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ORIGINAL ARTICLE

Clinical characteristics and electrodiagnostic features in patients with carpal tunnel syndrome, double crush syndrome, and cervical radiculopathy

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Abstract Similar unilateral neck and upper limb symptoms are often due to various entrapment neuropathies; carpal tunnel syndrome (CTS) and cervical radiculopathy (CR) are common causes among them. Therefore, we investigated the clinical characteristics and electrodiagnostic features of patients with carpal tunnel syndrome, cervical radiculopathy, and both conditions, called double crush syndrome (DCS). The medical records and electrodiagnostic reports of 866 patients with suspected CTS and CR visited a tertiary-care hospital were retrospectively analyzed. After excluding 101 patients with confounding conditions, 151 (20%) patients were diagnosed to have sole cases of CTS; 362 (47%) patients were diagnosed to have sole cases of CR; 198 (26%) patients were diagnosed to have DCS, while 54 (7%) patients had mere symptoms. Sole cases of CR had the highest incidences of neck pain, upper back pain, wrist and hand weakness. Female patients had the highest incidences of all the diseases in their sixth decade. Male patients had comparably distinguished high occurrence of all the diseases in their fifth to sixth decades. Although comparison of nerve conduction studies between patients with mere symptoms and patients with sole cases of CTS or DCS showed statistical differences, comparison between the latter two revealed no difference. We found most patients referred for electrodiagnostic studies had cervical radiculopathy. High concomitant occurrence of CTS and CR suggests cautious evaluation of patients with upper limb symptoms is important, because the management of these conditions is quite different.

Keywords Carpal tunnel syndrome · Cervical radiculopathy · Double crush syndrome · Electrodiagnosis

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Introduction

Unilateral neck and upper limb symptoms, such as pain, numbness, or tingling sensation, are frequent complaints of ambulatory patients in clinical visits. Carpal tunnel syndrome (CTS) and cervical radiculopathy (CR) are the common etiologies responsible for these clinical symptoms. In clinical practice, these two conditions can at times be difficult to differentiate. On the other hand, we often observe these two conditions occurring together in what is known as double crush syndrome (DCS). In 1973, Upton and McComas postulated that nonsymptomatic impairment of axoplasmic flow at more than one site along a nerve might summate to cause symptomatic neuropathy [1]. This concept is supported by later studies that found

association between cervical myeloradiculopathy and carpal tunnel syndrome [2], which increase the incidence of bilateral carpal tunnel syndrome in patients with cervical arthritis [3]. Other studies that found the association between cervical radiculopathy and carpal tunnel syndrome failed to demonstrate the etiological relationship between these two conditions [4, 5]. In clinical practice, it is not unusual to find the concomitant occurrence of these two conditions. Therefore, other reasons may be responsible for these associations.

In view of the above findings, the present study investigates the clinical characteristics and electrodiagnostic features of these conditions in patients with neck and upper limb symptoms in order to have a clearer understanding of these conditions and subsequently aid in the establishment of more accurate diagnosis and effective management.

Materials and methods

Medical records and electrodiagnostic data of 866 patients with neck and upper limb symptoms, referred from different departments for electrodiagnostic studies of the nerves of the upper limbs in a tertiary-care, hospital-based electrodiagnostic laboratory, were collected during a seven-year period (January 2001 to February 2008) and reviewed. The study was approved by the Institutional Review Board of China Medical University Hospital.

We enrolled the records of patients with neck and upper limb symptoms who received standard median, ulnar motor, and sensory nerve conduction studies, as well as needle electromyography examination of selected sample muscles in the C5 through T1 myotomes, with or without electrophysiological diagnosis of CTS and/or cervical radiculopathy. Physiatrists experienced in electrophysiology performed electrodiagnostic studies in accordance with the Kimura technique [6, 7], adhering to the uniform operating protocol of the electrodiagnostic machine (NEuropack-MEM3202). Cervical radiculopathy was diagnosed according to the presence of spontaneous activities and/or increase polyphasic action potentials in myotomal pattern distribution including the paraspinal muscles and selected upper limb muscles; carpal tunnel syndrome was diagnosed according to the delayed sensory and/or motor nerve conduction [6, 7]. These studies were performed in the laboratory with controlled ambient room temperature of 25°C. Cool limbs were warmed to the desired temperature. Physiatrists generated the report after their interpretation of the electrodiagnostic data. Cases with electrophysiological diagnosis of ulnar neuropathy were excluded.

After considering the confounding conditions of upper limb trauma, diabetes mellitus, rheumatoid arthritis, hypothyroidism, renal failure, pregnancy, and previous history of carpal tunnel syndrome, 101 patients were excluded. Further data analyses were made on the remaining 765 patients. Information including basic demographic data, history, symptom characteristics, physical examination findings, nerve conduction studies, and electromyography examination findings was obtained.

Chi-square test was used to compare the clinical characteristics among patients with electrophysiological diagnosis of CTS, CR, and DCS. Fisher's exact test was used when one cell had an expected count of <1 or >20% of the cells had an expected count of <5. Results were considered statistically significant when p-values were less than 0.05. Kruskal–Wallis (nonparametric) test was used to compare the electrophysiological study data among patients with different diagnoses. The statistical analysis was performed by using the statistical package for social sciences (SPSS version 12.0).

Results

Among the 765 enrolled patients, 151 (20%) patients were diagnosed with sole cases of CTS; 362 (47%) patients were diagnosed with sole cases of CR; 198 (26%) patients were diagnosed with both CTS and CR, otherwise known as double crush syndrome (DCS), and the remaining 54 (7%) symptomatic patients had no definite diagnoses from the electrophysiological study.

Table 1 shows the demographic data, pertinent clinical characteristics, and physical examination findings of the patients with the diagnoses of sole cases of CTS, sole cases of CR, and DCS. The average ages of the three groups of patients were similar (53.0 ± 12.0 vs. 51.9 ± 14.8 vs. 54.9 ± 11.9 years old, $P > 0.05$). Generally, higher susceptibility to sole cases of CTS (72.5% vs. 28.5%) and DCS (68.7% vs. 31.3%) was found in women compared to men. Male patients were more susceptible to sole cases of CR relative to DCS or sole cases of CTS (48.9% vs. 31.3% vs. 28.5%, $P < 0.05$). On the contrary, female patients were more susceptible to sole cases of CTS and DCS with respect to sole cases of CR (72.5% vs. 68.7% vs. 51.1%, $P < 0.05$). Patients with sole cases of CTS, DCS, and sole cases of CR had similar predominant upper limb pain or paresthesia symptoms (45.7% vs. 40.9% vs. 48.3%, $P > 0.05$). An increasing proportion of patients with wrist and hand weaknesses was observed from sole cases of CTS to DCS to sole cases of CR (3.3% vs. 5.6% vs. 9.9%, $P < 0.05$). An increasing proportion of patients with neck pain was seen from patients with sole cases of CTS to DCS to sole cases of CR (13.9% vs. 21.7% vs. 28.5%, $P < 0.05$). Increasing proportion of patients with upper back pain was noted from patients with sole cases of CTS to DCS to sole cases of CR (8.6% vs. 15.7% vs. 22.7%, $P < 0.05$).

Table 1 Pertinent clinical characteristics and symptoms distribution of the enrolled patients according to electrodiagnostic categorization

	Sole cases of CTS, $n = 151$ n (%)	DCS, $n = 198$ n (%)	Sole cases of CR, $n = 362$ n (%)	P-value
Man	43 (28.5)[5]	62 (31.3)	177 (48.9)	<0.05*[a]
Woman	108 (72.5)	136 (68.7)	185 (51.1)	
Mean age (years)	53.0 ± 12.0	54.9 ± 11.9	51.9 ± 14.8	>0.05[b]
Main pertinent neck and upper limb symptoms				
Upper limb pain or paresthesia	69 (45.7)	81 (40.9)	175 (48.3)	>0.05[a]
Wrist and hand weakness	5 (3.3)	11 (5.6)	36 (9.9)	<0.05*[c]
Neck pain	21 (13.9)	43 (21.7)	103 (28.5)	<0.05*[a]
Upper back pain	13 (8.6)	31 (15.7)	82 (22.7)	<0.05*[a]
Physical examination				
Tinel's sign (+)	55 (36.4)	37 (18.7)	46 (12.7)	<0.05*[a]
Tinel's sign (−)	1 (0.4)	9 (4.5)	15 (4.1)	>0.05[c]
Phalen's test (+)	51 (33.8)	37 (18.7)	37 (10.2)	<0.05*[a]
Phalen's test (−)	4 (2.6)	11 (5.6)	13 (3.6)	>0.05[c]

[a] Chi-square test; [b]ANOVA; [c]Fisher's exact test

* $P < 0.05$

Table 2 Sensitivity and specificity of Tinel's sign and Phalen's test using electrodiagnosis as the gold standard in diagnosis of carpal tunnel syndrome

Physical examination	Patients with electrodiagnostic confirmed carpal tunnel syndrome	Symptomatic patients	Sensitivity (%)	Specificity (%)
Tinel's sign (+)	92	18	90.2	5.3
Tinel's sign (−)	10	1		
Phalen's test (+)	88	16	85.4	5.9
Phalen's test (−)	15	1		

Positive Tinel's sign or Phalen's test was most frequently provocated in patients with sole cases of CTS, but least frequently provocated in patients with sole cases of CR (36.4% vs. 12.7%, $P < 0.05$ and 33.8% vs. 10.2%, $P < 0.05$, respectively). The sensitivity and specificity of Tinel's sign and Phalen's test used in the examination of our patients with carpal tunnel syndrome were further investigated using electrodiagnosis as the gold standard, as shown in Table 2. We found both high sensitivity (90.2%, 85.4%) and low specificity (5.3%, 5.9%) of Tinel's sign and Phalen's test, respectively.

Age distribution of 711 patients with electrodiagnostically confirmed diagnoses was analyzed and is shown in Table 3. In patients with sole cases of CTS, the highest percentage of female patients [(42/108) × 100% = 38.9%] was in the sixth decade while the highest percentage of male patients [(10/43) × 100% = 23.2%] was in the broad range of fifth to seventh decades. In patients with DCS, the highest percentage of female patients [(62/136) × 100% = 45.6%] was in the sixth decade while a similar distinguishable high percentage of male patients [(17/62) × 100% = 27.4%, (15/62) × 100% = 24.2%), (14/62) × 100% = 22.6%)] was in the fifth to seventh decades, respectively. In patients with CR, the highest percentage of female patients [(65/185) × 100% = 35.1%] was in the sixth decade while the highest percentage of male patients [(44/177) × 100% = 24.9%, (43/177) × 100% = 24.3%] was in the fifth to sixth decades. In the comparison of different types of diseases in each age group, we generally found the highest occurrence of sole cases of CR in men and women across all age ranges.

Age- and sex-matched comparisons were made between patients with mere symptoms, without electrodiagnostically confirmed diagnosis, patients with sole cases of CTS, and patients with DCS, with respect to the median motor distal latency at 8 cm distance (MDL) and the orthrodromic median sensory nerve conduction velocity from palm to wrist (SNCV, P–W). As shown in Table 4, 36 patients with mere symptoms, 32 patients with sole cases of CTS, and 43 patients with DCS were eligible for comparison. Compared to patients with mere symptoms, patients with sole cases of CTS and DCS had delayed right MDL and left MDL, (3.60 ± 0.75 vs. 4.75 ± 1.41 vs. 4.91 ± 1.24 ms, $P = 0.0001$) and (3.33 ± 0.72 vs. 4.64 ± 1.44 vs. 4.47 ± 1.18 ms, $P = 0.0001$), respectively, and decreased right SNCV, P–W and left SNCV, P–W (38.10 ± 9.36 vs. 32.16 ± 8.37 vs. 29.80 ± 9.50 m/sec, $P = 0.004$) and (41.54 ± 9.77 vs. 33.44 ± 8.14 vs. 30.42 ± 8.47 m/sec, $P = 0.001$), respectively. However, comparison between patients with sole cases of CTS and patients with DCS showed no significant difference.

Table 3 Age distribution of sole cases of CTS, DCS, and sole cases of CR

Age range	Sole cases of CTS			DCS			Sole cases of CR		
	All patients *n* (%)	Male *n* (%)	Female *n* (%)	All patients *n* (%)	Male *n* (%)	Female *n* (%)	All patients *n* (%)	Male *n* (%)	Female *n* (%)
20 ~ 29	3 (8.6)	2 (8.7)	1 (8.3)	4 (11.4)[a]	2 (8.7)	2 (16.7)	28 (80.0)	19 (82.6)	9 (75.0)
30 ~ 39	16 (19.5)	5 (16.1)	11 (21.6)	14 (17.1)	3 (9.7)	11 (21.6)	52 (63.4)	23 (74.2)	29 (56.9)
40 ~ 49	34 (22.1)	10 (14.1)	24 (28.9)	40 (26)	17 (23.9)	23 (27.7)	80 (52.0)	44 (62.0)	36 (43.4)
50 ~ 59	52 (21.9)	10 (14.7)	42 (24.9)	77 (32.5)	15 (22.1)	62 (36.7)	108 (45.6)	43 (63.2)	65 (38.5)
60 ~ 69	26 (22.4)	10 (21.7)	16 (22.9)	40 (34.5)	14 (30.4)	26 (37.1)	50 (43.1)	22 (47.8)	28 (40.0)
70 ~ 79	18 (28.6)	4 (13.8)	14 (41.2)	18 (28.6)	9 (31)	9 (26.5)	27 (42.9)	16 (55.2)	11 (32.4)
≧80	2 (8.3)	2 (14.3)	0 (0)	5 (20.8)	2 (14.3)	3 (30)	17 (70.8)	10 (71.4)	7 (70.0)
All ages	151 (21.2)	43 (15.2)	108 (25.2)	198 (27.9)	62 (22)	136 (31.7)	362 (50.9)	177 (62.8)	185 (43.1)

Number in parenthesis is the percentage of the total patients in the designated age range

Table 4 Comparison of electrodiagnostic studies among patients with only symptoms and no electrodiagnostic confirmed diagnosis, patients with sole cases of CTS, and patients with DCS

Electrodiagnostic studies	Patients with mere symptoms ($n = 36$)	Patients with sole cases of CTS ($n = 32$)	Patients with DCS ($n = 43$)	*P*-value
Right MDL (ms)	3.60 ± 0.75*	4.75 ± 1.41	4.91 ± 1.24	0.0001
Left MDL (ms)	3.33 ± 0.72*	4.64 ± 1.44	4.47 ± 1.18	0.0001
Right SNCV, P–W (m/sec)	38.10 ± 9.36*	32.16 ± 8.37	29.80 ± 9.50	0.004
Left SNCV, P–W (m/sec)	41.54 ± 9.77*	33.44 ± 8.14	30.42 ± 8.47	0.001

Kruskal–Wallis (nonparametric) test

MDL Median motor distal latency at 8 cm distance

SNCV, *P–W* Median sensory nerve peak conduction velocity from palm to wrist

*Statistical significant differences were found when patients with sole cases of CTS and DCS were compared to patients with mere symptoms

Discussion

From our reviewed data in Table 1, we found that the average ages of the patients with neck and upper limb symptoms were similar and within the range of 50–55 years, which is the peak age range of patients with CR and CTS found in previous studies [8–10]. One study found the prevalence of symptomatic and electrodiagnostically confirmed CTS in about 2% among men and 3% among women in the general population [11]. Another study found the sex-specific annual incidences of CTS were 505.6 per 1,00,000 person-years in women and 139.1 per 1,00,000 person-years in men in the general population [10]. Similar to most of the previous studies [10–13], our data revealed higher incidence of carpal tunnel syndrome in women compared to men. Very few studies in the past investigated the prevalence of cervical radiculopathy. One study found the annual incident rate of cervical radiculopathy was 107.3 per 1,00,000 for men and 63.5 per 1,00,000 for women in the general population [8]. The male predominance of cervical radiculopathy in the previous report is different from our present study, which shows similar percentages of sole cases of CR in both sexes, and even higher percentages of cervical radiculopathy in women when DCS was taken into account. The higher percentage of DCS in women in our present study was also contrasted with previous studies, which found higher incidence of DCS in men [3, 14]. We postulated that the difference may be due to different susceptibility to cervical radiculopathy in the Asian population, the impact of changing human lifestyle, and the working conditions of women in the last two decades.

Our study found high concurrent occurrence of cervical radiculopathy and carpal tunnel syndrome as previously reported [5, 15]. Although our electrodiagnostic studies did not support the double crush hypothesis as proposed by Upton and McComas, the high coincidence of cervical radiculopathy and carpal tunnel would be unlikely to occur through chance alone. Rather than focusing narrowly on nerve disturbance in the upper extremity, Donaldson et al. [16] proposed a wider integration of physiological systems in the etiology and maintenance of carpal tunnel syndrome involving muscular dysfunction in the neck that leads to dysfunction at the carpal tunnel. In a case series of 18 carpal tunnel syndrome patients, Skubick et al. [17], using

surface electromyography to retrain dysfunctional neck muscles, found decreased forearm flexor electromyographic activity with reduction in the sternocleidomastoid muscle asymmetry. Hence, changing head positions affects limb-muscle activity and vice versa [16]. All these neurophysiological and biomechanical evidence support the linkage between cervical radiculopathy and carpal tunnel syndrome. Therefore, it is not surprising to find high incidence of concurrent occurrence of cervical radiculopathy and carpal tunnel syndrome in past and present reports. These findings also suggest the importance of proper posture and movement pattern of both the neck and the upper limb in the prevention of cervical radiculopathy and carpal tunnel syndrome.

We found the highest percentage of male patients with sole cases of CR, and highest percentage of female patients with sole cases of CTS, in comparison with the other diagnoses. This finding is compatible with previous reports, which suggest that men are more susceptible to cervical radiculopathy and women are more susceptible to carpal tunnel syndrome [8–13]. Patients with sole cases of CTS, sole cases of CR, and DCS had similar likelihood of having upper limb pain or paresthesia, suggesting that the differential diagnosis of these conditions cannot rely on these symptoms, which are nonspecific in these conditions. In our present study, the incidences of wrist and hand weaknesses were highest in patients with sole cases of CR and lowest in patients with sole cases of CTS, which suggest that cervical nerve root lesion causes more profound motor deficit with respect to carpal tunnel syndrome. The incidences of neck and upper back pain were highest in patients with sole cases of CR and lowest in patients with sole cases of CTS. These findings reveal good association of neck and upper back pain with cervical lesion.

Positive findings of Tinel's sign and Phalen's test decrease from CTS to DCS to CR. A possible reason for these findings may be attributed to the addition of symptoms from cervical lesion, which may cause the patients to visit the clinic before the carpal tunnel syndrome becomes severe enough to cause provocation signs. We found low incidences of negative provocation signs in our data review. Possible reasons may be due to the neglect of the physicians in performing the provocation tests or, more likely, failure to record the negative findings of the tests due to limited time in patient evaluation and medical record writing in the outpatient clinic. However, we found high sensitivities of Tinel's sign and Phalen's test, but low specificity of these provocation tests. Previous studies showed great variation of sensitivity and specificity of the provocation tests, which have controversial diagnostic values. The sensitivity of Tinel's sign ranged from 30 to 97% and that of Phalen's test ranged from 47 to 92%. The specificity of Tinel's sign ranged from 65 to 91% and that of Phalen's test ranged from 17 to 88% [18, 19]. The sensitivities of Tinel's sign and Phalen's test of our present study approach the high values obtained in the previous study [19], but the specificities are relatively lower than that obtained in previous reports [18]. This finding suggests that the Tinel's sign and Phalen's test are valuable in positive screening of patients with carpal tunnel syndrome, but of lower value in the negative confirmation of patients without the disease.

Regarding the age distribution of patients with sole cases of CTS, DCS, and sole cases of CR (Table 3), we found that the highest percentage of female patients with sole cases of CTS was in the sixth decade and that for male patients were in the sixth to eighth decades, which were compatible with a previous study [10]. The highest percentage of female patients with DCS was in the sixth decade while a similar distinguishable high percentage of male patients with DCS was in the fifth to seventh decades. This finding suggests that DCS tends to occur in the middle-to-old age groups. The highest percentage of female patients with sole cases of CR was in the sixth decade while a similar highest percentage of male patients with sole cases of CR was in the fifth to sixth decades, which were compatible with previous study [8]. This finding suggests that the fifth to sixth decade age groups have the highest risk for cervical radiculopathy. In the comparison of different types of diseases in each patient age group, we generally found the highest occurrence of sole cases of CR in men and women. This finding suggests that the neck and upper limb symptoms of most patients visiting our medical center were due to cervical radiculopathy. A possible explanation may that the symptoms and signs of cervical radiculopathy, which cause more discomfort and impairment of activities of daily living, urging the patients to visit the hospital. Further studies are needed to confirm the actual and exact explanations.

Compared to patients with only symptoms and no electrodiagnostically confirmed diagnosis, patients with sole cases of CTS and DCS have delayed MDL and decreased SNCV, P–W. These findings confirmed the validity of the electrodiagnosis of our physiatrists. However, comparison between patients with sole cases of CTS and patients with DCS showed no significant difference of MDL and SNCV, P–W. These findings did not support the double crush hypothesis. In patients with electrodiagnostically confirmed carpal tunnel syndrome (sole cases of CTS + DCS), the lowest mean value of MDL was found to be 4.47 ms, which is longer than the upper limit of comparable MDL (4.3 and 4.4 ms) found in previous studies [20, 21]. In patients with mere symptoms and no electrophysiologically confirmed diagnosis, the greatest average peak SNCV, P–W was 41.54 m/sec, which is comparable to the normal published average peak SNCV, P–W value (41.85 m/sec) [22]. In patients with electrophysiologically confirmed CTS, the

greatest average peak SNCV, P–W was 33.44 m/sec, which is lower than the lower limit of published value (34.05 m/sec) [22]. Our nerve conduction study (NCV) data add further supportive evidence to using the aforementioned limiting values for the diagnosis of CTS and confirm the validity of employing these published data for the diagnosis of CTS in the population of Taiwan. In this study, we used the short segment (palm-wrist) nerve conduction study for comparison between different patient groups to avoid the diluted effect of long-segment (wrist-digit) study [23, 24]. The sensitivity of wrist-palm sensory nerve conduction was also found to be very high (90.5%) in previous study [25]. These arguments further validate our diagnostic accuracy in the present study.

Study limitations: Retrospective studies have a substantial amount of inherent limitations and difficulties. We could not obtain all the information from all the patients, and some missing data were noted. We were also unable to determine each physician's exact reasons for the referral of the electrodiagnosis. Therefore, we only collected the main pertinent neck and upper limb symptoms for analysis. We performed the electrodiagnostic studies at controlled room temperature without measuring skin temperature. This is justifiable in our study since we are in a subtropical region with warm-hot climate most of the time in a year, and we are accustomed to palpate for cool limbs and warm them to the desired temperature before examination of the patient.

In conclusion, we found the highest portion of patients with cervical radiculopathy, high concomitant occurrence of CTS and CR, and less sole cases of CTS in our study. These are quite different from previous studies in the general population in America and Europe [8, 11], which showed higher incidences of CTS when compared to CR. Our findings reveal that patients who visit our tertiary-care medical center for neck and upper limb symptoms are mostly with cervical radiculopathy, which may cause more intolerable symptoms and lead to more clinical visits and referral for electrodiagnostic studies. We also found high concomitant occurrence of CTS and CR. Although the double crush hypothesis cannot be supported by our electrodiagnostic studies, we must be careful in the diagnosis and management of patients with upper limb symptoms due to high concomitant occurrence of CTS and CR, as their management strategies are quite different.

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References

1. Upton RM, McComas AJ (1973) The double crush in nerve entrapment syndromes. Lancet 2:359–362
2. Hurst LC, Weissberg D, Carroll RE (1985) The relationship of the double crush to carpal tunnel syndrome: an analysis of 1, 000 cases of carpal tunnel syndrome. J Hand Surg [Br] 10(2):202–204
3. Baba H, Maezawa Y, Uchida K, Furusawa N, Wada M, Imura S et al (1998) Cervical myeloradiculopathy with entrapment neuropathy: a study based on the double-crush concept. Spinal Cord 36:399–404
4. Morgan G, Wilbourn AJ (1998) Cervical radiculopathy and coexisting distal entrapment neuropathies: Double–crush syndrome? Neurology 50:78–83
5. Richardson JK, Forman GM, Riley B (1999) An electrophysiological exploration of the double crush hypothesis. Muscle Nerve 22:71–77
6. Kimura J (1989) Electrodiagnosis in diseases of nerve and muscle: principles and practice, vol 2. Philadelphia, FA Davis
7. Kimura J (2001) Electrodiagnosis in diseases of nerve and muscle: principles and practice, vol 3. Oxford University Press, New York
8. Radhakrishan K, Litchy WJ, O'Fallon WM, Kurland LT (1994) Epidemiology of cervical radiculopathy. A population-based study from Rochester, Minnesota, 1976 through 1990. Brain 117:325–335
9. Salemi G, Savettieri G, Meneghini F, Di Benedetto ME, Ragonese P, Morgante L et al (1996) Prevalence of cervical spondylotic radiculopathy: a door-to-door survey in a Sicilian municipality. Acta Neurol Scand 93:184–188
10. Mondelli M, Giannini F, Giacchi M (2002) Carpal tunnel syndrome incidence in a general population. Neurology 58:289–294
11. Atroshi I, Gummesson C, Johnsson R, Ornstein E, Ranstam J, Rosén I (1999) Prevalence of carpal tunnel syndrome in a general population. JAMA. 282:153–158
12. de Krom MC, Knipschild PG, Kester AD, Thijs CT, Boekkooi PF, Spaans F (1992) Carpal tunnel syndrome: prevalence in the general population. J Clin Epidemiol 45:373–376
13. Bongers FJ, Schellevis FG, van den Bosch WJ, van der Zee J (2007) Carpal tunnel syndrome in general practice (1987 and 2001): incidence and the role of occupational and non-occupational factors. Br J Gen Pract 57:36–39
14. Moghtaderi A, Izadi S (2008) Double crush syndrome: an analysis of age, gender and body mass index. Clin Neurol Neurosurg 110:25–29
15. Flak M, Durmala J, Czernicki K, Dobosiewicz K (2006) Double crush syndrome evaluation in the median nerve in clinical, radiological and electrophysiological examination. Stud Health Technol Inform 123:435–441
16. Donaldson CCS, Nelson DV, Skubick DL, Clasby RG (1998) Potential contributions of neck muscle dysfunctions to initiation and maintenance of carpal tunnel syndrome. Appl Psychophysiol Biofeedback 23:59–72
17. Skubick DL, Clasby RG, Donaldson CCS, Marshall WM (1993) Carpal tunnel syndrome as an expression of muscular dysfunction in the neck. J Occup Rehabil 3:31–44
18. El Miedany Y, Ashour S, Youssef S, Mehanna A, Meky FA (2008) Clinical diagnosis of carpal tunnel syndrome: old tests-new concepts. Joint Bone Spine 75:451–457
19. LaJoie AS, McCabe SJ, Thomas B, Edgell SE (2005) Determining the sensitivity and specificity of common diagnostic tests for carpal tunnel syndrome using latent class analysis. Plast Reconstr Surg 116:502–507
20. Fitz WR, Mysiw WJ, Johnson EW (1990) First lumbrical latency and amplitude. Control values and findings in carpal tunnel syndrome. Am J Phys Med Rehabil 69:198–201

21. Chang MH, Liu LH, Lee YC, Wei SJ, Chiang HL, Hsieh PF (2006) Comparison of sensitivity of transcarpal median motor conduction velocity and conventional conduction techniques in electrodiagnosis of carpal tunnel syndrome. Clin Neurophysiol 117:984–991
22. Oh SJ (2003) Clinical electromyography : nerve conduction studies, 3rd edn. Lippincott Williams & Wilkins, Philadelphia
23. Lew HL, Date ES, Pan SS, Wu P, Ware PF, Kingery WS (2005) Sensitivity, specificity, and variability of nerve conduction velocity measurements in carpal tunnel syndrome. Arch Phys Med Rehabil 86:12–16
24. Sheu JJ, Yuan RY, Chiou HY, Hu CJ, Chen WT (2006) Segmental study of the median nerve versus comparative tests in the diagnosis of mild carpal tunnel syndrome. Clin Neurophysiol 117:1249–1255
25. Lee KY, Lee YJ, Koh SH (2009) Usefulness of the median terminal latency ratio in the diagnosis of carpal tunnel syndrome. Clin Neurophysiol 120:765–769