Journal of Musculoskeletal Research, Vol. 7, No. 2 (2003) 87–96

WORK-RELATED CARPAL TUNNEL SYNDROME: CURRENT CONCEPTS

Mircea Fagarasanu* and Shrawan Kumar†,‡

*Faculty of Rehabilitation Medicine, University of Alberta
†Department of Physical Therapy, Faculty of Rehabilitation Medicine and Professor, Neuroscience, Faculty of Medicine, University of Alberta
‡shrawan.kumar@ualberta.ca

Received April 7, 2003; Accepted May 1, 2003

ABSTRACT

Carpal Tunnel Syndrome (CTS) has been the subject of a growing number of studies, most of them leading to contradictory outcomes. The dual aim of this paper is to provide the foundation for a thorough understanding of CTS history, and to emphasize the strong relationship between upper extremity activities and occupational CTS. Evidence of work relatedness, as well as contradictory opinions regarding the role of job-related risk factors on CTS development are addressed. It is proposed that a thorough understanding of the factors that intervene in the task-CTS causal relationship, as well as the assessment of workers' adaptation capacity will lead to ergonomic interventions that will ensure a reduction in the number of work-related CTS cases.

Keywords: Musculoskeletal disorders; Work relatedness; Physical factors; Psychosocial factors.

HISTORY OF CARPAL TUNNEL SYNDROME

It is highly probable that due to the poor-designed tools and work techniques the first victim of Carpal Tunnel Syndrome (CTS) was the Stone Age Man.[20] After thousands of years, CTS is not only present, but also due to the same reasons, has an exponential increase in incidence and prevalence from one decade to the next. Due to the clinical symptomatic diversity and because the preoccupation with the motor manifestations was far greater as compared to that with sensory signs,[38] the exact diagnosis of CTS has not been achieved or, in many cases, postponed.

The first worker's disease was reported in 1717 by Ramazinni[83] who noticed that during work activities, factors like unnatural postures of the body, violent and irregular motions were the

Correspondence to: Dr. Shrawan Kumar, Department of Physical Therapy, 3-75 Corbett Hall, University of Alberta, Edmonton, AB, T6G 2R4, Canada.

major contributors that cause "the natural structure of the vital machine to become so impaired that serious diseases gradually develop". The first description of a CTS case was attributed to Sir James Paget,[62] who observed in a male patient with a healing fracture of the distal extremity of the radius, that the ulceration of the first three fingers was caused by the pressure on the median nerve.

The major symptoms were described for the first time by Putnam.[67] His observations were based on 37 female cases that presented numbness that occurred repeatedly during the night, or in some cases, early in the morning. Hunt[32] was the first to emphasize the relationship between occupational overuse and CTS occurrence. He showed that the nerve compression (motor fibers) is the major factor that leads to thenar atrophy. A major step back in the understanding of CTS development was made in the early 1900s when Hunt[31] mitigated the importance and role of sensory manifestations as compared to motor symptoms. The intrinsic relationship between motor and sensory signs has been emphasized by Wartenberg[82] and Zabriskie[86] who showed that almost all the patients presented paresthesiae.

The histological modifications were remarked for the first time by Marie and Foix in 1913[48] who reported the myelin sheath's absence at the constriction level. They were the first to propose the retinaculum transection as a suitable therapeutic method if applied in the early stages of the disease. The median nerve pressure role on thenar musculature atrophy and paresthesia was also highlighted by Abbott and Saunders.[1] They reported chronic nerve compression after inappropriate fracture reduction. Learmonth[42] and Cannon and Love[15] reported the first carpal ligament release for post-traumatic and for spontaneous median nerve compression, respectively.

A complete pathophysiologic mechanism for CTS development was proposed by Brain,[11] who linked the resulting ischemia with the applied pressure that causes oedema. This in turn led to increased pressure and precipitated a vicious cycle. The term Carpal Tunnel Syndrome was first used in the early 1950s.[35] In their article about CTS, Schiller and Kolb[72] used the terms "Tardy Median Palsy", "Median Neuritis", "Partial Thenar Atrophy" and "Carpal Tunnel Syndrome" as synonyms.

Phalen[63, 65] is the one who deserves the most recognition for popularizing CTS and raising it to the attention of medical community. He had proposed a provocative wrist flexion test that now is known as Phalen's test.[64] Chronic flexor tenosynovitis as the primary cause for nontraumatic CTS was also proposed.[65]

Gilliatt and Sears,[24] Simpson[76] and Buchthal and Rosenfalck[12] demonstrated the reduction of nerve conduction in patients with CTS. The role of ischemia was noted by Gilliatt[23] and LaBan,[37] who noted that the presence of prolonged sensory evoked potentials in transient CTS patients during wrist flexion.

Nowadays, due to the use of poorly designated tools, repetitive work procedures and non-ergonomic workplaces, CTS' presence has been extended to a vast area of occupational activities and has became one of the most important causes of lost productivity. The term CTS is used "to describe all cases of compression neuropathy of the median nerve at the wrist", following Phalen and Kendrick's recommendation.[65]

Magnitude of the Problem

In 1981, only 18% of all worldwide illnesses were Cumulative Trauma Disorders (CTD). In 1984, 28% of all occupational illnesses reported were RSI.[13] It grew to 52% in 1992 and 70% in 2000.

The CTD burden on US economy in 1994 equalled $3.6 billion in direct workers' compensations. Including the indirect costs, the total cost was $10.8 billion with $12,000 per case.[7] In 1998, there were 500,000 reported cases of Work Related Upper Extremity Disorders (WRUEDs) that needed more than one day off,[47] and from these, CTS results in the highest number of days lost among all work-related injuries. CTS is the most commonly reported nerve entrapment syndrome.[75] Currently, Carpal Tunnel Syndrome affects over 8 million Americans.[80] Almost half of the carpal tunnel cases resulted in 31 days or more of work loss.[56] The non-medical costs of a CTS case from compensation settlements and disability average $10,000 per hand. Include medical and indirect costs and the amount is elevated to $20,000 to $100,000 per hand.[78] Up to 36% of all Carpal Tunnel Syndrome patients require treatment for the rest of their lives,[80] and the total costs are enormous (Table 1).

Table 1 List of Direct and Indirect Costs Associated with CTD Incidence as Noted by Lloyd and Haslam (1998).

CTS Costs	Expenditures' Structure
Direct costs (20%)	1. Medical expenses 2. Workers' compensation premiums 3. Lost and light duty workdays
Indirect costs (80%)	1. Loss of injured worker's production 2. Time lost of employee paid by employer 3. Time lost by uninjured employees 4. Temporary help 5. Training and retraining 6. Reporting and claims 7. Management time 8. Worker/management discussions 9. Litigations costs

Dimmitt[19] noted that litigations represent an important part of the total cost of CTS with lawyer fees and other legal taxes accounting for 25% of costs. Company policy should encourage employees to return to work with subsequent job rotation. Employee expenses can reach $30,000 if the worker returns to work and $100,000 if he is unable to work again in that position.[66]

Evidence of Work Relatedness

Although some authors[26, 28, 55, 58, 77] questioned the causal relationship between work exposure and CTS, there is strong evidence of the effect of repetitive and/or forceful tasks on the musculoskeletal system. The relationship between physical exposure and Work Related Upper Extremity Disorders (WRUEDs) was noted by an overwhelming number of previous studies, some of which are being cited.[3, 4, 6, 30, 49, 75] Approximately 260,000 carpal tunnel release operations are performed each year, with 47% of the cases considered to be work-related.[56] There is a direct correlation between increased exposure and increased incidence.

In an evaluation of occupational and non-occupational factors associated with CTS, Roquelaure *et al.*[71] noted force exertion >1 kg (odds ratio (OR) = 9.0), short working circle <10s (OR = 8.8), lack of rest for at least 15% of the worktime (OR = 6.0) and manual supply of the worker (OR = 5.0) as having an important impact on CTS occurrence. Among the personal factors, only parity of at least 3 (OR = 3.2) was associated with CTS. Interestingly, no upper extremity posture was associated with CTS. They also noted a cumulative effect of risk factors on CTS development, with musculoskeletal disease increasing stridently when more than 3 factors were simultaneously present. Although the presence/absence of a specific risk factor is easy to assess, there is still a need to develop a method of quantifying the risk factors' overall effect on the probability of developing CTS. Moore and Garg[52] proposed a semi-quantitative job analysis methodology (Strain Index). It encloses the assessment/appraisal of six variables (repetition, wrist posture, task duration per day, force intensity and duration per cycle, and exertion speed). While this method is very straightforward, resulting in a numeric score (the product of all six ratings multiplied by a constant), it fails to account for psychophysical stress, which is an important risk factor. Also, posture, force intensity, and speed are subjectively recorded reducing the method's power.

The activities with the highest risk for CTS development are: data entry, poultry and meat processing/packaging, dentistry, the use of vibratory tools and cashiering (Table 2). Poultry workers have an increased risk for developing CTS (odd ratio 8–36).[36, 46, 50] The claim incidence rates in meat/poultry industry between 1987 and 1995 in Washington State were 308/10,000 workers, resulting in a major loss in poultry farms' profits.[74] All the generic work-related risk factors (force, repetitiveness, localized mechanical compression, awkward posture, working with cold hands)[5, 44, 75] were met in the poultry industry. The relationship between work postures, force, repetitiveness in poultry tasks and CTS development was studied in previous research[34, 73, 85] but future extensive research is still needed in order to develop task and employee-specific ergonomic interventions.

In a review of workers' compensation board (WCB) claims in Manitoba, Yassi *et al.*[85] assessed that the most frequent diagnosis (27.5%) of all accepted claims was CTS. The meat and poultry processing-related industry is the highest risk activity in the area. Frost *et al.*[22] assessed a prevalence ratio of 3.23 for non-deboning slaughterhouse workers and 4.91 for deboning

Table 2 Occupational Carpal Tunnel Syndrome Symptoms Prevalence and Risk Factors.

Occupation	Risk Factor for CTS	Prevalence	Reference
Poultry and meat processing/packaging	Force, localized mechanical compression, repetition, awkward posture, working with cold hands and in cold environment	37–41%	17
		53%	21
		27.5%	85
Data entry	Repetitive finger motion, awkward posture, force applied, lack of rest, muscle overuse	13%	79
		11.7%	14
		3.5%	77
Cashiers	Repetitive wrist motion, localized pressure, awkward posture, inadequate recovery time	12%	51
		11%	8
		10–63%	61
Vibratory tools	Compressive force, repetitive trauma, shock absorption, elevated muscle contraction, inadequate force, work cycles < 30 seconds	21–33%	45
		14%	59
		38.4%	10
		44%	16
Dentists	Repetitiveness, localized compressive force, work cycles < 30 seconds, awkward postures	56%	39
		4.8%	29
		11%	70

slaughterhouse workers. Gorsche *et al.*[25] found a non-significant difference in CTS prevalence in modern, mechanized meat plants when compared with older plants.

Among WRUEDs, CTS has the biggest impact in the professional computer users' health and in the industrial-related medical and non-medical costs. From the 37,804 cases of CTS reported in 1994, 7897 (24%) were attributed to repetitive typing or keyboard data entry.[78] The loss in productivity is manifested before (less typing speed), during and after (days of hospitalization) the treatment of CTS. During typing, the causes for CTS are keystroke activation force, tactile and proprioceptive feedback, repetitiveness of the task,[18] percentage of time typing, typing speed, the unequal distribution of finger usage, keyswitch make force and typing force.[2] Although typing does not lead to CTS due to the high force required,[69] the elevated level of repetition makes it a major factor in CTS pathogenesis.[60]

During typing, the posture is such that the wrist is extended and ulnar deviated. Also, in order to fit the keyboard, fingers are extended leading to an elevated intracarpal tunnel pressure.[84] Although the maximum acceptable rate is 30/min,[90] frequencies above 38–40/min are constantly met during typing. Latko *et al.*[41] found association between work repetitiveness and CTS (OR = 1.22 per unit of repetition, $p = 0.08$). Also, the significant difference between low and high repetitive activities was assessed (OR = 3.11). When positive electrodiagnostic aspect in the dominant hand (difference in peak latency of 0.5 ms between ulnar and median nerves), and hand diagrams consistent with CTS (score 2 or 3 on a 0–3 scale that take into account the presence of numbness, tingling, burning, or pain in the fingers, hand or wrists in a minimum of three episodes or one episode in more than one week in the last year) were used to define CTS, there was an important difference between the prevalence recorded for low (2.7%) and high (7.9%) repetition jobs.

CTS among cashiers is due to high repetition, awkward posture and localized mechanical pressure.[8, 51, 61] The use of monooptic laser instead of a bioptic ones elevates the repetition of the task, and forces the worker to manipulate the objects for longer periods of time.[40] Although the checkstands are designated to accommodate standing postures in Asia, North America and Australia, while seated workplaces are more common in Europe and South America, there are no differences in the number of cumulative trauma disorders.[43] A major confounding factor in simulated studies that measure the CTS risk level assessment among cashiers is the lack of rescanning, which is highly common in the real task.[40]

The mechanism by which the use of vibratory tools leads to CTS is still shadowed because of the constant association between vibration, forceful and repetitive movements. Proposed mechanisms are: elevated muscle tonic vibration reflex followed by increased muscle contraction,[5] mechanical abrasion of tendon sheaths, constricted blood flow to the nerve[68] and unnecessary increase in the applied force due to the tactility impairments caused by vibration.[10, 81] A decreased peripheral nerve conduction due to affected myelinated nerve-fibre activity and parasympathetic activity is likely to occur.[53, 54]

In all work activities, the risk of developing CTS is highly increased when there is an association between different risk factors. Silverstein *et al.*[75] noted that tasks are most hazardous where both high repetition and high force are present.

Recent studies[29, 39] noted a growing incidence of CTS among dentists. Although their assessed CTS prevalence varies within a wide range, all of them support the idea of work as a causal factor in the development of CTS among dental professionals. The risk factors are multifactorial including awkward postures, short work cycles, repetitive movements and localized mechanical pressure.

Hadler[27] stated that psychosocial factors play an important role in cumulative trauma disorders development. He tends to overestimate the role of stress in the workplace and consider that all claimants' symptoms are not work-related. Considering that work-related CTS does not exist, one does not only disdains all the claimants and the physicians that diagnosed the cases, but also the entire system. Among all WRUEDs, CTS is the disorder in which psychosocial stress plays the least important role. In CTS pathogenesis, muscle activation due to mental stress is almost nonexistent. Factors such as fatigue, insecurity, organizational stress, and lack of job satisfaction are important in the initiation of litigation.[33] Mental factors do affect pain but they can only increase its level and cannot represent the trigger factor. Only by using information that arises from ergonomic studies, one can design jobs and workplaces that will allow the worker to execute tasks within the safe limits for the musculoskeletal system.

Discussion and Conclusions

The relationship between work and CTS occurrence was stressed by previous studies. This causal link is sustained by the difference in CTS prevalence found among employees in occupations with high physical exposure/ awkward posture level versus workers performing low exposure jobs. Also, targeted ergonomic interventions succeeded in reducing the number of upper extremity musculoskeletal disorders for workers in hazardous tasks. Although the role of psychosocial factors is not fully assessed, there is strong evidence in the literature regarding the relationship between physical exposure and CTS. Ignoring the problem will determine no other result than a growth in the number of work-related disorders especially due to the maintenance of poorly designed jobs and workplaces that allow the worker to perform daily tasks at elevated risk levels.

All causal characteristics (temporal association and contiguity, dose-response effect, and biological plausibility) are present in the hazardous work-MSD relationship (Musculoskeletal Disorders and the Workplace). The occurrence of CTS *after* prolonged exposure, and the decrease of CTS cases *after* ergonomic programs implementation (reduction at risk factors exposure) stress this point of view. The assessment of the temporal relationship between exposure and outcome is jeopardized by the fact that the majority of studies are cross-sectional. Also, this type of research design fails to include the most severe cases due to their absence from the workplace. Workers' non-response may be due to different reasons. Uninterested unaffected workers as well as the ones absent due to sick-leave or transfered to light exposure jobs are not included in the original data collection. The data extrapolation to non-included workers weakens the study external validity and introduces an important bias.

The examination of work-related CTS cases should address both the individual and the working population as a group. The individual approach of the problem would provide useful data regarding the personal adaptability at the workplace, the effect of injury on the individual, methods of coping with the impairment, the individual's experience in modifying work habits as well as case management information. Analyzing the high risk working population as a whole would provide an epidemiological synopsis of the situation, allowing for targeted strategies development. One should consider the effect of personal variance on musculoskeletal development. Job/device design adaptability plays an important role and ensures the ergonomic program success (the work-men interface optimization). The only valid solution is the identification of the causes that force workers to adopt sub-optimal positions.

Due to the strong evidence that work is etiologically-related with CTS, several proposed modifications for workplace, device and job design are presented (Table 3). Since returning to the same workplace configuration would lead to the occurrence of the same pathology, all these modifications should accompany the workers' treatment.

The presence of two distinct groups of authors is evident. While some question the epide-miological relationship between work-related risk factors and CTS, the others, based on extensive direct research and systematic reviews, demonstrated the association between CTS and force, repetition, and awkward positions. Close interrelations between different risk factors play an important role in the overall job hazardous level. An accurate assessment of the level beyond the point where a risk factor becomes hazardous is needed. One should not classify a job as generating CTS cases based just on the presence of one risk factor. False positive classifications, followed by unnecessary job/device redesign may cause a decline in productivity.

In view of the information from previous studies, it is suggested that future research should address on-site work activities. The need for more studies that address the effect of psychosocial factors on upper on CTS is evident. Also, a more complex classification, rather than just "yes"

Table 3 Proposed Redesign Modifications in Hazardous Industries for a Reduction in CTS Prevalence.

Job and Device Proposed Redesign	Poultry/Meat Industry	Data Entry	Dentists	Cashiers	Vibratory Tools
Textured surface for a better grip	X		X		X
Wide range of grip sizes	X		X		X
Equal distribution of applied pressure	X	X	X	X	X
Redesign for vibration absorption	X		X		X
Well fitted gloves	X		X		X
Wide variety of specialized tools	X		X		X
Pace task reduction	X	X	X	X	X
Task alternation	X	X	X	X	X
Microbreaks	X	X	X	X	X
Training programs for new workers	X	X	X	X	X
Apply minimum required force	X	X	X		X
Adjustable devices	X	X	X		X
Workplace below elbow level	X	X	X	X	

or "no" should be used for both risk factors assessment and disease prevalence. Binary classifications do not provide any information about intermediate levels of exposure, which are encountered the most. Once these questions are answered, in order to ensure the success of adopted ergonomic jobs and workplace modifications, there should be an increase in the workers' awareness level that will help the future job assessments. A normal consequence is an increase in productivity along with a reduction in the workers' discomfort. Only by combining job/device ergonomic redesign with programs that will reduce the psychosocial stress level, one will obtain a real reduction in the number of claims.

References

1. Abbott LC, Saunders JBD. Injuries of the median nerve in fractures of the lower end of the radius. *Surg Gynecol Obstet* **57**: 507–516, 1993.
2. Amell TK, Kumar S. Cumulative trauma disorders and keyboarding work. *Int J Ind Ergon* **25**: 69–78, 1999.
3. Armstrong TJ, Castelli WA, Evans FG, Diaz-Perez R. Some histological changes in carpal tunnel contents and their biomechanical implications. *J Occup Med* **26**: 197–201, 1984.
4. Armstrong TJ, Chaffin DB. Carpal tunnel syndrome and selected personal attributes. *J Occup Med* **21**: 481–486, 1979.
5. Armstrong TJ, Fine L, Goldstein S. Ergonomic considerations in hand and wrist tendonitis. *J Hand Surg* **12**: 830–837, 1987.
6. Armstrong TJ, Fine LJ, Radwin RG, Silverstein BS. Ergonomics and the effects of vibration in hand-intensive work. *Scand J Work Environ Health* **13**: 286–289, 1987.
7. Advisor. Average CTD comp case nears $4000. **6**: 4, 1996.
8. Baron SL, Habes D. Occupational musculoskeletal disorders among supermarket cashiers. *Scand J Work Environ Health* **18**(Suppl): 127–129, 1991.
9. Bergamasco R, Girola C, Colombini D. Guidelines for designing jobs featuring repetitive tasks. **41**: 1364–1383, 1998.
10. Bovenzi M, Zadini A, Franzinelli A, Borgogni F. Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration. *Ergonomics* **34**: 547–562, 1991.
11. Brain WR, Wright AD, Wilkerson M. Spontaneous compression of both median nerves in the carpal tunnel. Six cases treated surgically. *Lancet* **1**: 277–282, 1947.
12. Buchthal F, Rosenfalck A. Sensory conduction from digit to palm and from palm to wrist in the carpal tunnel syndrome. *J Neurol Neurosurg Psychiatry* **34**: 343–352, 1971.
13. Bureau of Labor Statistics. CTD News. http://ctdnews.com/bls.html. 2001.
14. Bureau of Labor Statistics. www.bls.com. 1999.
15. Cannon BW, Love JG. Tardy median palsy; median neuritis; median thenar neuritis amenable to surgery. *Surgery* **20**: 210–216, 1946.
16. Chatterjee DS, Barwick DD, Petrie A. Exploratory electromyography in the study of vibration-induced white finger in rock drillers. *Br J Ind Med* **39**: 89–97, 1982.
17. Chiang H, Chen S, Yu H, Ko Y. The occurence of carpal tunnel syndrome in frozen food factory employees. *Kao Hsiung J Med Sci* **6**: 73–80, 1990.
18. Coury HJCG, Kumar S, Rodgher S, Narayan Y. Measurement of shoulder adduction strength in different postures. *Int J Ind Ergon* **22**: 195–206, 1998.
19. Dimmitt BS. Repetitive stress injuries: Relieving pain at the bottom line. *Bus Health* 21–24, 1995.
20. Dionne ED. Carpal tunnel syndrome — The problem, Part 1. *Nat Saf News* 42–45, 1984.
21. Falck B,Aarnio P. Left-sided carpal tunnel syndrome in butchers. *Scand J Work Environ Health* **9**: 291–297, 1983.
22. Frost P, Andersen JH, Nielsen VK. Occurence of carpal tunnel syndrome among slaughterhouse workers. *Scand J Work Environ Health* **24**: 285–292, 1998.
23. Gilliatt RW. Chronic nerve compression and entrapment. In: *The Physiology of Peripheral Nerve Disease*, edited by AJ Summers, Philadelphia, WB Saunders, pp. 316–339, 1980.
24. Gilliatt RW, Sears TA. Sensory nerve action potentials in patients with peripheral nerve lesions. *J Neurol Neurosurg Psychiatry* **21**: 109–118, 1958.
25. Gorsche RG, Wiley JP, Renger RF, Brant RF, Gemer TY, Sasyniuk TM. Prevalence and incidence of carpal tunnel syndrome in a meat packing plant. *Occup Environ Med* **56**: 4–7–422, 1999.
26. Hadler NM. *Clinical Concepts in Regional Musculoskeletal Illness*, Grune & Stratton, Inc., Harcourt Brace Jovanovich, Publishers, 355–360, 1987.
27. Hadler NM. Coping with arm pain in the workplace. *Clin Orthop Rel Res* **351**: 57–62, 1998.
28. Hadler NM. *Occupational Musculoskeletal Disorders*,2nd edn., Philadelphia, Lippincott Williams & Wilkins, 1999, pp. 1–433.

29. Hamann C, Werner RA, Franzblau A, Rodgers PA, Siew C, Gruninger S. Prevalence of carpal tunnel syndrome and median mononeuropathy among dentists. *J Am Dent Assoc* **132**: 223–224, 2001.
30. Hart DL. Occupational Injury. *Phys Ther* **79**: 1084–1088, 1999.
31. Hunt JH. The thenar and hypothenar types of neuroatrophy of the hand. *Am J Med Sci* **141**: 224, 1911.
32. Hunt JR. Occupation neuritis of the thenar branch of the median nerve: A well-defined type of atrophy of the hand. *Trans Am Neurol Assoc* **35**: 84, 1909.
33. Jackson P, Martin R. Impact of just-in-time on job content, employee attitudes and well-being: A longitudinal study. *Ergonomics* **39**: 1–16, 1996.
34. Kirschberg GJ, Fillingim R, Davis VP, Hogg F. Carpal tunnel syndrome: Classic clinical symptoms and electrodiagnostic studies in poultry workers with hand, wrist, and forearm pain. *S Med* **87**: 328–331, 1994.
35. Kremer M, Gilliatt RW, Golding JSR. Acroparaesthesiae in the carpal-tunnel syndrome. *Lancet* **ii**: 590–595, 1953.
36. Kurppa K, Viikari-Juntura E, Kuosma E, Huuskonen M, Kivi P. Incidence of tenesynovitis or peritendinis in a meat processing factory. *Scand J Work Environ Health* **17**: 32–37, 1991.
37. LaBan MM, MacKenzie JR, Zemenick GA. Anatomic observations in carpal tunnel syndrome as they relate to the tethered median nerve stress test. *Arch Phys Med Rehabil* **70**: 44–46, 1989.
38. LaBan MM, Spliteri DJ. History and differential diagnosis of carpal tunnel syndrome. *Phys Med Rehab Clin N Am; Carpal Tunnel Syndrome,* W.B. Saunders Company **8**: 409–418, 1987.
39. Lalumandier JA, McPhee SD. Prevalence and risk factors of hand problems and carpal tunnel syndrome among dental hygienists. *J Dent Hyg* **75**: 130–134, 2001.
40. Lannersten L, Ringdahl KH. Neck and shoulder muscle activity during work with different cash register systems. *Ergonomics* **33**: 49–65, 1990.
41. Latko WA, Armstrong TJ, Franzblau A, Ulin SS, Werner RA, Albers JW. Cross-sectional study of the relationship between repetitive work and the prevalence of upper limb musculoskeletal disorders. *Am J Ind Med* **36**: 248–259, 1999.
42. Learmonth JR. The principle of decompression in the treatment of certain diseases of peripheral nerves. *Surg Clin N Am* **13**: 905–913, 1933.
43. Lehman KR, Psihogios JP, Meulenbroek GJ. Effects of sitting versus standing and scanner type on cashiers. *Ergonomics* **44**: 719–738, 2001.
44. Loslever P, Ranaivosoa A. Biomechanical and epidemiological investigation of carpal tunnel syndrome at workplaces with high risk factors. *Ergonomics* **36**: 537–554, 1993.
45. Lucas E. Lesion of the peripheral nervous system due to vibration. *Work Environ Health* **7**: 67–79, 1970.
46. Luopajarvi T, Kuorinka I, Virolainen M, Holmberg M. Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. *Scand J Work Environ Health* **5**: 48–55, 1979.
47. Mani L, Gerr F. Work-related upper extremity musculoskeletal disorders. *Occup Environ Med* **27**: 845–864, 2000.
48. Marie P, Foix C. Atrophie isolee de l'eminence thenar d'origine n'evritique: Role du ligament annulaire anterieur du carpe dans la pheogenie de la lesion. *Rev Neurol (Paris)* **26**: 647–649, 1913.
49. Marklin RW, Simoneau GG, Monroe JF. Wrist and forearm posture from typing on split and vertically inclined computer keyboards. *Hum Factors* **41**: 559–569, 1999.
50. McCormack R, Inman R, Wells A, Bernsten C, Imbus H. Prevalence of tendinitis and related disorders of the upper extremity in a manufacturing workforce. *J Rheum* **17**: 958–964, 1990.
51. Morgenstern H, Kelsh M, Kraus J, Margolis W. A cross-sectional study of hand/wrist symptoms in female grocery checkers. *Am J Ind Med* **20**: 209–218, 1991.
52. Moore JS, Garg A. The strain index: A proposed method to analyze jobs for risk of distal upper extremity disorders. *Am Ind Hyg Assoc* **56**: 443–458, 1995.
53. Murata K, Araki S, Aono K. Central and peripheral nervous system effects of hand-arm vibrating tool operation. A study of brainstem auditory-evoked potential and peripheral nerve conduction velocity. *Int Arch Occup Environ Health* **62**: 183–187, 1990.
54. Murata K, Araki S, Maeda K. Autonomic and peripheral nervous system dysfunction in workers exposed to hand-arm vibration. A study of R-R interval variability. *Int Arch Occup Environ Health* **63**: 205–211, 1991.
55. Nathan PA, Keniston RC, Myers LD, Meadows KD. Longitudinal study of median nerve sensory conduction in industry: Relationship to age, gender, hand dominance, occupational hand use, and clinical diagnosis. *J Hand Surg* **17A**: 850–857, 1992.
56. National Center for Health Statistics. www.cdc.gov/nchs/ 2000.
57. National Research Council. *Musculoskeletal Disorders and the Workplace-Low Back and Upper Extremities,* edited

by JA Barondess, National Academy Press, 2001, pp. 38–85.
58. Nilsson T, Hagberg M, Berstrom L, Lundstrom R. A five year follow up of nerve conduction over the carpal tunnel. Stockholm Workshop 94. Hand-Arm Vib Syndrome, Arbete Och Halsa Vetenskaplig Skriftserie **5**: 117–120, 1995.
59. Nilsson T, Hagberg M, Burstrom L. Prevalence and odds ratio of numbness and carpal tunnel syndrome in different exposure categories of planters. In: *Hand-Arm Vibration*, edited by A Okada, WTH Dupuis, Kanazawa, Japan, Kyoei Press Co, 1990, pp. 235–239.
60. Nordstrom DL, Vierkant RA, DeStefano F, Layde PM. Risk factors for carpal tunnel syndrome in a general population. *Occup Environ Med* **54**: 734–740, 1997.
61. Osorio AM, Ames RG, Jones J, Castorina J, Rempel D, Estrin W. Carpal tunnel syndrome among gracery store workers. *Am J Ind Med* **25**: 229–245, 1994.
62. Paget T. *Lectures on Surgical Pathology*. Philadelphia, Lindsay & Blakiston, 1854.
63. Phalen GS. Neuropathy of the median nerve due to compression beneath the transverse carpal ligament. *J Bone Joint Surg [Am]* **32**: 109–112, 1950.
64. Phalen GS. Spontaneous compression of median nerve at the wrist. *JAMA* **145**: 1128–1133, 1951.
65. Phalen GS, Kendrick JI. Compression neuropathy of the median nerve in the carpal tunnel. *JAMA* **164**: 524–530, 1957.
66. Pinkham J. Carpal tunnel syndrome suffers find relief with ergonomic design. *Occup Saf Health* 1988.
67. Putnam JJ. A series of cases of paresthesia, mainly of the hand, of periodical reoccurrence and possibly of vasomotor origin. *Arch Med* **4**: 147–162, 1880.
68. Putz-Anderson VE. Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs. Taylor & Francis 1988.
69. Rempel DR, Tittiranonda P, Burasteno S, Hudes M, So Y. Effect of Keyboard Keyswitch Design on Hand Pain. *JOEM* **41**: 111–119, 1999.
70. Rice VJ, Nindl B, Pentikis JS. Dental workers, musculoskeletal cumulative trauma, and carpal tunnel syndrome, Who is at Risk? A Pilot Study. *Int J Occup Saf Ergon* **2**: 218–233, 1996.
71. Roquelaure Y, Mechali S, Dano C, Fanello S, Benetti F, Bureau D, Mariel J, Martin Y-H, Derriennic F, Penneau-Fontbonne D. Occupational and personal risk factors for carpal tunnel syndrome in industrial workers. *Scand J Work Environ Health* **23**: 364–369, 1997.
72. Schiller F, Kolb FO. Carpal tunnel syndrome in acromegaly. *Neurology* **4**: 271–282, 1954.
73. Schottland JR, Kirschberg GJ, Fillingim R, Davis VP, Hogg F. Median nerve latencies in poultry processing workers: An approach to resolving the role of industrial "cumulative trauma" in the developing of carpal tunnel syndrome. *J Occup Med* **33**: 627–631, 1991.
74. Silverstein B, Welp E, Nelson N, Kalat J. Claims incidence of work-related disorders of the upper extremities: Washington state, 1987 through 1995. *Am J Public Health* **88**: 1827–1833, 1998.
75. Silverstein BA, Fine LJ, Armstrong JA. Occupational Factors and Carpal Tunnel Syndrome. *Am J Ind Med* **11**: 343–358, 1987.
76. Simpson JA. Electrical signs in the diagnosis of carpal tunnel and related syndromes. *J Neurol Neurosurg Psychiatry* **19**: 275–280, 1956.
77. Stevens JC, Witt JC, Smith BE, Weaver AL. The frequency of carpal tunnel syndrome in computer users at a medical facility. *Neurology* **56**: 1568–1570, 2001.
78. Szabo R M. Carpal tunnel syndrome as a repetitive motion disorder. *Clin Orthop Rel Res* **351**: 78–89, 1998.
79. Ulin S, Armstrong W, Latko AF. *The Relationship Between Low and Medium Keyboard Use Office Jobs and Upper Extremity Cumulative Trauma Disorders in a Cross-Sectional Study*. AIHA Press, www.aiha.org.
80. US Department of Labor. 1999. Notes: CTD News. http://ctdnews.com/bls.html.
81. Viikari-Juntura E, Silverstein B. Role of physical load factors in carpal tunnel syndrome. *Scand J Work Environ Health* **25**: 163–185, 1999.
82. Wartenberg R. Partial thenar atrophy. *Arch Neurol Psychiatry* **42**: 373, 1939.
83. Webreference. Repetitive Strain Injurie — The Hidden Cost of Computing. 2001. Notes: http://webreference.com/rsi.html
84. Werner R, Armstrong TJ, Aylard MK. Intracarpal canal presure: The role of finger, hand, wrist and forearm position. *Clin Biomech* **12**: 44–51, 1997.
85. Yassi A, Sprout J, Tate R. Upper limb repetitive strain injuries in Manitoba. *Am J Ind Med* **30**: 461–472, 1996.
86. Zabriskie EG, Hare CC, Masselink RJ. Hypertropic arthritis of the cervical vertebrae with thenar muscular atrophy occurring in three sisters. *Bull Neurol Inst NY* **4**: 207, 1935.