Original Article

Ultrasound-Guided Percutaneous Carpal Tunnel Release with Hook Blade

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Background: Carpal tunnel syndrome (CTS) is the most common cause of upper limb entrapment neuropathy. Transverse carpal ligament release is a definitive treatment for advanced stage of disease. However, the evidence to support ultrasonographic guidance of this procedure is scarce.

Objective: To evaluate the results of ultrasound-guided percutaneous carpal tunnel release (USG-PCTR) with hook blade, specifically on median nerve anatomical and physiological improvements, symptom relief, functional recovery, complications, and satisfaction outcomes.

Materials and Methods: The present study was single center, prospective cohort study. Patients diagnosed as moderate to severe degree CTS with electrodiagnostic confirmation, symptoms persisting more than six months and unresponsive to conservative treatment were enrolled. Patients with rheumatoid arthritis, previous CTR, pregnancy, bleeding risks, and space occupying lesion were excluded. The procedure was an USG-PCTR with hook blade. Boston Carpal Tunnel Questionnaire (BCTQ), median nerve cross-sectional area (CSA) at distal wrist crease, proximal and distal carpal tunnel, median nerve conduction studies including distal sensory latency (DSL), distal motor latency (DML), and compound motor action potential (CMAP) amplitude, and surgical complications were collected at three- and six-months follow-up.

Results: Nineteen wrists from 16 patients received USG-PCTR with hook blade were included in the present analyses. All outcome measurements (BCTQ, median nerve CSA and median nerve conduction studies) were significantly improved at three- and six-months follow-up compared to pre-treatment. Mean subject satisfaction scores was 9.68. Only five patients (26.31%) had a transient paresthesia, and no severe complication was observed.

Conclusion: USG-PCTR with hook blade was an effective treatment for advanced idiopathic CTS in terms of median nerve anatomy and physiology. The results showed significant improvement of patient's symptom and function with high-level of satisfaction and no major complications.

Keywords: Carpal tunnel release, Percutaneous, Ultrasound-guided

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Carpal tunnel syndrome (CTS) is the most common upper limb entrapment neuropathy, commonly in adults 20 to 80 years of age, and more frequently in women than men. In CTS, there is increasing intratunnel pressure resulting in compromised blood circulation and direct compression on the median nerve. Initial symptoms may be nighttime paresthesia and pain. However with disease progression, persistent numbness, pain, or weakness during activity disturb hand function. Atrophy of thenar muscles are often the end result of the disease. While the exact cause of CTS is unknown, it was found more commonly with repetitive wrist movement, poor ergonomic hand task, diabetic mellitus, hypothyroidism, rheumatoid arthritis with hypertrophic tenosynovium, and other space occupying condition such as carpal ganglion cyst[1].

Conservative treatments that include oral non-steroidal anti-inflammatory drugs, splinting, lifestyle modification, physical therapy, and corticosteroid injection, are first-line treatments for CTS[2,3]. If

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CTS is recurrent or recalcitrant, carpal tunnel release (CTR) surgery is often performed and involves the release of transverse carpal ligament by open or endoscopically surgery. While open carpal tunnel release (OCTR) is considered the "gold standard" of surgical treatment, it may be accompanied by painful scars and poor cosmetics. Endoscopic carpal tunnel release (ECTR) provides no significant symptom relief compared to OCTR but it offers a faster recovery of hand grip strength and return to work at a greater risk of iatrogenic neurovascular injuries[4,5].

The use of musculoskeletal diagnostic ultrasound imaging for the assessment and assistance in the management of anatomic and pathologic disorders has markedly increased. The high-resolution ultrasound machine and probe provide clear visualization of carpal tunnel structures, whether it be bony structures, median and ulnar nerves and branches, ulnar artery, superficial palmar arch, transverse carpal ligament, palmar aponeurosis, muscles, and tendons. Ultrasound-guided percutaneous carpal tunnel release (USG-PCTR) offers a novel treatment approach that allows for real-time visualization of the carpal tunnel structures during the procedure.

Several studies evaluated the safety and efficacy of USG-PCTR. McCone et al used hypodermic needle as a device for carpal tunnel release under ultrasound guidance and found favorable results but complete release of transverse carpal ligament was questionable[6]. Rojo-Manaute et al studied the safety of ultra-minimally invasive sonographically guided carpal tunnel release with hook blade in cadaveric hands and studied carpal tunnel anatomic structures in healthy subjects by magnetic resonance imaging. He found that this procedure provided complete carpal tunnel release without any injury to neurovascular bundles[7]. Moreover, he compared this procedure with 2-cm blind mini-open carpal tunnel release. The outcomes showed that ultra-minimally invasive carpal tunnel release provides earlier functional return and less post-operative morbidity with the same neurologic recovery[8]. However, recovery of median nerve, in terms of anatomic and physiologic aspects was not mentioned in the study. Similarly, recent study of interventionist, Patrover et al about USG-PCTR with hook blade in 129 CTS patients were evaluated. The results were successful median nerve decompression in all patient without complications, but a scalpel was used to create site of entry of about 2 to 5 mm[9]. There is a non-scalpel technique for USG-PCTR by using thread saw as a cutting device that could be effective and safe. However, a non-commercial worldwide, special-design instrument is needed[10,11].

While these studies demonstrated excellent outcomes without significant complications, they did not describe the changing of median nerve morphology at various levels of carpal tunnel and recovery of median nerve physiology after the procedures. The present study aimed to assess and describe the outcomes of USG-PCTR with hook blade, in terms of median nerve anatomical and physiological improvement, symptom relief, functional recovery, complications, and satisfaction outcomes.

Materials and Methods

Study design

The present study was a single center, prospective cohort study to evaluate the results of USG-PCTR with hook blade for patients with CTS. The study was approved by the Hospital Ethics Committee before commencement.

The study was performed in individuals with CTS seen in the Outpatient Unit of a Rehabilitation Medicine Division between March and July 2017. All patients diagnosed as moderate to severe degree CTS, confirmed by electrodiagnostic study, with symptoms that persisted longer than six months, and were unresponsive to conservative treatment were invited to participate in the present study. The patients who had underlying disease of rheumatoid arthritis or other connective tissue disease, previous carpal tunnel release surgery of the same side of symptom, abnormal ultrasonographic finding in carpal tunnel other idiopathic CTS (space occupying lesion or synovial hypertrophy), pregnant, and/or had bleeding risks were excluded from the study. All eligible patients received the procedure. Post-procedure, the patients were followed-up at four days, three months, and six months.

Data collection and operative outcomes

Patients' baseline demographic characteristics, including gender, age, and side of wrist involved were collected. The Boston Carpal Tunnel Questionnaire (BCTQ)[12], consisted of Symptom severity scale (SSS) and Functional status scale (FSS), median nerve cross-sectional area (CSA) at distal wrist crease, proximal and distal carpal tunnel levels, median nerve conduction studies, distal sensory latency (DSL), distal motor latency (DML), and Compound motor action potential (CMAP) amplitude were collected at pre-treatment, and three and six months post-treatment at outpatient clinic. Satisfaction score (using 10-cm visual analogue scale) was collected and surgical

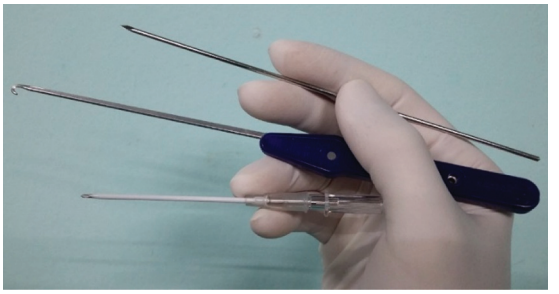

Figure 1. Retrograde knife (hook blade), Kirschner wire and intravenous cannula.

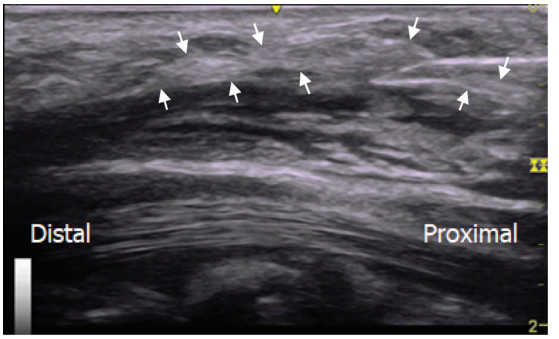

Figure 2. Ultrasound image of long axis at wrist show tip of 18-gauge hypodermic needle cutting antebrachial fascia at entry site.

Arrows: antebrachial fascia

complications were recorded each visit post-treatment.

Ultrasound-guided percutaneous carpal tunnel release with hook blade

In the treatment room at the outpatient rehabilitation clinic, the skin entry site and approach according to Rojo-Manaute et al studies[7,8], which includes patient's posture, wrist position, and pre-procedural US evaluations, had been followed. A LOGIQ™ e Premium ultrasound machine with an 8 to 13 MHz, linear transducer (manufactured by GE Healthcare™), was used to obtain US images.

Prior to the carpal tunnel release, the surgical skin surface was prepared in a sterile fashion. The probe was wrapped with a sterile plastic sleeve. Essential materials for the present study including retrograde knife (hook blade) 3.0 mm. ACUFEX (manufactured by Smith & Nephew™), blunt Kirschner wires size 1.2 mm, 1.6 mm, 1.8 mm, and 16-gauge intravenous cannula (Figure 1) were prepared.

The following processes were performed step by step manner.

Local anesthesia and hydrodissection: 1% lidocaine with adrenaline local anesthesia was injected using a 25-gauge, 1.5 inches, bent needle into the entry site, pointed to the distal direction, under real-time ultrasonographic visualization. The local anesthetic solution was infiltrated above and beneath the antebrachial fascia (hydrodissection), which continued to proximal carpal tunnel space, anesthetized and aimed to enhance the antebrachial fascia.

Antebrachial fascia opening: Bent 18-gauge hypodermic needle attached with a 5-ml syringe, faced bevel laterally was inserted into the entry site as cutting tool to divide the hydrodissected antebrachial fascia about 3 mm longitudinally to create the entrance to introduce th hook blade into the carpal tunnel (Figure 2).

Carpal tunnel dilatation: Blunt Kirschner wires were used. First, we started with size 1.2 mm to create a tract for the hook blade, keeping the wire just beneath the transverse carpal ligament and ulnar to the median nerve. After removal of the first wire, then a 16-gauge intravenous cannula was inserted, by sliding the cannula for 3 to 4 mm to cover the tip of its core needle while introducing the intravenous cannula into the carpal tunnel to prevent inadvertent injury. We removed the core needle and connected the cannula to a 5-ml syringe containing 1% lidocaine with adrenaline. The anesthetic solution was infiltrated intratunnel to anesthetized the transverse carpal ligament. In this process, the difference of pressure in each part of the intratunnel could be observed by the dispersion in real-time of the local anesthetic and the dynamic dilation of the carpal tunnel during the injection shots. Then, dilation of carpal tunnel was performed by blunt Kirschner wire size 1.6 mm and 1.8 mm, respectively.

Hook blade insertion: The hook blade was inserted by bringing the tip of the hook blade into the entry site first, then pushed the rest of the hook blade and shank pass through the divided antebrachial fascia into the dilated carpal tunnel along the track. Advancing the hook blade inside the tunnel, keeping the tip of the hook blade on the ulnar side, until it reaches the distal cutting point, then turning the tip of hook blade to place the hook blade in a steady position (Figure 3).

Transverse carpal ligament resection: In this steady position, after important structures in the area including median nerve, third common digital nerve, ulnar artery/superficial arch, and palmar aponeurosis were checked carefully, the transverse carpal ligament was divided by pulling the hook blade backward

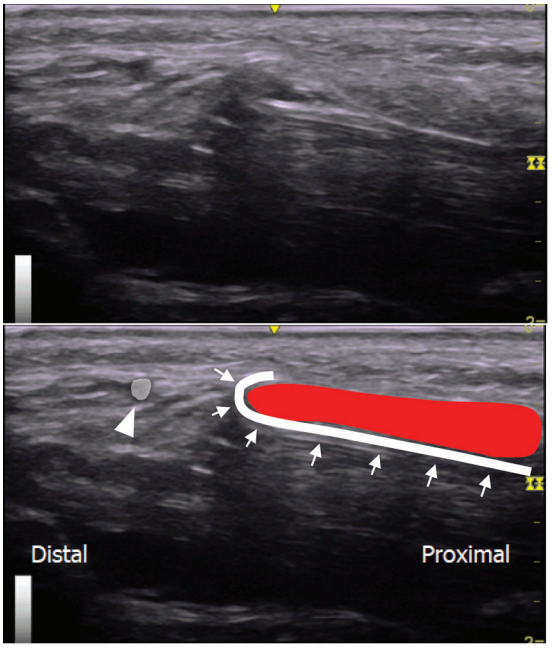

Figure 3. Ultrasound image of long axis at distal carpal tunnel show hook blade at distal cutting point of transverse carpal ligament.

Arrow head: superficial palmar arch, Shade area: transverse carpal ligament, Arrows: hook blade

until the proximal cutting point, usually about one centimeters proximal to distal wrist crease, was reached. Keeping the divided site ulnar of the median nerve as far as possible or approximately 2 mm radial to hook the hamate to avoid recurrent motor branch injury and prevent fibrosis formation at nearby median nerve that slows the healing process is important. Repeat this step until the transverse carpal ligament is released.

Confirmation of complete release: Kirschner wire size 1.8 mm was inserted into the carpal tunnel to confirm a successful complete release by moving the distal part of the wire inside the carpal tunnel in dorsal-volar direction or passing through the divided transverse carpal tunnel ligament dynamically from proximal to distal cutting points, which is easily observed in real-time ultrasonographic image.

All of above processes, performed under real-time ultrasonographic guidance, changing transducer in long and short axis alternatively, aimed to obtain the best image for each procedure. Bulky dressing was done without stitch. Patients were instructed to keep dry, active fingers, flex-extend motion, and allowed to use light activities as tolerated, taking pain medications as needed. First follow-up at day 4 post-procedure to remove the dressing and check the surgical wound. No any wrist splints were recommended and vigorous hand function activities were prohibited for a few weeks (Figure 4). Appointments in the next three and six months were made for follow-up assessment.

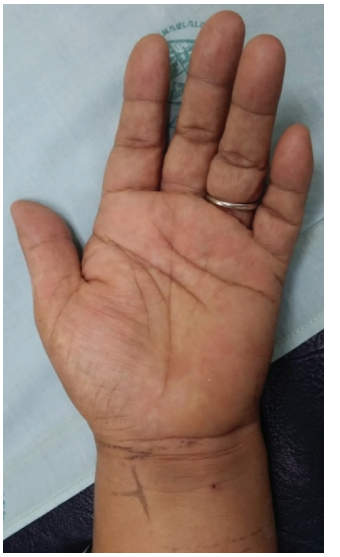

Figure 4. Surgical wound at 4 days post procedure.

Statistical methods

Descriptive statistics were used, including percentage, proportion and mean with standard deviation (SD) to describe baseline data and surgical outcomes. Paired t-test was used to compare data of pre-treatment and post-treatment. All statistical analyses were performed using Statistics Package for the Social Sciences (SPSS) version 20 for Windows. A p-value <0.05 is considered as a statistical significance.

Results

Patients' characteristics

Twenty wrists from 17 patients with moderate to severe degree CTS, electrodiagnostic confirmation, persisting symptoms longer than six months, unresponsive to conservative treatments were invited to participate in the present study. All wrists received the USG-PCTR with hook blade. One patient (one wrist) was excluded from the study analyses due to being loss to follow-up at three and six months. Therefore, 19 wrists from 16 patients were included for study analyses. Most patients were female (male to female 2 to 14) with a mean age of 54.7 years, and most affected sides were right, (right to left 11 to 8).

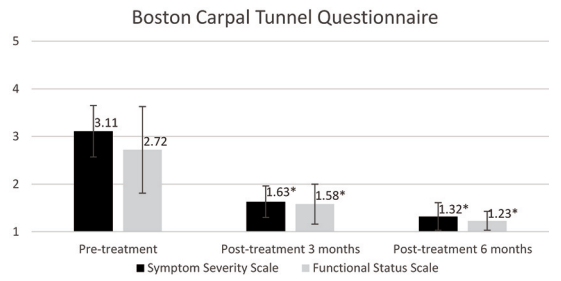

Figure 5. Boston Carpal Tunnel Questionnaire (BCTQ) scores.

* p-value <0.001

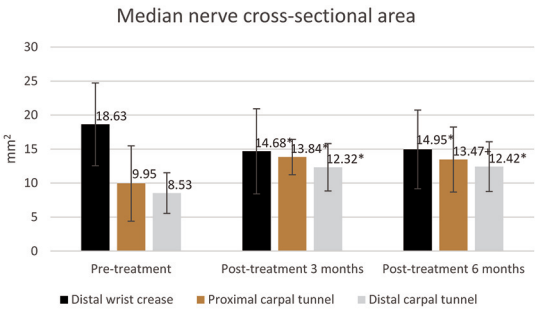

Figure 6. Median nerve cross-sectional area (CSA).

* p<0.001 + p=0.015

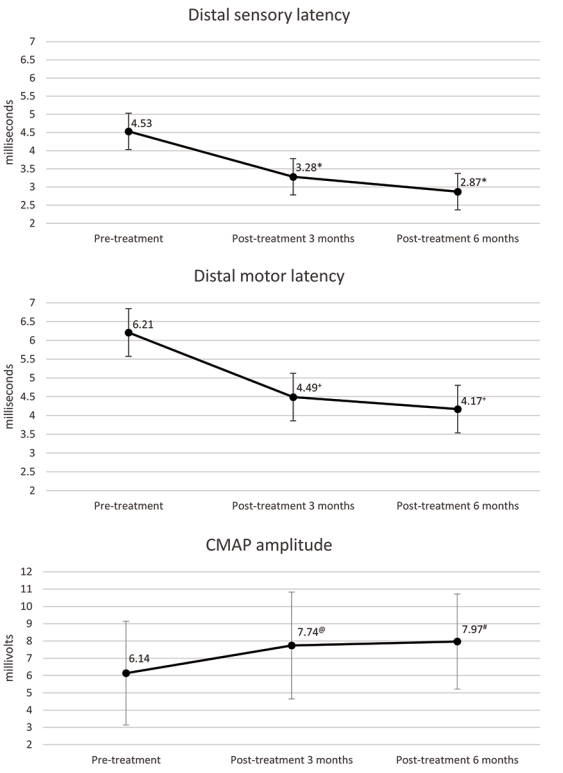

Figure 7. Median nerve conduction study (DSL, DML, CMAP amplitude) of 11 patients.

* p<0.001 + p=0.004, @ p=0.043, # p=0.018

Surgical outcomes

A significant improvement of BCTQ scores were found in all patients. Mean symptom severity scale and mean functional status scale (SSS:FSS) were decreased significantly pre-treatment (3.11±0.54:2.72±0.91), compared to three months (1.63±0.33:1.58±0.42) and six months (1.32±0.29:1.23±0.2) post-treatment (p<0.001) (Figure 5).

Median nerve CSA were found to have significant change in all levels. Mean median nerve CSA at distal wrist crease appeared to decrease from pre-treatment (18.63±6.08 mm²), compared to three months (14.68±6.26 mm²) and six months (14.95±5.79 mm²) post-treatment (p<0.001). On the other hand, mean median nerve CSA at proximal and distal carpal tunnel levels (proximal to distal) appeared to increase from pre-treatment (9.95±5.54 mm², 8.53±3.0 mm²) compared to three months (13.84±2.6 mm², 12.32±3.48 mm²) and six months (13.47±4.78 mm², 12.42±3.65 mm²) post-treatment (p<0.05) (Figure 6).

Eight wrists could not obtain a Sensory nerve action potential (SNAP). Therefore, 11 wrists were included for data analyses. All parameters of median nerve conduction study were found to be with significant improvement. Mean DSL were increased from pre-treatment (4.53±1.14 msec), compared to three months (3.28±0.64 msec) and six months (2.87±0.42 msec) post-treatment (p<0.001). Mean DML were increased from pre-treatment (6.21±2.03 msec), compared to three months (4.49±0.95 msec) and six months (4.17±0.89 msec) post-treatment (p<0.05). Likewise, CMAP amplitude was found increased from pre-treatment (6.14±3.0 mV), compared to three months (7.74±3.09 mV) and six months (7.97±2.75 mV) post-treatment (p<0.05) (Figure 7).

There was 1 mm surgical scar with no major neurovascular injuries, hematoma, surgical site infection, tendon laceration or bowstring. All patients' surgical wound healed with no bleeding or oozing at follow-up day 4 post-treatment. Only five patients (26.31%) reported a new symptom of transient paresthesia along median nerve distribution, which disappeared within one to two weeks. The average satisfaction score was 9.68.

Table 1. Median nerve conduction studies of 8 wrists which had no response of some parameters

Pre-treatment			Post-treatment 3 months			Post-treatment 6 months		
DSL	DML	CMAP amplitude	DSL	DML	CMAP amplitude	DSL	DML	CMAP amplitude
NR	6.5	10.6	7.5	4.55	13	3.2	4.4	12.2
NR	6	9.2	2.8	3.9	11.4	2.5	3.65	10
NR	9.05	5.4	7.3	5.45	7.7	6.67	4.79	5.6
NR	4.5	1.1	7.15	4.85	1.0	5.63	4.38	1.3
NR	14.05	0.2	NR	4.95	0.3	NR	4.5	0.3
NR	5.35	0.5	NR	5.05	0.4	NR	4.6	0.5
NR	8.5	1.8	NR	4.2	1.5	NR	4.3	1.6
NR	NR	NR	NR	8.25	0.3	NR	6.72	0.6

DSL=distal sensory latency; DML=distal motor latency; CMAP=compound motor action potential; NR=no response

Discussion

In the present prospective study, 19 wrists received USG-PCTR with hook blade. All patients had symptoms relieved and improved hand function, as presented with a significant decrease in SSS and FSS at three- and six-months post-treatment. This study agrees with results of previous studies of Rojo-Manaute et al and Patrover et al[7,9]. Although, our USG-PCTR with hook blade was the same procedure, there were differences in the details. In the present study, some techniques were proposed. First, antebrachial fascia opening with bevel of 18-gauge hypodermic needle was used as a tool to facilitate hook blade insertion into the carpal tunnel. Second, an intravenous cannula was used to infiltrate the anesthetic solution in the carpal tunnel to anesthetize the carpal tunnel hydrodilation and for dynamic intratunnel pressure assessment, including needle core bevel covering technique during advancement into carpal tunnel. Third, the confirmation technique for the complete release of the transverse carpal ligament was done immediately after the procedure.

In term of anatomical recovery of the median nerve after USG-PCTR, the median nerve morphology in CTS will change according to the intratunnel pressure, which increase the most at hook of hamate level due to the thickness of the distal part of the transverse carpal ligament and the anatomical dimension of the carpal tunnel itself[13-15]. In other words, the CSA of the median nerve will enlarge at the carpal tunnel inlet or just proximal to the proximal carpal tunnel before it run into the pressurized carpal tunnel. When ultrasonographic evaluation was performed in the long axis of the median nerve in the CTS, a "notch sign" (sometime reverse notch sign) is often observed, indicating a particular part of the median nerve is compressed[16]. In accordance with the present study, before treatment, the mean median nerve CSA was the largest at the distal wrist crease and smallest at the distal carpal tunnel. After the USG-PCTR got rid of the pathologic condition, the complete course of the median nerve CSA along its in carpal tunnel trended to be of equal size after three- and six-months post-procedure[17,18].

Many studies evaluated a diagnostic aspect of ultrasound imaging in CTS patient. Several parameters were found consistent with the severity of the disease, whether it be median nerve echogenicity, decreased median nerve gliding, median nerve flattening ration, hypervascularity detection, or transverse carpal ligament bowstring, but the parameter that is most being studied and referenced is median nerve CSA at proximal carpal tunnel and/or carpal tunnel inlet. When it is larger CSA, then it refers to more advanced disease[19,20]. In the literature reviews, the level that is a good indicator to represent the disease severity is still inconclusive. From the author's opinion, measuring median nerve CSA at the carpal tunnel inlet, just proximal to the proximal carpal tunnel or at the level of distal wrist crease will provide the largest CSA in CTS patient[21], according to results of the present study.

In terms of physiological recovery of median nerve after USG-PCTR, eleven wrists with all the parameters (DSL, DML, CMAP amplitude) were analyzed. Significant improvement in all parameters were found at three- and six-month follow-up. The other eight wrists were not included in analysis due to SNAP and/or CMAP were unable to obtained, indicating more severity of the disease[22] (Table 1).

Nonetheless, four of them were able to obtain SNAP at three months follow-up and trended to improve at six months follow-up. In three of them, SNAP was still unobtainable at six-months follow-up but seemed to improve DML at three- and six-months follow-up. One wrist that unable to obtain neither SNAP nor CMAP at pre-treatment but CMAP was able to detect at three- and six-months follow-up. Corresponding to previous study of median nerve recovery after CTR, it depends on the severity of the disease before the operation[23]. The electrophysiological studies were not meaningful in determining the outcome in CTS patients in term of symptoms relief[24].

About the safety concern, most of the carpal tunnel structures and the related anatomy can be assess by high-resolution ultrasonography, whether it be median nerve including variations (e.g., bifid median nerve), ulnar nerve, third and fourth common digital branches, ulnar artery and superficial palmar arch, transverse carpal ligament, interthenar fascia, antebrachial fascia, and even palmar aponeurosis[25]. Therefore, USG-PCTR procedure can be performed selectively without trauma to non-pathologic structures. For Berrettini branch (median ulnar anastomosis), type I anastomosis is the most prevalent. The distance between its origin is proximal from forth common digital nerve, which is distal to distal limit of transverse carpal ligament, with a mean distance of 7 mm and run distally to the third common digital nerve[26]. Rojo-Manaute et al study in cadavers found that the Berretini branch was distal to distal end of transverse carpal ligament or hook of hamate, with a mean distance of 9.9 mm[7], with a clear ultrasonographically visualization distance and enough safety margin for USG-PCTR procedure. In the present study, a new symptom of transient paresthesia along median nerve distribution was reported in five wrists. This was probably because of the introduced instruments into the restricted carpal tunnel, which might be repeating the injury to the compressed median nerve[27]. However, all the patients who had this symptom reported complete resolution within one to two weeks with high satisfaction. From author's point of view, the only weak point of the USG-PCTR procedure is being unable to obtain clear ultrasonographic image of recurrent motor branch of median nerve because of its course and anatomical variations(28). Regarding the previous in vivo studies of the USG-PCTR surgery[6,8-11], with more than 300 wrists, the results showed no single wrist had recurrent motor branch injury. It indicated that the technique of transverse carpal ligament resection described in these studies is safe.

The present study has several limitations, mainly due to lack of control group to compare results with open or ECTR surgery. Severity of CTS were not classified, grip strength measurement was not be evaluated, and only six months follow-up period may not enough to collect some complications such as recurrent symptoms. Finally, ultrasound guidance intervention is operator dependent. Therefore, a learning curve of ultrasound probe handling to obtain proper image, smooth and precise instrumental placement was required. Finally, from the dynamic evaluation about the intratunnel pressure as proposed in the present study, we found that level of hook of hamate had most pressurized and much less beyond this level (distal part of flexor retinaculum or interthenar fascia). Interesting question after the present study is whether transverse carpal ligament needs to be divided completely, especially the distal portion, as exact part of compressed median nerve can be evaluated by ultrasonography. Further study is needed for this question.

Conclusion

USG-PCTR with hook blade is an effective treatment for moderate to severe degree idiopathic CTS, in terms of median nerve anatomy and physiology, patient's symptom, and function with a high level of satisfaction and no major complications. For physician with experience in ultrasonographic guidance interventions, this promising procedure will provide very high level of efficacy and safety. In the other hand, devastating complications might occur for untrained physician.

What is already known on this topic?

Ultrasound-guided carpal tunnel release technique is available, has been proven as a safe procedure, and is effective to relieve symptoms and recover functions. This minimally invasive carpal tunnel release surgery can provide fast wound healing and limited surrounding tissue trauma.

What this study adds?

This report adds improved results after ultrasound-guided percutaneous carpal tunnel release surgery in term of anatomy and electrophysiology of median nerve. In addition, detailed surgical technique were proposed.

Conflicts of interest

The author declares no conflict of interest.

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