Rheumatology 2005;44:1442–1446 doi:10.1093/rheumatology/kei037
Advance Access publication 2 August 2005

Chronic compartment syndrome, an important cause of work-related upper limb disorder

M. H. Pritchard, R. L. Williams[1] and J. P. Heath[2]

Objectives. **Work-related upper limb disorders (WRULD) are common and disabling complaints in industry, but a tissue diagnosis can be difficult where the pain is diffuse and variable, and this prevents effective treatment. Diffuse arm pain is frequently found in those doing rapid or strenuous repetitive work, such as factory assembly workers or keyboard operators. Similar symptoms occur in the legs in athletes, where chronic compartment syndrome (CCS) is a recognized entity, so we investigated the possibility that this might also be caused by prolonged repetitive work.**
Methods. **Patients were selected if they were unable to continue with work because of chronic forearm pain. They were divided into three groups: 42 patients with symptoms consistent with CCS as defined in the text, 15 volunteers and patients with other arm complaints, and 10 asymptomatic arms of patients with unilateral CCS. We measured the pressure inside the extensor muscle compartment of the forearm at rest and after a 2 min repetitive gripping exercise using an electronic pressure-sensitive probe.**
Results. **The results show that CCS is a common and disabling forearm complaint associated with prolonged repetitive work. Fifteen patients have now had decompressive surgery on the extensor muscle compartment with good relief of symptoms.**
Conclusion. **CCS is responsible for chronic peripheral neurological dysfunction in addition to muscle pain, and awareness of this diagnosis allows early identification and treatment of a currently unrecognized disorder with potential resolution of a long-lasting arm disability.**

KEY WORDS: WRULD, Chronic compartment syndrome, Complex regional pain syndrome.

Work-related upper limb disorder (WRULD) is a general and non-specific label referring to a range of musculoskeletal conditions affecting the upper limb, caused or made worse by work [1]. Such conditions constitute 66% of reported cases of musculoskeletal complaints in the UK [2]. Eighty-two per cent of these are attributed to repetitive work, mostly keyboard work [3]. This is a growing, expensive and erratically treated problem throughout industry and commerce, accounting for 60% of all occupational illnesses in the USA in 1990, and the annual cost for compensation is of the order of $20 billion [4].

WRULDs fall into two main symptomatic categories: localized and diffuse. While localized disorders, such as tendon injuries, are well recognized and seen frequently in rheumatology clinics, diffusely painful arm conditions are difficult to diagnose accurately, and many end up mislabelled or with the non-specific and confusing label of repetitive strain injury (RSI). Without a tissue diagnosis, neither treatment nor attribution is possible, and as a result few patients get adequate or appropriate treatment and many lose their jobs. Harrington and colleagues [5] recognized the concept of diffuse forearm pain as a clinical subgroup, but without defining any specific pathology.

One feature of some diffuse forearm pain conditions is the rapid worsening on usage and persistence of symptoms for a substantial period of time afterwards. The object of the present work was therefore to establish whether chronic compartment syndrome (CCS) involving the muscles of the forearm could be a valid diagnosis in such patients. This condition is characterized by intracompartmental pressure rising abnormally on usage, causing increasing pain and disability through the effect of pressure on muscles and nerves. This possibility has been suggested before but never followed up. Viikari-Juntura noted that 'the symptoms of CCS were consistent with cases sometimes seen by occupational physicians' and he also pointed out that, if valid diagnostic criteria could be determined, some workers with previously poorly understood symptoms might be correctly diagnosed [6]. Botte referred to this condition as 'exertional compartment syndrome' and described a stress test, but did not associate this with repetitive work and stated that the cause and pathogenesis remained unknown [7].

Patients

Published data exist for lower limb compartment pressure but only one paper has studied this in the arm [8]. Therefore we had to establish a reproducible normal range for the study in order to establish the validity of the method. This was done by initially measuring extensor muscle pressures in volunteers [ourselves and patients with other defined chronic forearm pain (Hand Arm Vibration Syndrome, atypical carpal tunnel, postviral myopathy, tendonitis, Reflex Sympathetic Dystrophy, radial head ligament injury and referred pain)] (group 1; two males, 13 females), and to this was added data from the asymptomatic arm of 10 of the patients with unilateral CCS (group 2; two males, eight females).

To make a potential diagnosis of CCS, patients had to fulfil certain clinical criteria in terms of history and examination: (i) the forearm pain must have been of gradual, not acute, onset, deteriorating to a point where repetitive usage of the affected arm in the workplace and at home was becoming restricted and

Departments of Rheumatology, [1]Orthopaedics and [2]Neurophysiology, University Hospital of Wales, Cardiff, UK.

Submitted 25 April 2005; revised version accepted 28 June 2005.

Corresponding author: M. H. Pritchard, Department of Rheumatology, University Hospital of Wales, Cardiff CF14 4XW, UK.
E-mail: mhpritchard@tiscali.co.uk

which persisted after work; (ii) there should be distal neurological complaints (paraesthesiae, burning sensation, loss of sensation in the hand, often with a history of shooting pains down the forearm to the wrist after strenuous use, and of interrupted sleep due to forearm pain and paraesthesiae over the back of the wrist); and (iii) other diagnoses must have been excluded. All such complainants had been in jobs requiring prolonged minimal-variation repetitive work involving the painful arm; (keyboard, light assembly/food processing/packing/heavy industrial assembly), so this appears to be a *de facto* requirement as well.

In addition to the above, clinical examination should elicit tenderness, with or without swelling, on local pressure over the extensor muscle compartment in the upper forearm and often with a positive Tinel's test over the posterior interosseus nerve (PIN) at this point. Repetitive gripping ability over a 2 min test period in the affected hand should be both reduced and progressively painful. Pain and altered sensitivity to touch or pinprick over the dorsum of the wrist and mild median nerve sensitivity are often found but without typical carpal tunnel symptoms. A total of 42 patients fulfilling these criteria have been studied (group 3; 11 males, 31 females).

All patients in all groups had been referred either to the rheumatology or orthopaedic clinics at the University Hospital of Wales, Cardiff, or for medical reports to one of us (M.H.P.). Participants were given a detailed written explanation of the investigation and gave their fully informed written consent. The study was approved by the Hospital Trust Peer Review Committee and by the local research ethical committee.

Methods

Muscle pressure test

A 14 gauge Venflon intravenous cannula was inserted into the extensor muscle compartment of the symptomatic forearm under local anaesthetic (lidocaine) by either R.L.W. or M.H.P., with J.P.H. acting as observer and carrying out EMG and nerve conduction tests. A pressure-sensitive probe (Kodiag; B. Braun Medical, Sheffield, UK) connected to an automatic electronic readout was then introduced through the cannula and the resting pressure of the muscle was measured in mmHg. The probe is very sensitive and requires some practice in placing it to obtain steady and consistent readings.

Once a stable measurement had been obtained, this was recorded and the patient undertook a 2 min repetitive gripping exercise using a standard dynamometer linked to a computer readout, gripping to near-maximum strength at an approximate rate of one grip every 1–2 s. This was recorded together with grip strength and EMG studies of the arm were measured simultaneously using surface electrodes. The latter, however, did not prove to be of any diagnostic value and has not been reported further. Nerve conduction of the median, ulnar and radial nerves was also carried out. The results were invariably normal, even when there was apparent carpal tunnel sensitivity.

After 2 min the exercise was stopped and the intracompartmental pressure read again. Once stabilized, measurements were then recorded for 5 min at intervals of 1 min. In normal volunteers, those with other specific diagnoses and the asymptomatic arms of patients with unilateral CCS, the resting pressure in the compartment was usually between 3 and 5 mmHg and returned to this level within a few seconds of stopping exercise. This was therefore taken as the normal range; 6 mmHg was taken as the upper limit. This is as expected, being consistent with the data of Rydholm and colleagues [8] and only slightly less than published data for lower limb compartments [9]. In addition, the gripping exercise should cause no pain in the forearm or hand either during or after the test.

Assessment

To be considered positive, several criteria had to be fulfilled. The resting pressure should be elevated above 6 mmHg and, after the specified 2 min gripping exercise, should rise further (usually doubling the resting pressure) and be maintained for several minutes. The pressure was in practice observed for 5 min. This increase in pressure should be accompanied by an increase in the generalized forearm and wrist pain and dysaesthesia over the back of the hand, reproducing the patient's symptoms at work. Symptoms could last up to 20 min and sometimes the pain was sufficient for the patient to be unable to continue for the full 2 min.

Patients with raised post-exercise forearm compartment pressure and who were unable to continue with their normal work as a result of the arm pain were then invited to consider surgical decompression of the compartment as definitive treatment for their complaint (i.e. fasciotomy or limited fasciectomy). Milder cases were treated with a local steroid injection into the muscle compartment (1 ml depomedrone). If sufficiently symptomatic, referral for surgery has now become a routine procedure in those fulfilling the CCS criteria described above.

Fifteen patients have so far undergone decompressive surgery. Two patients have had bilateral decompression; all the others had unilateral complaints.

Surgical procedure

Decompression of the extensor muscle compartment was performed in a standard manner similar to that described in orthopaedic surgical texts [10], under either local or general anaesthetic according to the patient's preference. Under tourniquet, a skin incision was made 4 cm distal to the lateral epicondyle between ext. digitorum communis and extensor carpi radialis brevis and extended approximately 5 cm distally. The subcutaneous tissue was lifted gently and fasciotomy performed under direct vision with dissection scissors, down to the level of the extensor retinaculum. In one patient the decompression had to be repeated since the fascia had clearly reunited after 3 months with return of symptoms and raised pressure; the decompression was repeated; this time a longitudinal segment of fascia was excised to prevent further recurrence. Limited fasciectomy then became standard practice to eliminate this potential complication, which has not occurred since.

The skin was closed with continuous subcuticular suture and a compression bandage was applied. No operative complications occurred in these patients.

Results

Intracompartmental pressure tests

The results are shown in Figs 1 and 2. Figure 1 shows the combined results of the volunteers and those with defined forearm conditions (group 1, 15 subjects), together with the asymptomatic arm of those with unilateral CCS (group 2, 10 subjects). The asymptomatic arm group showed slightly higher readings than the normals/other diagnoses, but this was not significant. None of the three groups complained of pain during the 2 min gripping exercise.

Figure 3 shows the results of all the patients with the clinical symptoms of CCS as described (group 3, 42 subjects).

The data are presented as mean and 1 S.D. The median was almost identical to the mean in every case. Symptoms and disability varied from moderate to severe in the CCS patient group, as did the results of the pressure tests. No formal assessment of the pain level was attempted, although in general those

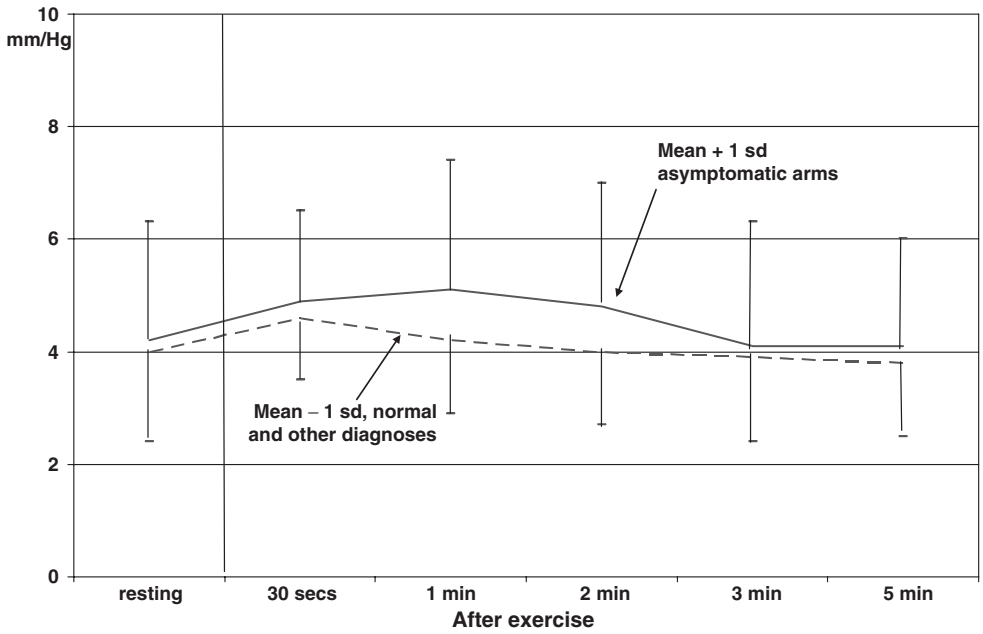

FIG. 1. Results of intra-compartmental pressure tests at rest and after a standard two minute repetitive gripping exercise. (Group 1, volunteers, (15) and other specific diagnoses, Group 2, asymptomatic arms of CCS patients with unilateral symptoms (10).

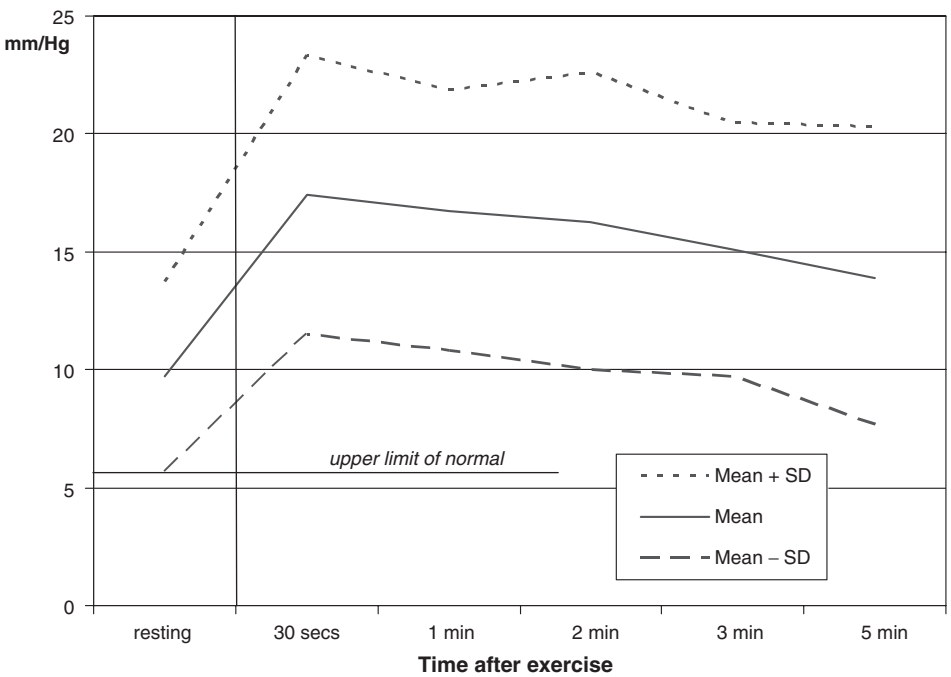

FIG. 2. Results of pressure changes inside the extensor muscle compartment in 42 patients with clinical compartment syndrome.

with the more severe exercise induced pain tended to have the higher pressures.

Postoperative assessments

Patients were assessed 8–12 weeks after surgery and continue to be reviewed at intervals of 3 months. The longest post-operative period is now 20 months, the patient concerned being fit and symptom-free, having been unable to work at all prior to surgery. Compartment pressure tests were repeated after 3 months and the levels of pain and arm function were recorded. Pressures were normal except for the one patient who had required repeat decompression due to reclosure of the fascia.

Where resolution of symptoms is concerned, all patients reported a rapid improvement of the severe forearm/hand pain, including rest and night pain, and most stopped taking their regular analgesics.

There have, however, been some continuing complaints which are of interest in determining the aetiopathology of this disorder. The commonest, occurring in most patients to some extent but significantly in five, has been persistent neuropathic pain,

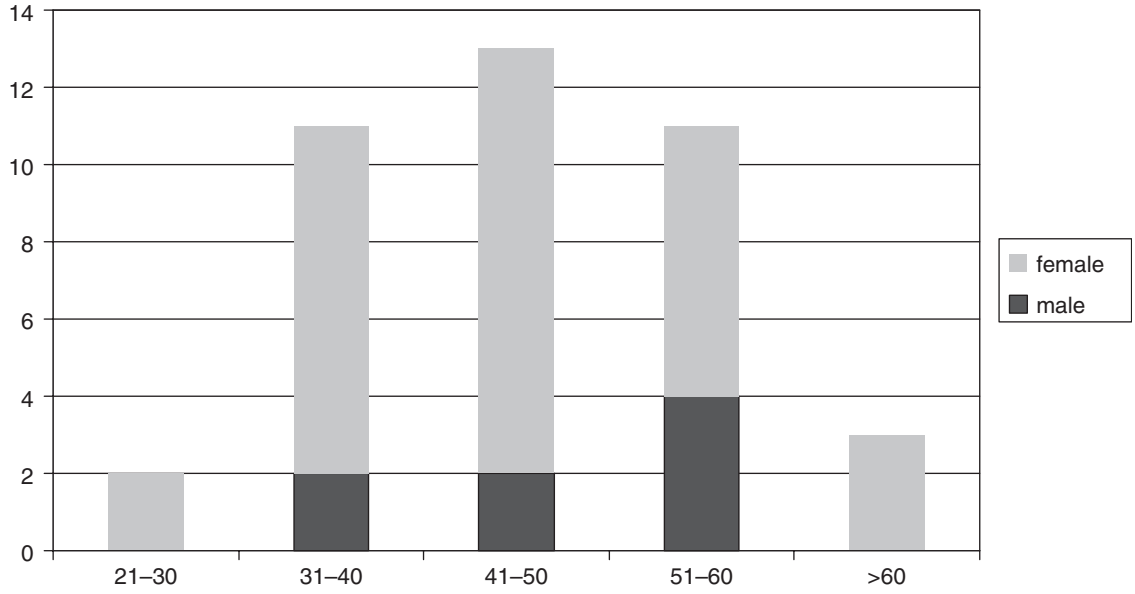

FIG. 3. Incidence of CCS by age.

worse on usage and similar to that seen in complex regional pain syndrome (CRPS). In three cases this was accompanied by vasomotor changes and cold sensitivity. The implications of this are discussed below.

Discussion

It is unfortunate that, due to misuse and lack of definition, such terms as RSI and WRULD have become so pejorative that any scientific research into an increasing disability in a young and economically important age group has been marginalized. It should be a matter of great concern that healthy women in their thirties should be receiving Disabled Living Allowance without even a pathological diagnosis being made, as is often the case.

This study has shown that CCS of the extensor compartment of the upper forearm is a common and undiagnosed cause of disabling forearm pain in workers carrying out rapid or strenuous repetitive tasks. Since starting this study and demonstrating the relationship between the specific features of the complaint described above and the raised intracompartmental pressure, increasing numbers of cases have been identified and we now undertake compartment pressure testing on a weekly routine basis in those fulfilling the above criteria. The crucial point, and possibly the reason why it has not been identified before, is that, unlike most other musculoskeletal disorders, CCS is only symptomatic on usage with minimal findings at rest: normal clinical examination therefore rarely detects it. The 2 min repetitive gripping test gets round this problem. It is a simple clinical screening procedure that can be carried out in any clinic or practice, similar in principle to testing for angina using a treadmill.

It is also clear that the disability caused by CCS is not only painful muscles but a compression neuropathy of the PIN as well, evolving in some cases into the typical signs of a CRPS. While primarily a motor nerve, the PIN has a small sensory branch to the wrist joint; referred pain here that intensifies on usage, although paradoxically suggesting a local wrist lesion, is an important early sign of the condition. Nerve conduction studies of the PIN are not technically feasible.

Most patients reported some persistent neurological pain after decompression. Because these symptoms were also present prior to the operation, it is possible that this was the result of decompressing a nerve which had been under pressure for months or even years and which had sustained chronic damage as a result. Such pressure-induced damage has been recorded in animal models at the pressures described here [11]. It is also well known in chronic carpal tunnel syndrome, where persistent pressure leads to fibroblast invasion and endoneurial fibrosis [12]: this is presumably the cause of the persistent pain sometimes seen in patients after apparently successful carpal tunnel decompression.

The implication from this is that, over time, the clinical symptoms may evolve into a form of CRPS, but the point is that this is type 11, i.e. due to specific neurological trauma, not type 1, idiopathic. The neurological insult here is the damage to the nerve caused by the chronically raised compartment pressure, intermingled in the pre-decompressed state with the muscular pain. A previous study [13] had shown that patients with this complaint tended to vasoconstrict the radial artery on repetitive exercise rather than showing the normal vasodilator response. It is possible that this observation can be attributed to the vasomotor instability common in CRPS.

This persistence of neurological hypersensitivity (which decreases over time) has also meant that some patients also found it difficult to return to the same rapid repetitive work as before and tended to look for alternative employment, although those in industry usually did better at returning to heavy work than keyboard operators. Those with milder pain and smaller pressure increase on testing who were still in work often (but not always) responded to an intracompartmental steroid injection and work advice on forearm rests. In others, amitriptyline or gabapentin has been helpful.

CCS has not been previously described as a work-related condition, although similar clinical complaints are known under different names, such as 'radial tunnel compression' [14] and 'posterior interosseus nerve syndrome' [15]. The latter is usually thought to be due to specific entrapment of the PIN under the vascular arcade of Frohse, generally due to vascular or ligamentous abnormality. This rare occurrence is likely to be congenital and there is no reason to associate it with repetitive work, where the primary aetiology is pressure due to muscle hypertrophy. Some of these cases may therefore be unrecognized CCS.

Only one paper [8] has described a series involving exercise-induced extensor compartment pain. This study found raised

muscle pressure during exercise, and four out of six patients responded to surgical decompression, although the cause was not specified. The problem with the technique described is that they concentrated on rise on muscle pressure during exercise. With the sensitive electronic probe, muscle pressure is easily shown to be variably high during muscle contraction anyway, even in normal subjects, and the pressures at rest and after exercise are the crucial discriminatory readings.

Forearm CCS has been found in motocross riders [16–18], presumably due to the combination of tight gripping, vibration and overextended wrists, but is rarely caused by muscle hypertrophy associated with bodybuilding techniques. This supports a specific pathological mechanism rather than simple hypertrophy being the initiating cause. The exact process triggered by repetitive work remains conjectural, but as athletes, especially distance runners, develop a similar problem in the legs through prolonged use, it is reasonable to hypothesize a similar pathway of overuse, fatigue, muscle structural damage and finally reactive inflammation/oedema. It has been shown that increased muscle compartment pressure decreases capillary flow and causes relative muscle ischaemia [19]. This induces vasodilatation and increased capillary permeability, leading to a further increase in pressure, thus causing the development of a self-perpetuating mechanism, which would account for the continuation of the complaint months or even years after stopping work.

Most complainants, even keyboard operators, had unilateral pain. In keyboard operators, the arm pain was invariably worse in the mouse operating hand, suggesting the angle of wrist extension is significant. Serina *et al.* [20] found that 73% of VDU operators type with the wrist extended by over 15° and more than 20% at over 20°. Wells *et al.* [21] showed that typing required constant repetitive or continuous low-level forearm extensor muscle loading for maintenance of working posture, and that this increased with the angle of the wrist. Upper forearm rests, therefore, rather than wrist rests, are the logical solution to reducing this constant extensor muscle work.

The incidence and individual susceptibility of this complaint remains unpredictable. The demographics of the 42 patients with CCS (Fig. 3) shows that there is an increase with age, as with all WRULDs (the local Office of National Statistics data show that the rate of employment in the population over 50 falls by about 25%, which may account for the smaller numbers in the 50–60 age group) and patients had been in work for an average of 16 (range 4–34) yr. Most cited an increase in workload as a 'last straw' factor, so psychological stress may be an additional factor to muscular overuse.

Chronic compartment syndrome leading to a compression neuropathy is a common under-recognized condition related to prolonged repetitive work. Recognizing the complaint early at a potentially reversible stage is the key to preventing the development of a chronic, disabling and ultimately very expensive process.

The authors have declared no conflicts of interest.

References

1. HSE. Upper limb disorders in the workplace, 2nd edn. Health and Safety Executive, 2002, Sudbury: Health and Safety Executive, 2002.
2. Cherry NM, Meyer JD, Chen Y, McDonald JC. The reported incidence of work related musculo-skeletal disease in the UK. MOSS 1977–1999. Occup Med 2001;51:450–5.
3. Fogelman M, Brogmus G, Computer mouse use and cumulative trauma disorders of the upper extremities. Ergonomics 1995;38: 2465–75.
4. Yassi A. Repetitive strain injuries. Lancet 1997;349:943–7.
5. Harrington JM, Carter JT, Birrell L, Gompertz, D. Surveillance case definitions for work related upper limb pain syndromes. Occup Environ Med 1998;55:264–7.
6. Viikari-Juntura E. The role of physical stressors in the development of hand/wrist and elbow disorders. In: Gordon SL, Blair SJ, Fine LJ, eds. Repetitive motion disorders of the upper extremity. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1995:7–30.
7. Botte MJ, Fronek J, Pedowitz *et al.* Exertional compartment syndrome of the upper extremity, compartment syndrome and Volkmann's contracture. Hand Clin 1998;14:477–82.
8. Rydholm U, Werner CO, Ohlin P. Intracompartmental forearm pressure during rest and exercise. Clin Orthop 1983;175:213–5.
9. Botte MJ, Gelberman RH. Acute compartment syndrome of the forearm. Hand Clin 1998;14:391–403.
10. Jobe MT, Compartment Syndromes and Volkmann Contracture. In: Canale ST, ed. Campbell's operative orthopaedics. Mosby, St. Louis, Illinois, 2003:3742–3.
11. O'Brien JP, Mackinnon SE, MacLean AR *et al.* A model of chronic nerve compression in the rat. Ann Plastic Surg 1987;19:430–5.
12. Sunderland S. The nerve lesion in carpal tunnel syndrome. J Neurol Neurosurg Psychiatry 1976;39:615–26.
13. Pritchard MH, Pugh N, Wright I, Brownlee, M. A vascular basis for repetitive strain injury. Rheumatology 1999;38:636–9.
14. Roles NC, Maudsley RH. Radial tunnel syndrome: resistant tennis elbow as a nerve entrapment. J Bone Joint Surg Br 1972;54:499–508.
15. Jayson MIV. Reports on rheumatic diseases. Practical problems, No. 11: Work related upper limb disorders. Arthritis and Rheumatism Council, Chesterfield, 1997.
16. Allen MJ, Barnes MR. Chronic compartment syndrome of the flexor muscles of the forearm. J Hand Surg Br 1989;14:47–8.
17. Tompkins DG. Exercise myopathy of the extensor carpi ulnaris muscle: report of a case. J Bone Joint Surg Am 1977;59:407–8.
18. Pedowitz RA, Toutounghi FM. Chronic exertional compression syndrome of the forearm flexors. J Hand Surg Am 1988;135:694–6.
19. Hoffmeyer P, Cox JN, Fritschy D. Ultrastructural modifications of muscle in three types of compartment syndrome. Int Orthop 1987; 11:53–9.
20. Serina ER, Tal R, Rempel D. Wrist and forearm postures during typing. Ergonomics 1999;42:938–51.
21. Wells RP, Keir PJ, Moore AE. Applications of biomechanical hand and wrist models to work related musculo-skeletal disorders of the upper extremity. In: Gordon SL, Blair SJ, Fine LJ, eds. Repetitive motion disorders of the upper extremity. Rosemont, IL: American Academy of Orthopaedic Surgeons, 111–122. 1995.