain? *Nature Neuroscience Supplement* 5:1062-1067
- Slipman CW, Plastaras CT, Palmitier RA, Huston CW, Sterenfeld EB 1998 Symptom provocation of fluoroscopically guided cervical nerve root stimulation: Are dynamical maps identical to dermatomal maps? *Spine* 23(20): 2235-2242
- Takahashi N, Yabuki S, Aoki Y, Kikuchi S 2003 Pathomechanisms of nerve root injury caused by disc herniation. *Spine* 28(5): 435-441
- Wainner RS, Gill H 2000 Diagnosis and non-operative management of cervical radiculopathy. *Journal of Orthopaedic & Sports Physical Therapy* 30(12): 728-744
- Wainner RS, Fritz JM, Irrgang JJ, Boninger ML, Delitto A, Allison S 2003 Reliability and diagnostic accuracy of the clinical examination and patient self-report measures for cervical radiculopathy. *Spine* 28(1): 52-62
- Winkelstein BA 2004 Mechanisms of central sensitization, neuroimmunology & injury biomechanics in persistent pain: implications for musculoskeletal disorders. *Journal of Electromyography and Kinesiology* 14(1):87-93