ORIGINAL ARTICLE

Outcome after carpal tunnel release: effects of learning curve

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Abstract

Introduction In carpal tunnel release, it is yet unclear whether a learning curve exists among surgeons. The aim of our study was to investigate if outcome after carpal tunnel release is dependent on surgeon's experience and to get an impression of the learning curve for this procedure.

Methods A total of 188 CTS patients underwent carpal tunnel release. Patients completed the Boston Carpal Tunnel Questionnaire at baseline and 6–8 months postoperatively together with a six-point scale for perceived improvement.

Results Patients operated by an experienced resident or certified surgeon reported a favorable outcome more often than patients operated by an inexperienced resident (adjusted OR 3.23 and adjusted OR 3.16, respectively). In addition, a negative association was found between surgeon's years of experience and postoperative Symptom Severity Scale and Functional Status Scale scores.

Discussion Outcome after carpal tunnel release seems to be dependent on surgical experience, and there is a learning curve in residents.

Introduction

Carpal tunnel release (CTR) is considered the most effective treatment of CTS [1]. Many studies have been done to identify prognostic factors for outcome, with varying results [2–8]. It is known from previous studies regarding neurosurgical, vascular, and gastrointestinal surgery, that a more experienced surgeon is associated with better results [9–14]. In CTS however, only one study has been done so far to investigate the relationship between surgeon experience and patient outcome after CTR. This study could not identify differences in outcome between high- and low-volume surgeons [15]. A major limitation of this study was that the procedures were performed in

highly specialized centers by very experienced hand surgeons. However, in daily practice, a great number of patients suffering from CTS will be admitted to a primary hospital and will undergo CTR by neurosurgeons, orthopedic surgeons, plastic surgeons, general surgeons, or residents, with different levels of experience. As the complexity of the open CTR procedure is relatively low, the learning curve of a resident or surgeon might flatten out at a relatively early stage. For this reason, investigating differences in outcome between less experienced surgeons (residents) and more experienced surgeons might be of more interest than investigating differences between highly specialized surgeons.

The aim of our study was to investigate if outcome after CTR is dependent on surgeon experience in a primary hospital with less experienced surgeons at the beginning of their training (residents) and more experienced surgeons, as well as to get an impression of the learning curve for this procedure.

Methods

Patients

Patients with complaints suggestive of CTS were referred to our outpatient clinic by their general practitioners. They were eligible for the study and consecutively enrolled if they

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complained about pain and/or paresthesias in and restricted to the territory innervated by the median nerve (whether or not including digits 4 and/or 5) and if they fulfilled two or more of the following clinical CTS criteria: (1) nocturnal paresthesias; (2) aggravation of paresthesias by activities such as driving a car, riding a bike, holding a book or holding a telephone; (3) paresthesias relieved by shaking the hand (positive Flick sign).

Exclusion criteria were age under 18, significant language barrier, history or clinical signs of polyneuropathy or known HNLPP (hereditary neuropathy with liability to pressure palsies), previous trauma or surgery to the wrist, history of rheumatoid arthritis, diabetes mellitus, thyroid disease, alcoholism, arthrosis of the wrist, pregnancy, or severe atrophy of the abductor pollicis brevis muscle. Written informed consent was obtained from each individual. All patients underwent an extensive clinical examination, including sensory and motor testing of the affected hand by an experienced neurologist (WV). Moreover, electrodiagnostic tests and ultrasonography of the median nerve were performed according to a standard protocol described previously [16]. If CTS was diagnosed in both hands, only the hand with the most severe complaints was included.

Surgeons

Patients were admitted to the departments of neurosurgery, orthopedic surgery, or plastic surgery to undergo an open carpal tunnel release (CTR). As our hospital is a training hospital, surgery was either performed by residents or by certified surgeons. Each surgeon and date of surgery was noted, and the years of experience were calculated from date of starting the surgical specialty training program. If residents had not started their training yet, this was considered as 0 years of experience. Residents were supervised by a certified surgeon related to their competence level. Residency programs for neurosurgeons, orthopedic surgeons, and plastic surgeons consist of six training years. An open CTR procedure is of relatively low complexity. Therefore, residents within the first 3 years of their program were considered as "inexperienced residents," residents in training from 4 to 6 years as "experienced residents" and after 6 years of training, they were qualified as "certified surgeons."

Outcome measures

At baseline (T_0) and about 6–8 months after CTR (T_1), patients completed a self-administered outcome measure, the Boston Carpal Tunnel Questionnaire (BCTQ), consisting of the Symptom Severity Scale (SSS) and the Functional Status Scale (FSS), which is frequently used and thoroughly validated [17]. Moreover, they rated their perceived treatment effect on a six-point Likert-like scale, with 1 representing "I am completely asymptomatic," 2 "I very rarely still have complaints," 3 "I occasionally still have complaints," 4 "I often still have complaints," 5 "My complaints are the same as before treatment," and 6 representing "My complaints have increased." For statistical analyses, we dichotomized the six-point scale to distinguish patients who had a "favorable outcome" (consisting of grade 1 and 2) and "non-favorable outcome" (consisting of 3 to 6).

Statistical analysis

Baseline characteristics were described as frequency (%), mean ± standard deviation (SD) in case of normal distribution, and otherwise as median plus range. If attributable, 95% confidence intervals (CIs) were included. Comparisons between different levels of surgeons' experience were assessed by applying chi-square test or, if applicable, Fishers exact test for categorical variables and Kruskal-Wallis test in case of continuous variables with non-normal distribution of the data. The unpaired T test was used to calculate differences in improvement of SSS and FSS between different levels of surgeons' experience. Statistical significance was assumed when $p < 0.05$.

To assess whether outcome was independently associated with surgical experience, a logistic regression was performed using "favorable outcome" as dependent variable and "years of experience" as independent variable (categorized as 0–3, 4–6 and > 6 years). In addition to years of experience, the following variables were assumed to be of prognostic value and were tested in a univariable logistic regression model as independent variable to investigate the association with outcome: age, BMI, gender, wrist side, surgeon's specialty, abnormal electrodiagnostic tests, abnormal ultrasonography, weakness opponens muscle, weakness abductor pollicis muscle, atrophy abductor pollicis muscle, abnormal two-point discrimination, and abnormal monofilament. Variables showing to have an association of $p < 0.20$ with outcome in this univariable model (years of experience, SSS at baseline, surgeon's specialty, electrodiagnostic tests, weakness of the m. opponens pollicis) were eligible to be included in the multivariable logistic regression model. Backward selection was applied to select variables which are independently associated with outcome and can be seen as important confounders. A $p < 0.05$ was set as criterion for the variables to remain in the final model. To explore the influence of years of experience on outcome, odds ratio (OR) was adjusted for these confounders.

Similarly, a multivariable linear regression analysis was performed to assess whether SSS and FSS scores at T_1 were independently associated with years of experience, again corrected for variables which proved to be significantly associated with SSS and FSS in a univariable linear regression analysis and were subsequently found to be independently associated in a multivariable linear regression analysis by backward selection (years of experience, SSS or FSS at

baseline, surgeon's specialty, abnormal electrodiagnostic tests, weakness of the m. opponens pollicis).

Results

Within the group of 234 patients with clinically defined CTS who completed the BCTQ and underwent CTR, 201 patients completed all questionnaires at follow up (response rate = 86%).

Complete surgery reports were available on 188 patients (Fig. 1). Data of these patients were used for this study. Mean age of the patients operated by inexperienced residents (58.26 ± 15.47) was higher than patients operated by experienced residents or certified surgeons (50.62 ± 12.62 and 51.97 ± 12.06 respectively, $p = 0.042$). Moreover, abnormal electrodiagnostic tests were less likely in the patients operated by certified surgeons (71.4%) compared to inexperienced and experienced residents (82.6% and 89.2% respectively, $p = 0.030$). More detailed baseline characteristics are shown in Table 1.

CTRs were performed by 29 different surgeons. Sixteen of them were certified specialists (5 of neurosurgery, 9 of orthopedic surgery, and 2 of plastic surgery) and 13 were residents (12 of neurosurgery, 1 of plastic surgery). A total of 153 CTRs (80%) were performed by residents. Six residents were considered as inexperienced and performed a total of 23 CTRs; 7 residents were experienced and did 130 CTRs and the remaining 35 CTRs were performed by certified surgeons. Median years of training were 0, 5, and 17 in inexperienced residents, experienced residents, and certified surgeons, respectively. Level of experience was different between specialties ($p < 0.001$). More details are shown in Table 2.

Overall, mean SSS improved from 2.93 ± 0.67 (95% CI 2.83–3.03) at T_0 to 1.64 ± 0.77 (95% CI 1.52–1.75) at T_1 ($p < 0.001$). Moreover, there was an improvement of FSS from 2.29 ± 0.79 (95% CI 2.17–2.41) to 1.64 ± 0.75 (95% CI 1.53–1.76, $p < 0.001$).

Strikingly, for SSS, this improvement was greater for patients who underwent CTR by an experienced resident (improvement 1.32 ± 0.89; 95% CI 1.18–1.49) or certified surgeon (improvement SSS 1.51 ± 0.82; 95% CI 1.22–1.79) compared to an inexperienced resident (improvement SSS 0.89 ± 1.04; 95% CI 0.34–1.28, $p = 0.030$ resp. $p = 0.015$). Improvement did not significantly differ between experienced residents and certified surgeons ($p = 0.332$). A similar trend was seen for FSS. Experienced residents achieved a greater improvement than inexperienced residents (improvement 0.72 ± 0.89; 95% CI 0.56–0.47 vs 0.03 ± 0.97; 95% CI − 0.41 to 0.47, $p = 0.002$). In addition, improvement in certified surgeons (0.74 ± 0.90; 95% CI 0.41–1.07) was greater than in inexperienced residents ($p = 0.01$). No difference exists between experienced residents and certified surgeons ($p = 0.91$). There were no differences in baseline SSS and FSS between groups ($p = 0.594$ and 0.279 resp.)

A favorable outcome was reported in 134 patients (71%). As illustrated in a multivariable logistic regression analysis (Table 3), surgical experience was independently associated with outcome. Patients who underwent CTR by an experienced resident reported a favorable outcome more often than patients operated by an inexperienced surgeon (75% vs. 48%, adjusted OR 3.23, $p = 0.013$). The same was seen for certified surgeons (71% vs. 48%, adjusted OR 3.16, $p = 0.046$). There was no difference in number of patients with a favorable outcome between experienced residents and certified surgeons ($p = 0.633$). The variance in favorable outcome explained by surgeon's experience only (Nagelkerke R^2) is 0.050, which

Fig. 1 Flow chart for inclusion of patients. CTS carpal tunnel syndrome; BCTQ Boston Carpal Tunnel Questionnaire; CTR carpal tunnel release
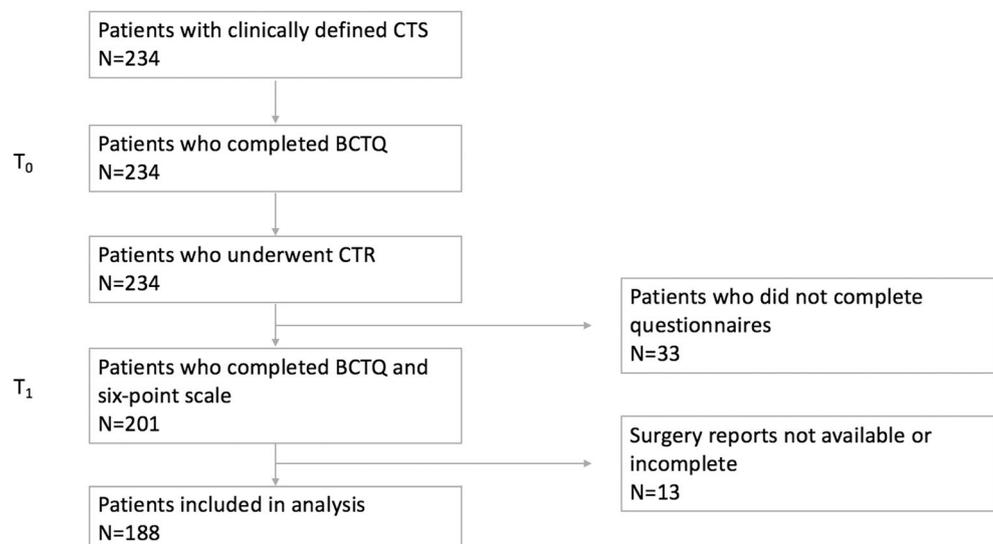
Table 1 Patient characteristics

Characteristic	Total	Years of experience			p value
	n = 188	≤3 n = 23	4–6 n = 130	> 6 n = 35	
Age (mean, SD, 95% CI)	52.01 ± 12.98, 50.04–53.97	58.26 ± 15.47, 51.57–64.95	50.62 ± 12.62, 48.42–52.82	51.97 ± 12.06, 47.83–56.12	0.042
Sex (female)	149 (79%)	20 (87%)	100 (76.9%)	29 (82.9%)	0.464
BMI (mean, SD, 95% CI)	27.29 ± 4.91, 26.54–28.03	27.51 ± 3.38, 25.88–29.14	27.48 ± 26.56–28.40	26.26 ± 24.58–27.95	0.426
Median duration of symptoms (range)	18 (1–420)	18 (3–120)	18 (1–420)	24 (3–150)	0.751
Wrist included (right)	109 (58%)	11 (47.8%)	79 (60.8%)	19 (54.3%)	0.453
Atrophy of abductor pollicis brevis muscle	23 (12%)	5 (22.7%)	14 (10.8%)	4 (11.4%)	0.283
Weakness					
Weakness of abductor pollicis brevis muscle	51 (27%)	7 (31.8%)	36 (28.1%)	8 (22.9%)	0.738
Weakness of opponens pollicis muscle	10 (5.4%)	2 (9.1%)	4 (3.1%)	4 (11.4%)	0.113
Disturbed sensibility					
Two-point discrimination	128 (68%)	17 (77.3%)	85 (65.4%)	26 (74.3%)	0.385
Monofilament	78 (41%)	10 (45.5%)	51 (39.5%)	17 (48.6%)	0.592
Diagnostics					
Abnormal electrodiagnostic tests	160 (85%)	19 (82.6%)	116 (89.2%)	25 (71.4%)	0.030
Abnormal ultrasonography	105 (57%)	9 (42.9%)	79 (61.2%)	17 (50.0%)	0.188

increases to 0.081 after including "abnormal electrodiagnostic tests" to the model.

In addition, an independent statistically significant negative association was found between years of experience of the surgeon and SSS at T_1 (for experienced residents compared to inexperienced residents: B = − 0.332, $p = 0.046$ and for certified surgeons compared to inexperienced residents B = − 0.527, $p = 0.019$) and FSS at T_1 (for experienced residents compared to inexperienced residents: B = − 0.514, $p = 0.002$ and for certified surgeons compared to inexperienced residents B = − 0.571, $p = 0.012$). Other factors independently associated with SSS and FSS at T_1 are FSS and SSS at baseline, abnormal electrodiagnostic tests, and surgeon's specialty. The variance in SSS and FSS at T_1 explained by experience of the surgeon only (R^2) is 0.024 and 0.027, which increases to 0.127 and 0.146, respectively, after addition of SSS or FSS at T_0, abnormal electrodiagnostic tests and surgeon's specialty to the model (Table 4).

No statistically significant differences in SSS, FSS, and proportion with a favorable outcome were found across individual surgeons ($p = 0.280$, resp. $p = 0.176$ and 0.594).

Discussion

Although a prior study failed to demonstrate an association between patient outcome after CTR and the number of CTR annually in highly specialized surgeons, in this study, we showed a tendency that outcome after CTR is associated with years of surgeon's experience in a mixed group of certified surgeons and residents. This is the first study which demonstrates that patient outcome after open CTR is related to a learning curve.

Significant differences in outcome were found in CTS patients who underwent CTR by a surgeon with 3 years' experience or less and patients operated by surgeons with more than 3 years' experience. The OR of a favorable outcome was approximately 3 when CTR was performed by an experienced resident or certified surgeon. CTR performed by an experienced surgeon was independently associated with lower postoperative SSS and FSS scores.

Our results are in contrast with an earlier study. The reason is probably our relatively inexperienced group of surgeons; 153 (81%) of the CTRs were performed by residents, of which 12% had a maximum of 3 years' experience since start of their training program. The previously reported study however consisted of highly specialized surgeons [15]. Apparently, open CTR is a relatively easy learnable procedure for residents and once operation skills are at level after 3 years of training, more experience will not further improve patient outcome. This existence of a learning curve is supported by our results, as we found a statistically significant higher number of patients reporting a favorable outcome when operated

Table 2 Surgeon characteristics

Characteristic	Total n = 188	Years of experience			p value
		≤ 3 n = 23	4–6 n = 130	> 6 n = 35	
Median years of surgeon's experience (range)	5 (0–29)	0 (0–3)	5 (4–6)	17 (8–29)	< 0.001
Specialty					< 0.001
Neurosurgery		23 (14%)	127 (76%)	18 (11%)	
Orthopedic surgery		0 (0%)	1 (6.7%)	14 (93%)	
Plastic surgery		0 (0%)	2 (40%)	3 (60%)	

by experienced residents (4–6 years' experience) compared to inexperienced residents (0–3 years), whereas no differences between experienced residents and certified specialists (> 6 years) were found. A similar observation was made for SSS and FSS. It is also demonstrated in studies regarding endoscopic carpal tunnel release, that a learning curve exists [18–21]. However, its steepness and length is yet unknown. It is however somewhat peculiar that a difference in outcome is seen since all starting residents are initially supervised by experienced surgeons before they are allowed to perform this surgery independently. The quality of care was therefore expected to be similar. The small number of patients treated by inexperienced surgeons might contribute to the difference.

Although surgeon's experience is associated with outcome, only about 2–5% of variance in outcome (SSS, FSS and six-point scale) could be explained by surgeons' experience alone. As adjusted partial regression coefficient (0.332–0.527) for SSS and FSS (0.514–0.571) will generally not exceed the minimal clinically important difference (MCID) for SSS (0.46 × 2.93 = 1.35) and FSS (0.28 × 2.29 = 0.64), clinical relevance of surgeon's experience alone is questionable [22]. In clinical practice therefore, outcome will be largely determined by other factors. Previous studies identified some other potential predictors for outcome, but results are controversial. Examples of factors associated with outcome are electrodiagnostic test results, gender, age, disease duration, hand muscle weakness, atrophy, and baseline symptom scores [3, 23, 24]. In accordance with these studies, we also found baseline SSS, FSS, and electrodiagnostic test results to be of prognostic value. Therefore, correction was made for these variables in the multivariable analysis. In addition, the specialty of the surgeon might affect outcome. In our cohort, patients who underwent CTR by neurosurgeons reported a better outcome than those operated by plastic surgeons. This finding is, however, inconclusive since referral for CTR to different specialties was not randomized in this study and the number of patients operated by orthopedic or plastic surgeons was very low. In contrast, age, gender, disease duration, hand muscle weakness, and atrophy did not prove to be independently associated with outcome.

A major strength of our study is the heterogeneity of the group of surgeons, including residents in different stages of their training program. Therefore, we were able to investigate results of surgeons with a low level of experience, but also certified surgeons with some decades' experience. This enabled us to illustrate a learning curve for this procedure. Moreover, surgeons of different specialties were included, which corresponds to daily practice in the Netherlands. Referrals were however not randomized, as it was not the scope of the study to investigate differences between specialties. As a result, the majority of the patients were operated by neurosurgeons, which hampers comparing results between specialties. Finally, sample size for the multivariable logistic regression model and the multivariable linear regression analysis was adequate, as a maximum of 5 to 18 variables in the models are allowed [25, 26].

A limitation of our study is that surgeon's experience was calculated from date of starting the surgical specialty training program. However, annual surgeon volume would have been more precise since experience is expressed as annual case load. Moreover, since 28 different surgeons participated in our study, the mean case load is only 6.5. Although this might

Table 3 Multivariable logistic regression analysis for association between surgeon's experience and favorable outcome. n = 188

Independent variable	Favorable outcome	No favorable outcome	Crude OR	Adjusted OR[a]	95% CI	p value	Nagelkerke R^2
Years of experience							
≤ 3	11 (48%)	12 (52%)	1	1			0.081
4–6	98 (75%)	32 (25%)	3.34	3.23	1.28–8.12	0.013	
> 6	25 (71%)	10 (29%)	2.73	3.16	1.01–9.79	0.046	

[a] Adjusted for: abnormal electrodiagnostic tests

Table 4 Multivariable linear regression analyses for association between surgeon's experience and Symptom Severity Scale and Functional Status Scale at T_1

	Crude B (95% CI)	Adjusted B (95% CI)	p value	SE B	β	R^2	R
Symptom Severity Scale							
Years of experience[a]							
4–6	−0.307 (−0.646–0.033)	−0.332[b] (−0.657 to −0.006)	0.046	0.165	−0.203	0.127	0.356
>6	−0.421 (−0.826 to −0.016)	−0.527[b] (−0.966 to −0.089)	0.019	0.222	−0.270		
Functional Status Scale							
Years of experience[a]							
4–6	−0.375 (−0.714 to −0.036)	−0.514[c] (−0.844 to −0.184)	0.002	0.167	−0.315	0.146	0.382
>6	−0.360 (−0.767 to 0.046)	−0.571[c] (−1.016 to −0.127)	0.012	0.225	−0.293		

B partial regression coefficient, SE B standard error partial regression coefficient, R multiple correlation coefficient, R^2 determination coefficient

[a] Reference is ≤3

[b] Adjusted for Symptom Severity Scale at baseline, abnormal electrodiagnostic tests, surgeon's specialty

[c] Adjusted for Functional Status Scale at baseline, abnormal electrodiagnostic tests, surgeon's specialty

be interpreted as a weakness, it confirms our conclusion that after a learning curve, the results after CTR are stable. In addition, baseline characteristics were largely, but not entirely, comparable. Patients operated by less experienced residents were older than patients who underwent CTR by experienced residents or certified surgeons. However, in multivariable regression, age was not an independent prognostic value, and therefore, this would not have influenced our results. Electrodiagnostic tests were less often abnormal in the patients operated by certified surgeons and because this factor was independently associated to outcome, and adjustment was made for this factor. The use of subjective outcome measures rather than objective outcome measures (e.g., electrodiagnostic tests or ultrasonography) could be seen as another limitation. From the authors' point of view, however, patients' satisfaction is of more importance than objective measurements. It is known from previous research that in CTS, patients reported outcome measures (PROMs) are very helpful to determine treatment effect, because clinical examination and well as neurophysiology tests are not by themselves sensitive enough to adequately evaluate outcome, and that standardized questionnaires like BCTQ are more sensitive to the clinical change produced by CTR [27–30]. Finally, the number of patients operated by inexperienced residents and certified surgeons were small. As a result, confidence intervals for OR and partial regression coefficient were wide. Further research is required to establish our results in a larger population.

In conclusion, this study shows that patient outcome after open CTR seems to be dependent on surgical experience and that there is a learning curve for open CTR in residents. Open CTR seems to be a relatively easily learnable procedure for residents and once operation skills are at level after a learning curve, more experience will not further improve patient outcome. However, the overall influence of surgeon's experience on outcome is low and other factors, such as the number of complaints before CTR and electrodiagnostic test results, also play a role.

Compliance with ethical standards

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