

Abstract

Objectives In this pilot study the effects of traction in the treatment of carpal tunnel syndrome (CTS) were evaluated and compared to the effects of splinting.

Methods The experimental group consisted of 8 patients who received traction treatment for a period of 12 weeks. The treatment consisted of 12 sessions. Control data were derived from Gerritsen's (2002) study, which included 77 patients. The latter group ("control group") received treatment consisting of splinting, for at least 6 weeks. All participants were examined before treatment and after 3 months of treatment. Patients included in the experimental group were also examined after 2 months of treatment. Primary outcome measures were general symptoms, functional status, pain, paraesthesia, hypoesthesia, waking up due to the symptoms and general improvement (success rate). The reliability of the measurement instruments was also assessed.

Results Although there was a tendency towards improvement in the traction group on all dependent variables, none of the changes was statistically significant. This may be due to the small power of the statistical tests resulting from the small number of participants. No clear differences between the effects of the traction and splinting treatment could be established. The success rate of the traction treatment was 66%, as compared to 54 % in the splinting group. The reliability of the outcome measures was high. Most of them had an intraclass correlation coefficient of 0.75 or higher, indicating excellent reproducibility.

Conclusions The tests and scales being used provided a good picture of the effects of treatment on CTS. Despite the lack of significant results, patients reported positive effects of the traction treatment. Further research on the effects of traction treatment including a larger number of participants seems warranted.

Introduction

Anatomy

Carpal tunnel syndrome (CTS) is a compression neuropathy of the median nerve at the wrist. Any condition that reduces the size of the carpal tunnel or increases the volume of its content will cause compression of the median nerve (Gerritsen, 2002). The carpal tunnel is comprised of two arches. The carpal arch is made up of the carpal bones and forms a concave base. A roof is made up of the flexor retinaculum that overlies the flexor tendons to form the tunnel. Nine flexor tendons (two extending to each finger and one to the thumb) traverse the carpal tunnel, along with the median nerve (Dawson et al., 1983), shown in figure 1.

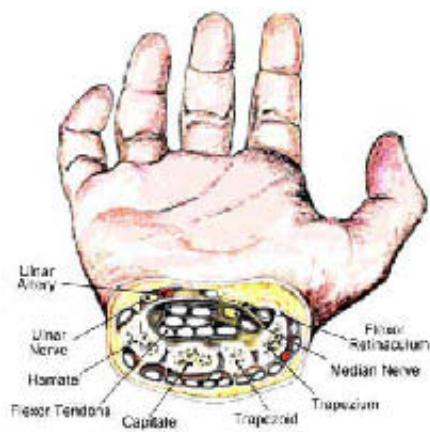


Figure 1. Anatomy of the carpal tunnel

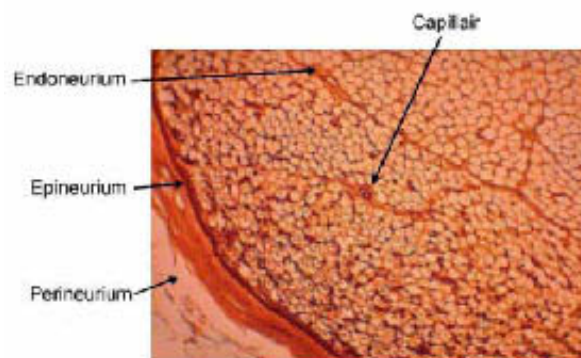


Figure 2. Anatomy of a typical nerve

The median nerve has the histological arrangement typical of a peripheral nerve (figure 2). The nerve consists of multiple nerve fibre fascicles loosely bound by the collagenous epineurium. An extensive network of arterioles, venules and lymphatics provides circulation within the epineurium. Each fascicle is encased in a tighter cellular and connective tissue sheath, the perineurium (Rosenbaum and Ochoa, 1993).

A small bundle of fibres, enclosed in a tubular sheath, is called a funiculus; if the nerve is of small size, it may consist only of a single funiculus; but if large, the funiculi are collected together into larger bundles or fascicles, which are bound together in a common membranous investment (Williams and Gray, 1989).

Pathophysiology

Any space-occupying mass may cause elevated pressure and median nerve compression. Dawson et al. (1983) reported tenosynovitis as a major causative factor for CTS. Rosenbaum and Ochea (1993) suggest that the most common synovial histological changes are related more to fibrosis and oedema instead of inflammation. Other space-occupying lesions include tumours, recent and old fractures and fracture-dislocation around the wrist, or arthritic conditions. Anomalous conditions of the flexor tendons within the carpal tunnel may also cause elevated pressure in the carpal tunnel. This increased pressure produces ischemia of the median nerve, resulting in impaired nerve conduction and attendant paraesthesia (abnormal skin sensations as tingling, tickling, itching or burning) and pain, known as CTS. (Dawson et al., 1983). When there is prolonged ischemia, axonal injury ensues, and nerve dysfunction may be irreversible (Katz and Simmons, 2002).

The nerve is particularly vulnerable to compression in the carpal tunnel, but there are features of its internal anatomy in this region which offer some protection to the contained nerve fibres. The median nerve in the carpal tunnel is usually composed of small funiculi well separated by large amounts of epineural tissue packing. This protects nerve fibres from compression (Sunderland, 1978). Therefore to deform the funiculi and their contained nerve fibres, a very large pressure is required. In individuals in whom the funiculi are larger and fewer in number and have less protective connective tissue packing, the nerve would be more vulnerable to compression (Sunderland, 1978).

A linear relationship exists between the size of a funiculus and the thickness of its perineural sheath. In the carpal tunnel the perineurium of the funiculi is thicker than it is for bundles of the same size at other levels. In contrast to the epineurium, the perineurium is not crossed by lymphatics and functions as a diffusion barrier. An intrafunicular pressure is maintained by the elastic perineurium resists and maintains an intrafunicular pressure (Sunderland, 1978). Inside the funiculi only capillaries are found. These capillaries are fed by arterioles and drain to veins, which are located in the epineurium. Venous vessels outnumber arterial vessels (Sunderland, 1978). The nutrient vessels take an oblique course as they pass through the perineural sheath, thereby introducing a valve mechanism which would lead to their obstruction with any pathological swelling of the funiculus (Lundborg, 1970 in Sunderland, 1978).

The pressure in the nutrient arteries in the epineurium (P_a), the capillary pressure inside the funiculi (P_c), the intrafunicular pressure (P_f), the pressure in the veins in the epineurium draining the funiculi (P_v) and the pressure within the carpal tunnel (P_t) are interrelated pressure systems in the carpal tunnel. In order to maintain the nutrition of the nerve, there must be an adequate intrafunicular circulation. The pressure gradient across this system must be $P_a > P_c > P_f > P_v > P_t$ (Sunderland, 1978). Because these pressure systems are in delicate balance there is little margin if the pressure within the carpal tunnel increases. In this respect veins succumb to compression before arteries (Sunderland, 1978). If the pressure inside the tunnel steadily increases a series of changes will take place, which must be regarded as passing through three stages (Sunderland, 1976). However these changes do not develop in a uniform manner so that at any one time these changes may be more advanced in some funiculi than in others. Following are the three stages concerning the effects of the elevated pressure in the carpal tunnel, based on the stages as described by Sunderland (1978).

Stage 1: Because veins succumb to pressure before arteries, the first changes are those due to obstruction to the venous return from the nerve, which leads to circulatory slowing in the epineural and intrafunicular tissues. When the pressure increases further these circulatory disturbances worsen and ultimately lead to pathological changes, of which the most damaging take place in the funiculi. The nutrition of the effected nerve fibres becomes impaired until hypoxia reaches levels where they become hyper excitable and commence to discharge spontaneously (Porter and Wharton, 1949 in Sunderland, 1978). In this respect, the thick myelinated fibres are affected first. Because the thick myelinated fibres exhibit little resistance to the longitudinal flow of current, they have a greater length constant (λ). The length constant affects the efficiency of electronic propagation of synaptic potentials. The largest axons have the lowest threshold. Fibre dissociation and imbalance of fibre activity originating in this way give rise to pain (Noordenbos, 1959 in Sunderland, 1978). Because not all funiculi or all fibres are affected to the same degree at the same time the distribution of the symptoms in the initial stages varies. The most characteristic feature of CTS is nocturnal paraesthesia and pain. This could be explained by the diminished return of blood flow. This diminished return of blood flow is probably caused by the hypotonia and the depression of movements during sleep.

Stage 2: The capillary circulation is finally slowed to a point where lack of oxygen damages the capillary endothelium. This leads to the leakage of protein into the surrounding tissues,

which become oedematous. Because the protein cannot escape across the perineurium, it steadily accumulates in the endoneurial places, which become increasingly oedematous. This further interferes with the nutrition and metabolism of the nerve fibres while the rising intrafunicular pressure adds to their difficulties. The protein exudate promotes the proliferation and increased activity of fibroblasts and the formation of constrictive endoneurial connective tissue. Individual nerve fibres show segmental demyelination, axon thinning and finally destruction of the axon. The sensory and motor deficit deepens as more funiculi and fibres are involved and the severity of the lesion increases.

Stage 3: When deforming forces interfere with not only the venous return from the nerve, but also the blood supply to it, stage 3 is achieved. When reaching this stage increasing numbers of nerve fibres are destroyed, the protein exudate is transformed into fibrous tissue and nutrient vessels disappear. Only a few nerve fibres survive inside the fibrosed funiculi which are encased in a now dense relatively avascular perineurium. Few regenerating axons are successful in penetrating this tissue, most terminating on reaching the fibrosed segment by contributing to the swelling of the nerve at that site.

With the degeneration of the nerve and the contraction of the perineurium about the now reduced contents of the funiculus, the funiculi shrink. The overall effect of the funicular shrinkage of the nerve trunk is determined by the relative amounts of the funicular and epineurial tissue originally comprised in the tunnel (Sunderland, 1978). Because this feature varies from individual to individual, the extent of the nerve atrophy will vary accordingly, atrophy being marked when funicular tissue occupies much of the cross-sectional area of the nerve and minimal when there are relatively large amounts of epineurial tissue (Sunderland, 1978). In figure 3 the pathomechanical changes in carpal tunnel syndrome are illustrated.

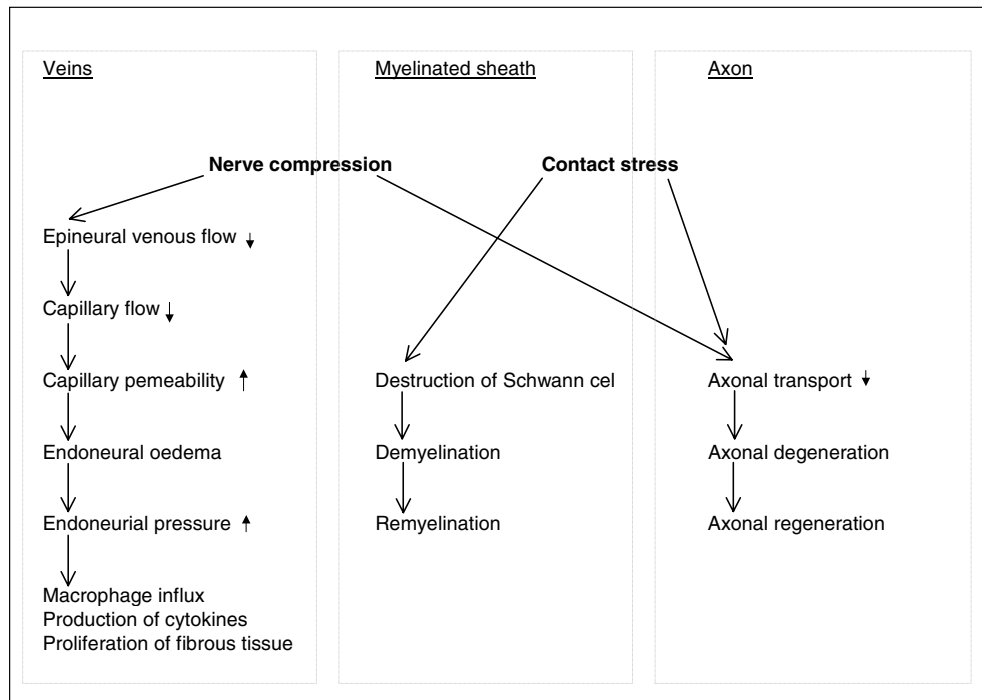


Figure 3. Pathomechanical pathway of carpal tunnel syndrome.

Symptoms

The most characteristic complaint of people suffering from CTS is attacks of painful tingling (paraesthesia) in one or both hands at night, sufficient to wake the sufferer after a few hours of sleep. The pain and paraesthesia are usually described as burning or agonising and a deep-seated ache may spread up from the forearm to the elbow. The ache is severest on the inner aspect of the forearm and more rarely may be felt in muscles as high as the shoulder. Another common symptom of CTS is hypoesthesia. With the pain and tingling there is a subjective feeling of not being able to use the fingers, which are sometimes described as swollen; yet on inspection little or no swelling is apparent. Relief may be obtained by hanging the arm out of bed or shaking or rubbing the hand; but, as symptoms increase, the patients often get out of bed and walk about until eased (Kremer et al., 1953). CTS is diagnosed largely based on symptoms. The high incidence of asymptomatic nerve compression, the inaccuracies of diagnostic signs and tests, the possibility of multiple common conditions contributing to hand symptoms, and the natural variations in the way patients experience and describe symptoms all contribute to diagnostic uncertainty. Table 1 offers a classification of types of median nerve neuropathy that may occur at the carpal tunnel.

Table 1 Classification of median neuropathies at the carpal tunnel (Rosenbaum and Ochoa, 1993).

Class	Symptoms	Signs
0 Asymptomatic	None	None
1 Intermittently symptomatic	Intermittent positive symptoms	Provocative tests often positive, but neurological deficit usually absent
2 Persistently symptomatic	Continual symptoms, positive or negative	Neurological deficit sometimes present
3 Severe	Usually present	Neurological deficit with evidence of axonal interruption

Prevalence and incidence

Carpal tunnel syndrome is the most common compressive neuropathy of the upper extremity (Dawson et al., 1983). High prevalence rates have been reported in certain occupations, but only few studies have been done about CTS in a general population. Atroshi et al. (1999) conducted an epidemiological study to estimate the prevalence of CTS. The population of this study was a sex- and age-stratified sample of 3000 subjects, aged 25 to 74 years, randomly selected. The population prevalence of pain, numbness, and/ or tingling in the median nerve distribution was 14.4 % (95% CI, 13.0% - 15.8%). The sex- and age-specific prevalence rates are shown in table 2. The prevalence of clinically certain CTS was 3.8 % (95% CI, 3.1 – 4.6) the prevalence of median nerve symptoms and electro-physiological median neuropathy was 4.9% (95% CI, 4.1% – 5.8%). The prevalence of clinically and electro-physiologically confirmed CTS was 2.7% (95 CI, 2.1% - 3.4%). The sex- and age-specific prevalence rates are shown in table 3. The ratio of female to male prevalence was 1.4:1 in this study. Among older persons, however, the prevalence in women was almost four times that in men.

Table 2. Prevalence of pain, numbness, and/ or tingling in the median nerve distribution in the hands (N= 2466)*. (Atroshi et al., 1999)

Age	Men			Women		
	Responders , No.	Sympt., No.	Prevalence, % (95% CI)	Responders , No.	Sympt., No.	Prevalence, % (95% CI)
25 - 34	219	11	5.0 (2.5 – 8.8)	244	30	12.3 (8.4 – 17.1)
35 - 44	213	17	8.0 (4.7 – 12.5)	280	55	19.6 (15.1 – 24.8)
45 - 54	209	32	15.3 (10.7 – 20.9)	280	50	17.9 (13.5 – 22.8)
55 - 64	259	41	15.8 (11.6 – 20.8)	252	59	23.4 (18.3 – 29.1)
65 - 74	234	20	8.5 (5.3 – 12.9)	276	39	14.1 (10.2 – 18.8)
All **	1134	121	10.4 (8.6 – 12.2)	1332	233	17.3 (15.3 – 19.4)

* CI indicates confidence interval
** The sex-specific overall prevalence rates are age standardized to the Swedish general population

Table 3. Sex- and age-specific prevalence rates of carpal tunnel syndrome.* (Atroshi et al., 1999)

Men						
Age	Clinically certain CTS		Electrophysiological Median Neuropathy at the Carpal Tunnel		Clinically and electrophysiologically Confirmed Diagnosis of CTS	
	No.	Prevalence, % (95% CI)	No.	Prevalence, % (95% CI)	No.	Prevalence, % (95% CI)
25 - 34	3	1.4 (0.3 - 3.9)	4	1.8 (0.5 - 4.6)	2	0.9 (0.1 - 3.3)
35 - 44	3	1.4 (0.3 - 4.1)	6	2.8 (1.0 - 6.0)	2	0.9 (0.1 - 3.3)
45 - 54	11	5.3 (2.7 - 9.2)	17	8.1 (4.8 - 12.7)	9	4.3 (2.0 - 8.0)
55 - 64	10	3.9 (1.9 - 7.0)	14	5.4 (3.0 - 8.9)	8	3.1 (1.3 - 6.0)
65 - 74	4	1.7 (0.5 - 4.3)	7	3.0 (1.2 - 6.1)	3	1.3 (0.3 - 3.7)
All **	31	2.8 (1.8 - 3.8)	48	4.3 (3.1 - 5.5)	24	2.1 (1.3 - 3.0)
Women						
Age	Clinically certain CTS		Electrophysiological Median Neuropathy at the Carpal Tunnel		Clinically and electrophysiologically Confirmed Diagnosis of CTS	
	No.	Prevalence, % (95% CI)	No.	Prevalence, % (95% CI)	No.	Prevalence, % (95% CI)
25 - 34	7	2.9 (1.2 - 5.8)	5	2.0 (0.7 - 4.7)	4	1.6 (0.5 - 4.1)
35 - 44	16	5.7 (3.3 - 9.1)	11	3.9 (2.0 - 6.9)	8	2.9 (1.2 - 5.5)
45 - 54	11	3.9 (2.0 - 6.9)	18	6.4 (3.8 - 10.0)	8	2.9 (1.2 - 5.5)
55 - 64	14	5.6 (3.0 - 9.1)	20	7.9 (4.9 - 12.0)	8	3.2 (1.4 - 6.2)
65 - 74	15	5.4 (3.1 - 8.8)	18	6.5 (3.9 - 10.1)	14	5.1 (2.8 - 8.4)
All **	63	4.6 (3.5 - 5.7)	72	5.2 (4.0 - 6.3)	42	3.0 (2.1 - 3.9)

* CI indicates confidence interval
** The sex-specific overall prevalence rates are age standardized to the Swedish general population

De Krom et al. (1992) addressed the prevalence of undetected CTS in the general population. The population of this study was an age- and sex-stratified sample of 715 subjects, taken from the population register of Maastricht and the surrounding villages (the Netherlands). Seventy percent, 504 subjects (164 men and 340 women) could be interviewed. In this study a combination of the typical history and abnormal nerve conduction of the median nerve at the wrist, was taken as method to diagnose CTS. The prevalence of undetected CTS in men was 0.6% and in women 6.8%. The age-adjusted overall estimate taking the Dutch female population as the standard is 5.8% (95% CI, 3.5% - 8.1%). Another 3.4% (95% CI, 1.5% - 5.3%) of the women in this population had already been diagnosed with CTS.

Mondelli et al. (2002) calculated the incidence of newly diagnosed cases of CTS, identified by clinical and physiological criteria, in the Sienna area (Tuscany, Italy) in the 8-year period from 1991 to 1998. The annual average incidence was 329.4 per 100000 person-years (95%

CI, 317.9 – 340.9). The percentage distribution of sex- and age-specific incidence is shown in figure 4. The ratio of female to male annual average incidence was 3.6:1.

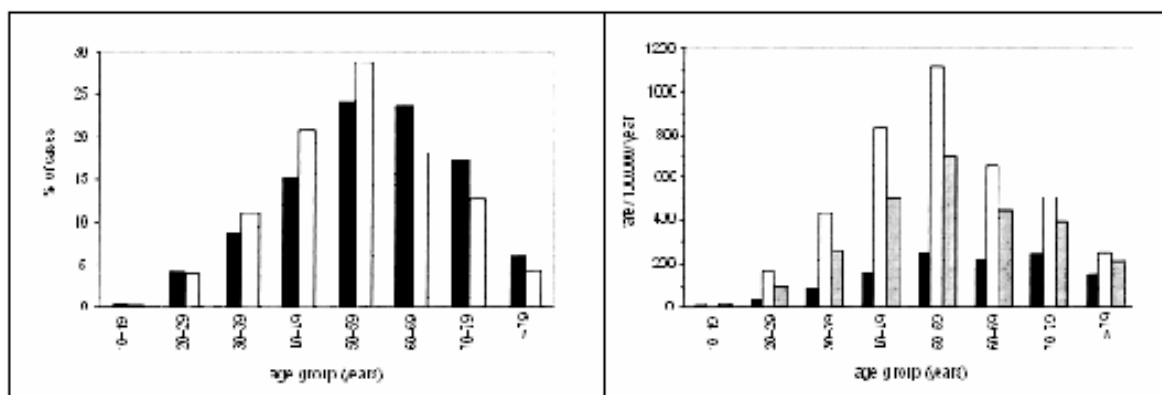


Figure 4. (Left panel) Percentage distribution of carpal tunnel syndrome cases grouped in decades by age and sex. Black histogram refers to men (638) and white histogram to women (2,504). (Right panel) Age-specific and sex-specific annual average incidences. Black histogram refers to men, white histogram to women, and grey histogram to the whole population. (Mondelli et al., 2002)

From these studies it can be concluded that the prevalence of CTS in the general population is around 3% - 10%, and that CTS is more common in women than in men. Carpal tunnel syndrome seems to be most common in people in the age of 40 – 70 years.

Treatment

CTS with pain and sensory- and motor deficit is treated with a variety of conservative (non-surgical) and non-conservative (surgical) interventions. These include splinting, manual procedures, prescription of non-steroidal anti-inflammatory drugs, injection of steroids in the carpal tunnel and several forms of surgery (Davis et al. 1998). Until now the patient is first treated with splinting and when splinting doesn't help the patient is given anti-inflammatory drugs or injections of steroids in the carpal tunnel. When there is still no effect, operation is the last option. The operation focuses on the release of the flexor retinaculum (or transverse carpal ligament). The release of the flexor retinaculum causes a widening of the carpal tunnel, allowing more room for the contents of the nine flexor tendons and the median nerve.

Gerritsen et al. (2002) found a success rate with regard to this surgery of 92%, one year after treatment (see appendix I).

These treatments can cause complications. Injections of steroids may cause complications such as chemical neuritis, tendon atrophy and aseptic necrosis (Valente et al. 1994). Surgery

is associated with complications that include infection, motor branch severance of the median nerve, injury to the palmar cutaneous branch of the median nerve, incomplete sectioning of the carpal ligament, pisotriquetral pain syndrome, reflex sympathetic dystrophy, hypersensitive scarring and transection of the digital sensory nerves (Kuschner et al. 1991).

Splinting:

Among the conservative treatments of CTS, splinting is the most popular method (Kruger et al. 1991, Kaplan et al., 1990, Weiss et al., 1994). It is simple, safe, relatively inexpensive, and often effective at least initially (Rosenbaum et al., 1993). Immobilizing the wrist in neutral position maximizes available carpal tunnel space, minimizing compression and providing symptomatic relief (Kruger et al., 1991). Some studies reported that splinting is an effective treatment. Kruger et al. (1991) reported that after splint use 67% of the subjects reported symptom relief. Akalin (2002) reported that the symptoms of the patients treated with splinting were relieved significantly. A total of 72,2% of the patients reported good or excellent results at the follow-up investigation, and only 27,8 % of the patients remained symptomatic.

However, there are many studies that report that splinting may be a less effective treatment. Destefano et al. (1997) showed that approximately 40% of conservatively treated patients with CTS continued to experience symptoms after 30 months. Katz and Simmons (1998) reported that approximately 60-70% of conservatively managed patients remained symptomatic after 18 months. Kaplan et al. (1990) showed that in 18,4% of the patients a treatment was successful. The treatment consisted of a wrist splint and anti-inflammatory medication. Follow-up averaged 15,4 months. Weiss et al. (1994) prospectively studied steroid injection and wrist splinting in 76 hands. Follow up examination averaged 11 months. Ten hands were noted to be symptom free. However, these studies did not have standardized, consistent, conservative treatment programs. Gerritsen (2002) conducted a randomised controlled trial comparing splinting with surgery. The success rate after 3 months was 54% for splinting. But after 18 months the success rate was only 37%.

From these preceding studies it can be concluded that splinting is effective for the initial relief but on the long term outcomes have been poor.

Traction method

A new treatment for CTS is the traction method. In The United States of America a traction apparatus was developed, the Phystrac TE10. Using this apparatus for treatment, the lower arm and the elbow are kept on the right place with fixation brims. The traction to the lower arm is given through a brim around the wrist, which is attached to a pneumatic mechanism. This gives a controlled traction of the lower arm and the wrist, and results in a relaxation of the structures, muscles and ligaments, which are involved in the complaints of CTS. It is comparable with manual traction. But the advantage of this device is that it can deliver an exact force, which can be repeated. This treatment pretends to release the pressure by the carpal ligament on the structures in the carpal tunnel and diminish the compression of the median nerve. Clinical experience and empirical tests have shown that the Phystrac is simple and in most of the times effective. Up till now, however, no scientific research has been executed to reveal the therapeutic value of this new treatment method.

Objective

The current study focuses on the effects of the traction treatment. The result of the treatment will be compared to that of a control group of people who were treated with splinting. From an ethical point of view, it's not possible to compare the traction treatment with a non-treatment condition, thereby denying patients appropriate medical care. This leads to the following research question: How do outcomes of traction treatment of CTS compare with outcomes of splinting.

Methods

Subjects

Patient were included in the experimental group when they suffered from pain, paraesthesia and/ or hypoesthesia (impairment of tactile sensitivity; decrease of sensitivity) in the hand area innervated by the median nerve, and when the treating physical therapist confirmed the diagnosis CTS. Furthermore the patients had to be 18 years of age or older and be able to complete written questionnaires (in Dutch). Exclusion criteria in this study were: 1) patients with recent fractures; 2) rheumatoid arthritis; 3) severe osteoporosis; and 4) severely damaged veins.

For the control group data from a study by Gerritsen (2002) were used. In that study, however, different inclusion and exclusion criteria were met compared to the current study. Inclusion criteria in the study by Gerritsen (2002) were: 1) electrophysiological confirmation of the diagnosis (median nerve sensory conduction velocity (index finger) ≤ 41.9 m/s in patients younger than 55 years or ≤ 37.3 m/s in patients older than 54 years, or median nerve distal sensory latency (DSL) (index finger) ≥ 3.5 milliseconds (ms) or median-ulnar DSL difference (ring finger) > 0.4 ms, or median nerve distal motor latency ≥ 4.34 ms). Additional exclusion criteria in the study of Gerritsen (2002) were: 1) previously treated with splinting or surgery; 2) a history of wrist trauma (e.g. fracture) or surgery; 3) a history suggesting underlying causes of CTS (e.g. diabetes mellitus, pregnancy); 4) clinical signs or symptoms or electrophysiological findings suggesting conditions that could mimic CTS or interfere with its validation (e.g. cervical radiculopathy, polyneuropathy); and 5) severe thenar muscle atrophy.

Unfortunately it was impossible to use the same inclusion and exclusion criteria in the current study, because this would have resulted in too small a sample. For the experimental group an assessment was made of potential prognostic indicators, such as age, sex, bilateral CTS complaints en whether or not the dominant side was most severely affected. When information about an electro-myographical (EMG) test was available, this information was registered. The treating physical therapists were asked to register information about the patient that concerned the exclusion criteria as they where used in the study of Gerritsen (2002).

Treatment

The experimental group was treated with the traction method. This intervention consisted of 12 treatment sessions each taking about 30 minutes, 15 minutes of which were used for an evaluation of the condition of the patient. The first 8 treatments took place with a frequency of twice a week, the next 4 treatments once a week, and the final 2 treatments once every two weeks, so the total treatment duration of the intervention period was 12 weeks. The treatment consisted of traction of the wrist with a standardized apparatus, the Phystrac TE 10 (see figure 5). The force with which the traction was accomplished was selected by the treating physical therapist. Each treatment session consisted of 30 tractions; each traction took 5 seconds, followed by a 5 second rest period. Ten of these tractions were accomplished in a horizontal hand position with the palm of the hand in an upward, supine position. Ten tractions were done with a twist to supination from the supine position, and ten tractions with a twist to pronation from the supine position. In addition to the traction treatment, physical therapists were allowed to give the patient neural gliding exercises of the wrist. No other types of treatment concerning the hand and wrist were permitted during the intervention period. No further standardisation of the treatment was used, because no specific force will be optimal for all patients. The physical therapists were encouraged to apply the forces they considered optimal for each patient in question. The forces used varied between 108 and 147 Newton. Subjects in the experimental group were treated at Tigra, Trainings-institute for Health, Rehabilitation and Working activities in Utrecht or at Physical therapy practice Michiel Trouw in Hengelo.



Figure 5. Phystrac TE 10

The control group taken from the study by Gerritsen (2002) had received a treatment consisting of splinting. The patients received either a custom-made splint (made of soft cast) or a prefabricated splint (trademark Tricodur) that immobilized the wrist in a neutral position.

The patients were instructed to wear the splint during the night for at least 6 weeks, and during the day only if they preferred to do so. No other types of treatment were permitted during the intervention period, except pain medication if necessary (Gerritsen, 2002).

Outcome assessment

Patients in the experimental group were examined by the experimenters before treatment, after 2 months of treatment and after 3 months of treatment. Patients in the control group had been examined before treatment and after 3 months of treatment. The measurements after two months of treatment in the experimental group were included because some therapists supposed that this treatment period might be sufficiently long.

Measurement of the experimental subjects included strength, activities of daily living (ADL), sensibility, and symptoms of CTS: Pain, paraesthesia and hypoesthesia, and waking up due to the symptoms. These variables had also been used in the control group, together with a number of additional variables. The variables measured for the control group that corresponded with the variables measured for the experimental group were used in this study. Before and after the treatment period each test session was done twice, with an inter-measurement interval of one week, the average value of each test item was entered into the analysis, to account for daily fluctuations. At the end of the treatment, after 3 months, one more variable was tested, namely general improvement.

Variables

The following variables were measured both in the experimental- and control group:

General symptoms

The most important symptoms of CTS were identified with the Dutch version of the 'Symptoms severity Scale' by Levine et al. (1993). The reliability and validity of this test are well established. Cronbach's alpha is 0.89. Test retest over a period of 2 days is $r=0.91$ (Levine et al 1993). Construct validity: Correlation of Symptom Severity Scale with the functional status scale is $r=0.63$. Correlation with the strength in hand (pinch and grip) is $r=0.47$ and $r=0.38$. Correlation with a 2 points discrimination test is $r=0.15$, with the Semmes Weinstein Filaments test $r=0.17$ and with the conduction velocity of the median nerve $r=0.11$ (Levine et al. 1993)

ADL

ADL is measured with the Dutch version of the 'functional status scale' (Levine et al. 1993). In the letter study the questionnaire was recommended for the evaluation of ADL in case of CTS. The reliability and validity of this test are also well established. The test-retest reliability over a period of 2 days is $r=0.93$. The construct validity: Correlation of the functional status scale with strength in hand (pinch and grip) is $r=0.60$ and $r=0.50$. Correlation with a 2 points discrimination test is $r=0.42$, with the Semmes Weinstein test $r=0.24$ and with the nerve conduction velocity of the median nerve $r=0.12$.

Pain

The pain during the day and during the night was also scored by the patient on an 11-point numerical rating scale (0 = no symptoms, 10 = severe symptoms).

Paraesthesia and hypoesthesia

The severity of paraesthesia and hypoesthesia at night and during the day in the past week was scored by the patients on a 11-point numerical rating scale (0 = no symptoms, 10 = very severe symptoms).

Waking up due to the symptoms

The number of nights the patients woke up due to the symptoms during the past week was scored. Waking up due to the symptoms is considered as one of the most characteristic complaints of people suffering from CTS.

General improvement

General improvement was indicated by the patients on a 6-point scale, ranging from 0 ('completely recovered') tot 5 ('much worse'). A priori, successful treatment was defined as 'completely recovered' (0) or 'much improved' (1).

The following variables were measured in the experimental group only:

Sensibility

The sensibility of the affected hand may be measured in different ways. There is no method available with well-established reliability and validity. In this study the sensibility of the

thickest axons, the A α axons, will be measured. The thickest axons will be first affected with CTS. These sensory axons are responsible for the proprioception of the skeletal muscles. In the present study proprioception was measured by means of a thumb-positioning task. This task was accomplished while the patients kept their eyes closed. The patient was asked to place his/ her hand with the thumb close to the index finger on a piece of paper, on which a spectrum of degrees was drawn. The experimenter abducted the patient's thumb to a certain position (goal position), and then moved the thumb back to the index finger. After that the experimenter abducted the thumb once again, this time the patient was asked to call 'stop' when he/ she felt the goal position was reached (actually reached position). This passive positioning task was repeated three times using three different goal positions. After this passive task an active positioning task followed. The patient placed his/ her hand in the same way as before. Then the patient was required to move the thumb in abduction until it was stopped by an obstruction (pen) at the goal position. The patient then moved the thumb back to the index finger. After that the patient was asked to abduct the thumb again to the goal position, without the obstruction being present (actually reached position). The active positioning task was repeated three times as well. The experimenters measured the difference in degrees between the goal position and the actually reached position.

Strength

The thenar muscle strength was measured with pinch grip dynamometer (Saehan Corp. hydraulic pinch gauge, model SH5005). The patient was asked to grasp the dynamometer between thumb, index finger and middle finger. In CTS patients the thenar muscle, innervated by the median nerve, is expected to be weakened because of degeneration of this nerve.

Pain

Pain was measured with a visual analogue scale (VAS), consisting of a 10 cm long horizontal line; the extreme left position meaning 'no pain' and the right position 'very severe pain'. The patient was asked to mark the line at the point corresponding to the degree of pain experienced during the last week. The score was measured in mm. Results of a test-retest reliability analysis for VAS show an intraclass coefficient of 0.98 (95% confidence interval 0.97-0.99) (Clark et al., 2002).

Statistical analysis

The reliability of the tests used in the current study was assessed by means of an intraclass coefficient. To detect changes of the dependent variables during treatment in the experimental group a Friedman two way analysis of variance was performed. The results of the traction treatment are compared to the results of the splinting treatment. Therefore the mean scores of the traction treatment group are compared to the mean scores of the splinting treatment-group for each test or scale. Unfortunately it was not possible to perform a two-way repeated measures ANOVA because only mean scores were available for the treatment with splinting, standard deviations were not available. Therefore a T-test was performed between the mean scores of the splinting and the traction group before and after treatment. So it can be revealed if there are significant differences at baseline between the traction group and the splinting group. Subsequently the difference between the mean score before treatment and the mean score after treatment for splinting as well as for the traction treatment were calculated, indicating the changes on each variable.

Validity of the different test items and -scales was assessed with Spearman correlations between the test scores and scales. Success rates of the treatment were calculated with a t-test on the results of general improvement. The success rates of the current study were compared to the success rates of splinting (Gerritsen, 2002).

Results

Patient flow

During a period of 1 month (November 2003 to December 2003) 12 patients were included in the current study. The physical therapists checked that all inclusion and exclusion criteria were met. All the patients received a traction treatment from a physical therapist. The treatment duration varied from 8 to 12 weeks determined by the physical therapist. By March 2004 8 patients had completed 12 weeks of treatment and the last measurement after 12 weeks of treatment resulting in a final measurement rate of 75 per cent. One patient received a treatment of 8 weeks. 3 patients withdrew from the study for several reasons, which are presented in figure 6. One patient missed one measurement after 12 weeks because she had to give birth.

Included in study	Follow-up
N=12	8 weeks N=9 * 12 weeks N=8 **
<i>* Reasons for withdrawal (N=3): Acute rheumatic disorder (N=1); preferred surgery (N=1); too much stress (N=1).</i>	
<i>** Reasons for withdrawal (N=1): Patient was satisfied with the effects of the treatment after 8 weeks</i>	

Figure 6. Number of patients participating in the study and number of withdrawals.

The mean age of the study population was 55 years with a standard deviation of 13. 78% of the study population was female. 44 % had bilateral CTS complaints. With 22% of the study population the dominant side was most severely affected. For the characteristics of the study population from splinting group we refer to the study of Gerritsen (2002).

Reliability of the dependent variables

Test-retest reliability was assessed by administration of the tests or scales on two different days with one week in between and calculating the intraclass correlation coefficients between the scores on the first and second day. This procedure was carried out both before and after treatment, the results are presented in table 4. A value of 0.75 or higher indicates excellent reproducibility (Andresen et al., 2003). Most of the variables have a intraclass coefficient of 0.75 or higher. Exceptions are passive and active thumb positioning with negative coefficients, whereas hypoesthesia at night and paraesthesia at night show relatively low intraclass coefficients before and after treatment, respectively. Notable is the fact that

hypoesthesia at night measured after treatment and paraesthesia at night before treatment do show high intraclass coefficients.

Table 4. Intraclass correlation coefficients before and after treatment, for each variable.

Test/ scale	Before treatment (df)	After treatment (df)
Symptom severity scale	0.82 (8)	0.99 (5)
Functional status scale	0.94 (8)	0.96 (5)
Thumb position passive	-0.41 (8)	-0.62 (5)
Thumb position active	-0.93 (7)	-0.18 (4)
VAS	0.73 (8)	0.99 (5)
Pinch grip (strength)	0.95 (8)	0.92 (4)
Waking up	0.99 (7)	0.99 (4)
Pain during day	0.97 (7)	1.00 (4)
Pain at night	0.82 (7)	0.99 (4)
Paraesthesia during day	0.90 (7)	0.98 (4)
Paraesthesia at night	0.76 (7)	0.39 (4)
Hypoesthesia during day	0.89 (7)	0.88 (4)
Hypoesthesia at night	0.52 (7)	0.99 (5)
General improvement		0.87(5)

Changes during treatment

Improvements during treatment were found for the scores on the symptom severity scale, VAS, strength, waking up at the night, pain during the day and at night and hypoesthesia during the day and at night, presented in figure 7. The results of the of the Friedman two way analysis of variance, however, indicated that none of the improvements were statistically significant. The improvement on VAS was almost significant ($p= 0.054$).

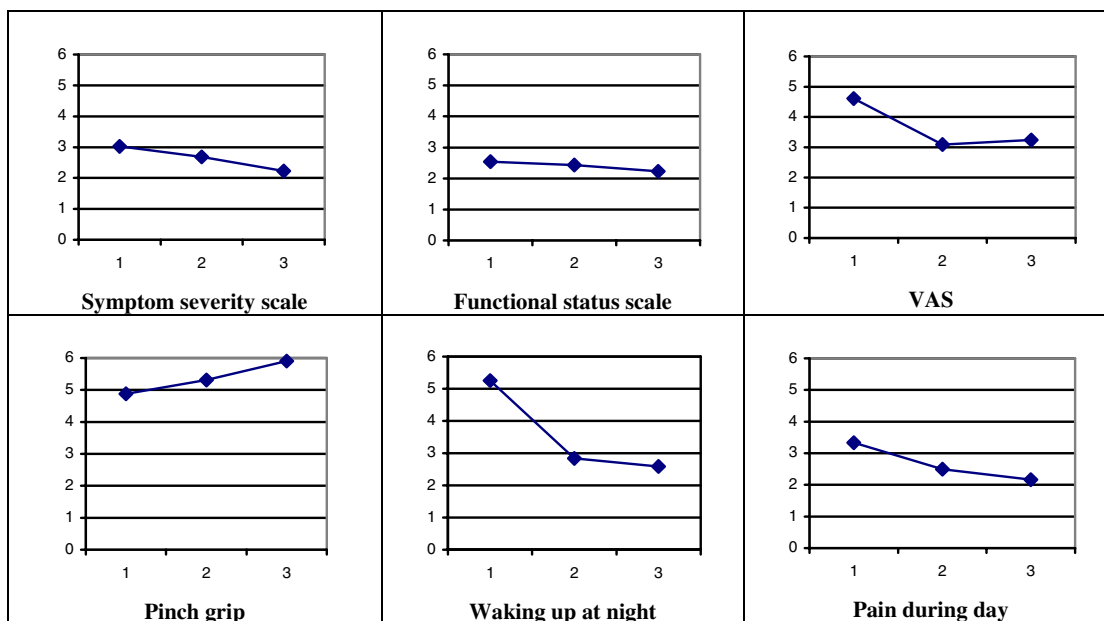


Figure 7. To be continued on the next page

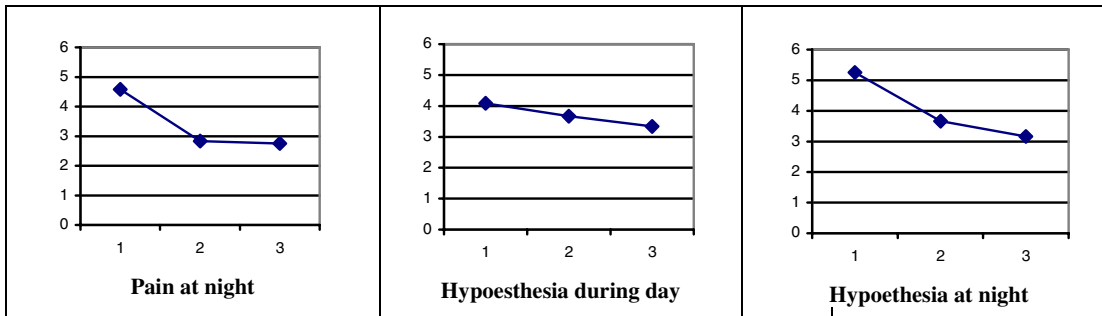


Figure 7. Changes during treatment on 8 of the variables, 1 = before treatment, 2 = after 8 weeks of treatment, 3 = after 12 weeks of treatment

Comparisons between the effects of the traction treatment and splinting

The mean scores of the traction treatment are compared to the mean scores of splinting for each test or scale. The mean scores of splinting (Gerritsen et al., 2002) are presented in appendix I. Unfortunately it was not possible to perform a two-way repeated measures ANOVA because only mean scores were available for the treatment with splinting, standard deviations were not reported. Because the control group is considerably larger than the experimental group, no standard deviations of the control group are required to perform a t-test. The difference between the mean score before treatment and the mean score after treatment for splinting as well as for the traction treatment were also calculated (see figure 8).

Before treatment a significant difference on the t-test was found between the mean scores of the traction treatment and splinting on the symptom severity scale ($p < 0.05$, $t = 3.48$, $df = 8$) the number of nights waking up ($p < 0.05$, $t = 4.33$, $df = 7$) and on hypoesthesia during the day ($p < 0.05$, $t = -2.48$, $df = 7$) see figure 8. Significant differences are referred to with a *. The mean scores of the traction population were significantly higher than the mean scores of the population treated with splints, on these variables. Hypoesthesia during the day was significantly lower for the experimental group, compared to the control group, before treatment ($p < 0.05$, $t = -2.48$, $df = 7$). A higher score on the measured variables means severer complaints concerning the symptoms of CTS, except for the variable strength.

After treatment, scores on the symptom severity scale ($p < 0.05$, $t = 4.26$, $df = 6$) and on the functional status scale ($p < 0.05$, $t = 5.13$, $df = 6$) of the traction group are significantly higher than those of the control group. A higher score on the measured variables means severer complaints with regard to the symptoms of CTS.

The difference between the mean score before treatment and the mean score after treatment for splinting as well as for the traction treatment were also calculated, see figure 8. The change on the number of nights waking up was larger at the traction group ($\Delta = -3.5$) than at the splinting group ($\Delta = -1.8$). On the symptom severity scale, functional status scale, hypoesthesia during the day and hypoesthesia during the night the changes in the traction group were smaller than in the splinting group, respectively $\Delta = -0.8$, $\Delta = -0.2$, $\Delta = -0.6$ and $\Delta = -0.9$ for traction and $\Delta = -1.8$, ($\Delta = -1.6$, $\Delta = -3.8$ and $\Delta = -2.5$ for splinting (as represented in figure 8).

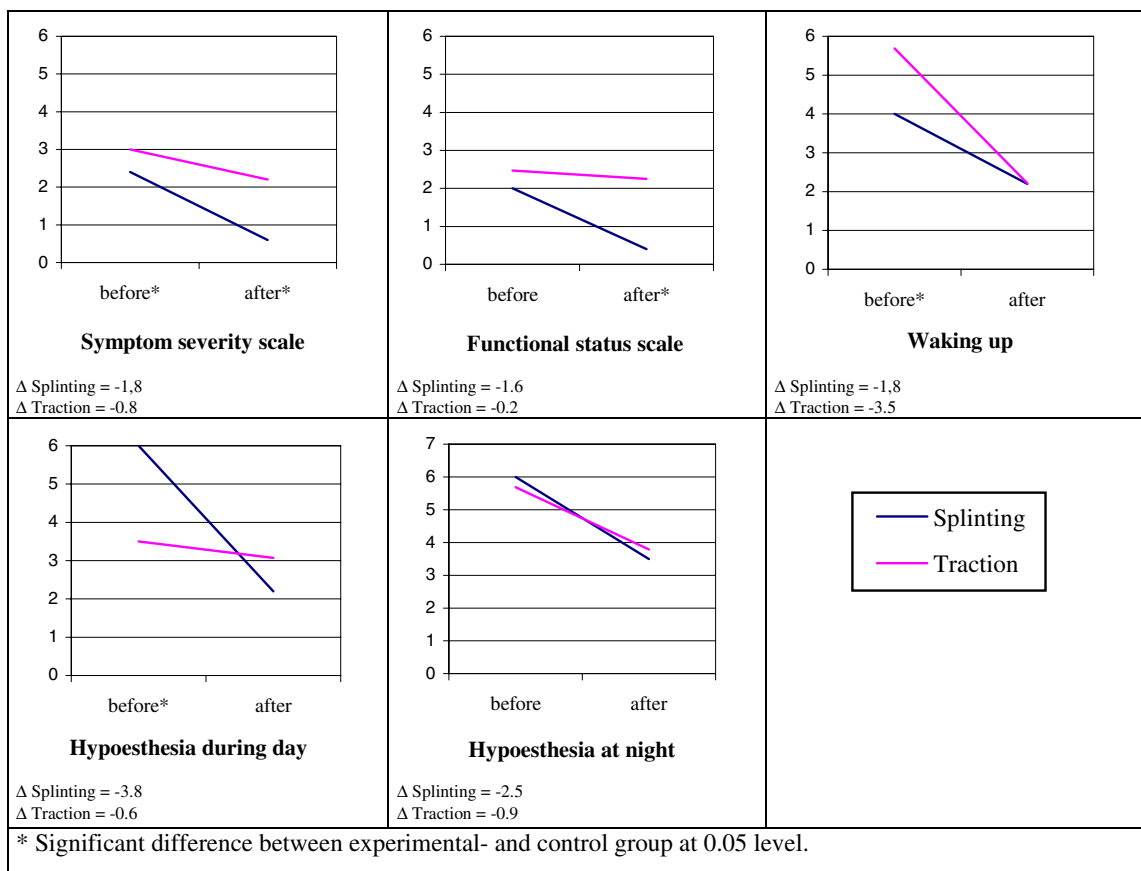


Figure 8. Comparisons between the effects of the traction treatment and splinting on five of the variables. Improvements (Δ) of the experimental and the control group, for each variable, are shown.

Correlation between the dependent variables

Validity of the different test items and -scales was assessed with Spearman correlations between the test scores and scales. The Spearman coefficient was used because of the small sample size and the non-normal distributions. Correlations between the scores on the scales and tests were determined three times: before treatment, after 8 weeks of treatment and after 12 weeks of treatment. In table 5 the median values of these scores are given. Almost all of the test items were positively correlated, except for the correlations with the score on the pinch grip. This was to be expected because strength increases when symptoms and disfunctionality decrease. The correlations of the test items with the score on the thumb positioning test were not calculated because this test appeared not to be reliable. It is shown in table 5 that the symptom severity scale is highly correlated with the VAS score, pain at night, paraesthesia during the day and hypoesthesia during the day. In previous studies it was concluded that the symptom severity scale and the functional status scale are reproducible, internally consistent and responsive to clinical change. This outcome can be considered as a validation of the test items, knowing that some of the symptoms scored on the symptom severity scale included pain, hypoesthesia and paraesthesia. Hypoesthesia during the day is highly correlated with paraesthesia during the day and with pain day. Hypoesthesia at night is highly correlated with paraesthesia at night.

The correlations before treatment, after 8 weeks of treatment and after 12 weeks of treatment are based on different sample sizes. The correlations determined before treatment are based 12 participants, after 8 weeks on 9 participants and after 12 weeks on 8 participants. However, correlations involving waking up at night, pain during the day and at night, paraesthesia during the day and at night, and hypoesthesia during the day and at night were based on 11 (before treatment), 8 (after 8 weeks) and 7 (after 12 weeks) participants.

Table 5. Spearman correlations before treatment, after 8 weeks of treatment and after 12 weeks of treatment between the test scores and scales.

	before	1	Pain day	Pain night	Paraes day	Paraes night	Hypoe day	Hypoe night	Waking up	sssc	Fssc	Pinch grip
8 weeks	2											
12 weeks	3											
Vas	1	0.826*	0.731*	0.788*	0.429	0.691	0.452	0.300	0.928**	0.367	-0.533	
	2	0.586	0.662	0.752*	0.525	0.922**	0.455	0.442	0.814**	0.912**	-0.196	
	3	0.618	0.436	0.252	0.500	0.037	0.414	0.393	0.429	0.750	-0.857*	
Pain day	1		0.699	0.867**	0.683	0.878**	0.659	0.178	0.903**	0.443	-0.371	
	2		0.511	0.372	0.708*	0.711*	0.634	0.549	0.600	0.585	-0.567	
	3		0.750	0.661	0.400	0.510	0.413	0.610	0.655	0.873*	-0.727	
Pain night	1			0.590	0.252	0.470	0.275	0.370	0.709*	0.00	-0.551	
	2			0.321	0.809*	0.599	0.685	0.363	0.843**	0.629	-0.350	
	3			0.771*	0.709	0.585	0.624	0.877**	0.837*	0.782*	-0.346	
Paraes day	1				0.299	0.970**	0.252	-0.069	0.818*	0.455	-0.216	
	2				0.137	0.602	-0.183	0.207	0.539	0.855**	-0.183	
	3				0.505	0.935**	0.645	0.548	0.955**	0.721	-0.396	
Paraes night	1					0.400	0.976**	0.191	0.506	0.286	-0.119	
	2					0.282	0.714*	0.764*	0.617	0.503	-0.704	
	3					0.222	0.216	0.393	0.571	0.750	-0.143	
Hypoeda y	1						0.327	-0.042	0.767*	0.473	-0.133	
	2						0.494	0.217	0.778*	0.762*	-0.024	
	3						0.673	0.447	0.852*	0.482	-0.296	
Hypoe night	1							0.191	0.54	0.357	-0.238	
	2							0.421	0.479	0.205	-0.173	
	3							0.774*	0.793*	0.396	-0.505	
Waking up	1								0.248	-0.300	-0.464	
	2								0.473	0.422	-0.593	
	3								0.692	0.505	-0.356	
sssc	1									0.388	-0.447	
	2									0.848**	-0.248	
	3									0.750	-0.500	
fssc	1										-0.583	
	2										-0.357	
	3										-0.679	

* correlation is significant at 0.05 level

**correlation is significant at 0.01 level

General improvement

The success rate was calculated with the general improvement score. In the traction group 4 out of 6 patients judged their condition as completely recovered or much improved after 12 weeks of treatment, resulting in a success rate of 66%. In the splinting group 46 out of 86 patients judged their condition as completely recovered or much improvement after 3 months of treatment, resulting in a success rate of 54%. No significant differences were found between de success rates of the traction group and the splinting group.

Discussion

The objective of this study was to compare the outcomes of traction treatment of CTS with outcomes of splinting. The results of this study do not show that outcomes of traction treatment differ significantly from outcomes of treatment with splinting.

The present findings indicate that the reliability of the used tests and scales is high. The validity and reliability of the symptom severity scale and the functional status scale have been previously investigated, as mentioned before. Levine et al. (1993) found a test retest reliability of $r=0.91$ on the symptoms severity scale and $r=0.93$ on the functional status scale. In the current study similar reliability scores were found on these same variables, namely $r=0.82$ (before treatment) and $r=0.99$ (after treatment) on the symptom severity scale and $r=0.94$ (before treatment) and $r=0.96$ (after treatment) on the functional status scale.

The test-retest reliability on both of the thumb positioning tasks was very low, whereas the other tests and scales all scored relatively high on intraclass correlation. The thumb positioning tasks show lack of standardization. It proved to be very difficult to precisely score the thumb position. Another source of error in the passive thumb positioning task was associated with the subjects, some subjects found it difficult to relax their thumb during the task. Because of the lack of reliability of this test, it was not used for further analysis.

No significant changes during treatment were found in the patients treated with traction, though there was a tendency towards improvement on all of the measured tests and scales. The lack of significance may be caused by the small number of subjects, which results in a small power of the statistical tests. Using the t-test formula, an estimation can be made on how many subjects would have been needed to get a significant difference, assuming that the effects of the treatment would have been the same and the scores would be normally distributed. A total number of 15 subjects completing the treatment would then have resulted in significant treatment effects on 4 out of 9 tests or scales, namely symptom severity scale ($p<0.001$), waking up at night ($p<0.01$), paraesthesia at night ($p<0.05$) and hypoesthesia at night ($p<0.01$).

From the comparison between the effects of the traction treatment and splinting it can be concluded that the splinting treatment had better results than the traction treatment on the

functional status scale and on hypoesthesia during the day. The group treated with traction scored better on the number of nights waking up, compared to the group treated with splinting. Gerritsen et al. (2002) defined waking up at night as one of their primary outcome measures. However the criteria applied in the experimental group aren't the same as the criteria applied in the control group by Gerritsen et al. (2002). Because for our subjects there was no information available about an electro-myographical (EMG) test, we could not apply this criterion. Also the other criteria applied by Gerritsen we could not be used in the current study because this would have resulted in too small a sample. Therefore, in our study some patients may have been included with conditions that were excluded in Gerritsen's study. For example, one of our patients was pregnant and with pregnancy it is known that hormonal changes may cause oedema in the wrist and therefore elevated pressure and median nerve compression. With traction treatment such underlying causes are not taken away. This may also be the case with other conditions suggesting underlying causes of CTS.

The validity of the test items and scales was assessed. Scores on the symptom severity scale were highly correlated with the VAS score, pain at night, paraesthesia during the day and hypoesthesia during the day. This outcome can be considered as a validation of these test items, given that in previous studies the symptom severity scale and the functional status scale proved to be reproducible, internally consistent and responsive to clinical change.

Success was defined a priori as being indicated by 'completely recovered' or 'much improved' on the general improvement scale. In the current study 66% (4 out of 6) of the patients were treated successfully, according to this criterion. Gerritsen et al. (2002) found a success rate of 54% (46 out of 86) on the splinting treatment. From these results it can be concluded that people treated with traction were generally satisfied with the results of the treatment. However, no significant differences were found between the success rates of the traction group and the splinting group.

The force with which the traction was accomplished was not standardized, but selected by the treating physical therapist. This procedure was chosen because the force of the traction depends on several variables such as, for example, age and sex of the patient. Therefore the treatment in this study is representative for the way traction is applied in treating carpal tunnel syndrome in practice.

Limitations

In this study a small number of subjects is used, which results in a small power of the statistical tests. The test retest reliability on both of the thumb positioning tasks was very low. The thumb positioning tasks show lack of standardization. It proved to be very difficult to precisely score the thumb position. Another source of error in the passive thumb positioning task was associated with the subjects, some subjects found it difficult to relax their thumb during the task. Therefore no information is available about the sensibility of the thumb in this study.

The criteria applied in the experimental group aren't the same as the criteria applied in the control group by Gerritsen et al. (2002). Because for the subjects of the current study there was no information available about an electro-myographical (EMG) test, this criterion couldn't be applied. The other criteria applied by Gerritsen could also not be used in the current study because this would have resulted in too small a sample.

Recommendations for future study

In future study it is recommended to conduct randomised controlled trials comparing the efficacy of different treatments, e.g splints, traction and surgery. The different treatments should be compared both with each other and with no treatment. People who are on a waiting list for surgery could be used as a control group. It is important to use a large sample size to make sure the statistical power is large enough. It's also important to use a homogenous group of subjects. So the different groups can be compared. The following inclusion criteria should be applied: 1) electrophysiological confirmation of the diagnosis (median nerve sensory conduction velocity (index finger) ≤ 41.9 m/s in patients younger than 55 years or ≤ 37.3 m/s in patients older than 54 years, or median nerve distal sensory latency (DSL) (index finger) ≥ 3.5 milliseconds (ms) or median-ulnar DSL difference (ring finger) > 0.4 ms, or median nerve distal motor latency ≥ 4.34 ms). The following exclusion criteria should be used: 1) previously treated with splinting, surgery or traction; 2) a history of wrist trauma (e.g. fracture) or surgery; 2) a history suggesting underlying causes of CTS (e.g. diabetes mellitus, pregnancy); 4) clinical signs or symptoms or electrophysiological findings suggesting conditions that could mimic CTS or interfere with its validation (e.g. cervical radiculopathy, polyneuropathy); and 5) severe thenar muscle atrophy.

The primary outcome measures should be number of nights waking up, symptom severity scale and functional status scale. Secondary outcome measures should be paraesthesia, hypoesthesia, pain, strength and general improvement. These scales proved to be reliable and valid. It's important to find a reliable and valid test to measure sensibility as well. The long-term effects should also be studied in future research. Because it is known that splinting is effective for the initial relief, however on the long term outcomes have been poor, it is important to find out whether the effects of traction treatment are permanent. Subjects should be examined before treatment, after 2 months of treatment, after 3 months of treatment and after 6 months by the experimenters. It's also interesting to see if a specific force could be applied in the traction treatment that is optimal for all patients. Therefore different forces should be compared in future study.

Conclusion

The current study must be seen as a pilot study. It reveals that the used tests or scales give a good insight on the effects of treatment on carpal tunnel syndrome, with exception of the thumb positioning tasks. It seems that there is still lack of reliable tests to measure sensibility in carpal tunnel syndrome.

This pilot study shows some improvements due to the traction treatment. Possibly because of a lack of statistical power, few of these improvements were significant. Most of the patients treated with traction were generally satisfied with their recovery. This indicates a positive effect of traction treatment for carpal tunnel syndrome. Further research is recommended. It's important to use a large sample in future research. It would also be interesting to study the long term effects of the treatment, knowing that splinting shows best results directly after treatment (Destefano et al., 1997, Gerritsen et al., 2002). When further studies show that the effects of traction treatment are permanent, this treatment might be considered as a valid alternative to surgery.

Acknowledgements

We would like to thank Piet van Wieringen for supervising this thesis. He helped us to approach several physical therapists in the Netherlands, during the initial stage of this study. His practical leads helped us through the execution of the research project and his critical view brought our thesis to a higher level. Also we would like to thank Gert Kwakkel, for revising the contents of this thesis. His critics were of great importance to the quality of our work because of his expertise on physical therapy.

Our gratitude goes out to the staff members of TIGRA, Utrecht, who initiated this project, and Physical therapy practice Michiel Trouw, Hengelo for welcoming us in their practice. A special thanks goes to Rob Oostenrijk en Tresca Braakhuis. Both of them helped us finding participants for this study and helped collecting essential information.

Last but not least we would like to thank each other for the pleasant cooperation. Despite of all the arguments and ‘almost-fights’, we managed to take each other to amazing heights.

References

Akalin E, El O, Peker O, Senocak O, Tamci S, Gulbahar S, Cakmur R, Oncel S. Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises. *American Journal of Physical Medicine and Rehabilitation* 2002; 81: 108-113.

Andresen EM, Catlin TK, Wyrwich KW, Jackson-Thompson J. Retest reliability of surveillance questions on health related quality of life. *Journal of Epidemiology and Community Health* 2003; 57: 339-343

Atroshi I, Gummesson C, Johnsson R, Ornstein E, Ranstam E, Rosen I. Prevalence of carpal tunnel syndrome in a general population. *The Journal of the American Medical Association* 1999; 281: 153-158.

Clark WC, Yang JC, Tsui SL, Ng KF, Clark S. Unidimensional pain rating scales: a multidimensional affect and pain survey (MAPS) analysis of what they really measure. *Pain* 2002; 98:241-247.

Davis TP, Hulbert JR, Kassak KM, Meyer JJ. Comparative efficacy of conservative medical and chiropractic treatments for carpal tunnel syndrome: A randomized clinical trial. *Journal of Manipulative and Physiological Therapeutics* 1998; 21: 317-326.

Dawson MD, Hallet M, Wilbourn AJ, Campbell WW, Terrono AL, Trepman E. Entrapment neuropathies. Little, Brown and Company, Boston 1983.

DeStefano F, Nordstrom DL, Vierkant RA. Long-term symptom outcomes of carpal tunnel syndrome and its treatment. *The journal of Hand Surgery* 1997; 22A: 200-210.

Gerritsen AAM. Conservative and surgical treatment options for carpal tunnel syndrome. Is there light at the end of the carpal tunnel? Academisch proefschrift Vrije Universiteit Amsterdam. Ponsen & Looijen BV, Wageningen 2002.

Kaplan SJ, Glickel SZ, Eaton RG. Predictive factors in the non-surgical treatment of carpal tunnel syndrome. *The journal of Hand Surgery* 1990; 15: 106-108.

Katz JN, Simmons BP. Carpal tunnel syndrome. *New England Journal of Medicine* 2002; 346:1807-1812.

Kremer M, Gilliatt RW, Golding JS, Wilson TG. Acroparaesthesiae in the carpal-tunnel syndrome. *Lancet* 1953; 265: 590-595.

Krom MCTFM de, Knipschild PG, Kester ADM, Thijs CT, Boekkooi PF, Spaans F. Carpal tunnel syndrome: Prevalence in the general population. *Journal of Clinical Epidemiology* 1992;45:373-379.

Kruger VL, Kraft, GH, Deitz JC, Ameis A, Polissar L. Carpal tunnel syndrome: Objective measures and splint use. *Archives of Physical Medicine and Rehabilitation* 1991; 72: 517-520.

Kuschner SH, Brien WW, Johnson D, Gellman H. Complications associated with carpal tunnel release. *Orthopedic Review* 1991; 20: 346-352.

Levine DW, Simmons BP, Koris MJ, Daltroy LH, Hohl GG, Fossel AH, Katz JN. A self-administered questionnaire of symptoms and functional status in carpal tunnel syndrome. *Journal of Bone and Joint Surgery* 1993;75:1585 – 1592.

Mondelli M, Giannini F, Giacchi M. Carpal tunnel syndrome incidence in a general population. *Neurology* 2002; 58: 289-295.

Rosenbaum RB, Ochoa JL. Carpal tunnel syndrome and disorders of the median nerve. Butterworth – Heineman, Boston 1993.

Sunderland S. Nerves and nerve injuries. Churchill Livingstone, Edinburgh 1978.

Valente R, Gibson H. Chiropractic manipulation in carpal tunnel syndrome. *Journal of Manipulative and Physiological Therapeutics* 1994; 17(4): 246-255.

Weiss AC, Sachar K, Gendreau M. Conservative management of carpal tunnel syndrome: A reexamination of steroid injection and splinting. *Journal of Hand Surgery* 1994; 19A: 410-415.

Williams PL, Gray H (1827-1861). *Gray's Anatomy*/ Edited by Peter L. Williams. Churchill Livingstone, Edinburgh 1989.

Appendix I - Success rates and improvements of splinting

Success rates and improvements of splinting after 1, 3, 6, 12 and 18 months. Number of patients were N=80, N=77, N=73 and N=68, respectively (intention to treat analysis)* (Gerritsen et al., 2002).

	Surgery	Splint	Difference**
Primary outcome measures			
Success rates			
1 month	29 % (23/80)	42 % (37/88)	-13 % (-28,1)
3 months	80 % (62/78)	54 % (46/86)	26 % (12, 40)
6 months	94 % (72/77)	68 % (57/84)	26 % (14, 37)
12 months	92 % (67/73)	72 % (60/83)	20 % (8, 31)
18 months	90 % (61/68)	75 % (59/79)	15 % (3, 27)
Number of nights per week waking up due to the symptoms (0-7)			
1 month	0.8 (3.2)	2.0 (3.0)	-1.3 (-2.2, -0.3)
3 months	2.6 (3.5)	2.2 (3.1)	0.4 (-0.7, 1.4)
6 months	3.6 (2.8)	2.6 (3.1)	1.0 (0.1, 2.0)
12 months	3.6 (2.9)	2.9 (3.0)	0.7 (-0.2, 1.7)
18 months	3.6 (2.9)	3.2 (3.1)	0.4 (-0.6, 1.4)
Paraesthesia during the day			
1 month	1.5 (3.0)	1.4 (2.1)	0.2 (-0.6, 1.0)
3 months	4.8 (3.2)	2.2 (3.2)	2.6 (1.6, 3.6)
6 months	5.5 (2.9)	3.7 (3.2)	1.8 (0.8, 2.8)
12 months	5.5 (2.9)	4.0 (3.4)	1.5 (0.5, 2.5)
18 months	5.3 (3.0)	4.0 (3.6)	1.4 (0.3, 2.5)
Paraesthesia at night			
1 month	1.3 (3.1)	2.5 (3.0)	-1.2 (-2.1, -0.2)
3 months	4.6 (3.8)	3.5 (3.3)	1.1 (0.0, 2.2)
6 months	5.4 (3.5)	4.1 (3.7)	1.3 (0.2, 2.4)
12 months	5.2 (3.6)	4.5 (3.4)	0.7 (-0.4, 1.8)
18 months	5.0 (3.6)	4.4 (3.6)	0.6 (-0.6, 1.7)
Secondary outcome measures			
Symptom severity scale (1-5)			
3 months	1.0 (0.9)	0.6 (0.7)	0.4 (0.2, 0.7)
6 months	1.3 (0.8)	0.9 (0.8)	0.4 (0.2, 0.7)
12 months	1.3 (0.8)	0.9 (0.9)	0.4 (0.1, 0.7)
18 months	1.3 (0.8)	0.9 (0.9)	0.4 (0.1, 0.6)
Functional status scale (1-5)			
3 months	0.6 (0.9)	0.4 (0.7)	0.2 (0.0, 0.5)
6 months	1.0 (0.9)	0.5 (0.8)	0.5 (0.2, 0.7)
12 months	1.0 (0.9)	0.7 (0.8)	0.3 (0.0, 0.6)
18 months	0.9 (0.9)	0.7 (0.8)	0.2 (-0.1, 0.5)

* Presented are the mean (standard deviation) improvements from baseline.

** Presented are the differences in success rates and the differences in the mean improvements from baseline (95 % confidence interval).