Avoiding Iatrogenic Nerve Injury in Endoscopic Carpal Tunnel Release

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KEYWORDS

• Iatrogenic • Nerve • Injury • Endoscopic
• Carpal tunnel release

With rates of beneficial outcomes quoted at 80% to more than 90%, carpal tunnel release (CTR) always has been an effective surgical procedure.[1] Considering that in the United States alone more than 460,000 carpal tunnels are released annually with direct costs of US $ 1 billion, its economic impact is sizeable.[2,3] Despite this, CTR is a major contributor to iatrogenic nerve injury.[4,5] The median is now the most frequently injured nerve (41/263, 16%) in our record of operated iatrogenic nerve injuries. Obviously, some of the necessary skills are at times underestimated or not appreciated in view of the short duration of this outpatient procedure.[6,7]

In our current patient pool of 263 iatrogenically injured nerves, we have noticed increasing rates of nerve damage caused by open and endoscopic attempts at CTR since 2000. We are not attempting to argue in favor of or against the endoscopic technique, but rather prefer to delineate some of the procedure's inherent pitfalls. A recent meta-analysis of controlled trials comparing endoscopic and open carpal tunnel decompression supported the conclusion that endoscopic release has an advantage over open decompression in terms of scar tenderness and increase in grip and pinch strength at a 3-month follow-up. With regard to symptom relief and return to work, however, the data were inconclusive.[8] In principle, two different endoscopic release techniques exist (monoportal and biportal), with additional variations (eg, extra- and transbursal Chow technique).[2,9–17] In 2007 alone, 5 of 22 iatrogenic nerve injuries operated at our department were caused by CTR (23%). Open and endoscopic CTR have their specific inherent risks for neurovascular injury. Overall, 55% of all CTR-related iatrogenic lesions were due to an endoscopic attempt.

Based on our own experience with endoscopic CTR of 170 to 220 releases per year, and after observing the intraoperative findings at revision surgery, we attempted to identify the most critical steps for endoscopic CTR to prevent neurovascular injury.

OUR METHOD

For our own practice of endoscopic CTR, we use a monoportal system. We prefer local anesthesia, with injection at the entry port just short of the distal flexor crease. Additional local anesthetic is placed in the proximal palm within and overlying the flexor retinaculum by way of needle advancement through the already anesthetized skin portion. For this maneuver, we hyperextend the hand over a rolled towel. A bloodless field is established and maintained with a combined pneumatic exsanguination bag for the whole extremity and a blood pressure cuff device. The pressure usually needs to be maintained for 10 minutes because

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hand preparation and draping add to the time. The critical release steps are emphasized below. After skin closure, we do not apply a splint but use gauze and a mildly compressive bandage, and encourage finger movement right away to prevent hand swelling and adhesions. However, to minimize the (low) likelihood of median nerve subluxation (higher with open CTR), patients are advised to avoid wrist excursions for 2 weeks. Patients leave the hospital after an observational period of 2 hours. Before that, the dressing is changed to rule out hematoma formation or new deficits.

ILLUSTRATIVE FINDINGS AFTER IATROGENIC INJURY

Evaluation of 10 consecutive reexplored cases that were referred to our department after endoscopic CTR elsewhere revealed substantial trauma, necessitating various microsurgical repairs. The cases accumulated within only 2 years, from January 1999 to December 2000.[18] Findings in the 10 reexplored cases of previous endoscopic CTR were as follows: In 5 cases, the median nerve was injured to an extent necessitating autograft reconstruction (**Fig. 1**). In 2 cases, nerves needed extensive external and internal neurolysis. The main median nerve trunk was affected twice, the recurrent thenar motor branch in 3 cases, a digital nerve distal to the retinaculum (n. digitalis palmaris communis) 3 times, and the sensory palmar branch to the thenar once. In 4 patients, the flexor retinaculum had not been transected and in 2 cases only incompletely so at the distal aspect. A reunited, scarred and thickened retinaculum was evident in 2 cases. Three patients reported marked, symptomatic hematomas after the primary operation.

As Birch and colleagues[19] have pointed out, the more frequent risks associated with CTR are

- Incomplete decompression of the median nerve (worsens symptoms)
- Nerve prolapse (reason why many hand surgeons are inclined to use postoperative splints)
- Injury to the main median trunk, the thenar motor branch, a palmar cutaneous branch, the sensory digital branches, or even the ulnar nerve
- Injury to the superficial arterial arc
- Painful sequelae of hematoma and fibrosis

Fig. 1. Median nerve at wrist (right side) to palm level (left side) of a 59-year-old patient, after unsuccessful attempt at endoscopic CTR. The main median nerve trunk shows a near complete transection. On the left side, the common digital nerve branches are encircled with vessel loops.

A Sudeck's syndrome or reflex sympathetic dystrophy (now complex regional pain syndrome type I), which is usually added in the operative consent, would be an extremely rare complication of CTR.

The whole array of "pillar pain," which is a consequence of correct flexor retinaculum transection, is a subject on its own and is not discussed here.[20] However, despite its controversial nature, prolonged postoperative pain in the proximal palm can sometimes be attributed to transection of one of the tiny sensory branches that can course through the retinaculum, rather than to "pillar pain." The high initial hopes that endoscopic release would eliminate pillar pain have not been fulfilled.[21]

ANATOMIC VARIATIONS

Knowledge of the pertinent local anatomy and its variations is important for preventing disaster. Variations of the median nerve in the vicinity of the carpal tunnel will be encountered in 3% to 12% of cases.[22–26] Examples are aberrations of the median nerve itself (high bifurcation, persistent median nerve artery, calcified median nerve artery) or its motor and palmar cutaneous branches, and muscle/tendon anomalies. Among these, the more frequent ones are variations in the course of the recurrent thenar motor branch in relation to the flexor retinaculum (transligamentous 23%, subligamentous 31%, and extraligamentous 46%);[22,26] the different courses of the palmar cutaneous branch, predisposing to injury during transection of the retinaculum from below[25,27] (eg, piercing the flexor retinaculum or having connections to the ulnar nerve at the retinacular level); and various additional muscle bellies within the carpal tunnel (eg, flexor digitorum superficialis sublimis, distal belly of the flexor palmaris longus). Aberrant muscles cannot only fill the tunnel and the entry port and thus preclude insertion of an endoscope unless they are resected but, if present, they can be the main cause of median nerve compression.[28–31] The superficial palmar communications between the median and ulnar nerves deserve special consideration.[32] This connection, also referred to as "the Berrettini branch," is a frequent finding. If such a communication is at the retinacular level or in close proximity to the distal edge of the retinaculum, this branch is injury prone with any retinacular transection from underneath. A large cadaver study demonstrated the Berrettini branch in 81 of 100 cadaver hands, suggesting that this branch is a normal anatomic finding. In 28% of hands, the branch was proximal to the edge of the distal ligament and therefore prone to iatrogenic injury in one-portal and two-portal endoscopic surgery.[33] Its inadvertent transection causes sensory deficits involving the middle and ring fingers. However, in the cases we reexplored and repaired, anomalies were not the cause of injuries. In other words, serious 2injuries had been inflicted despite straightforward "normal" anatomy.

CORRELATION OF NEUROVASCULAR INJURY WITH INAPPROPRIATE DISSECTION STEPS

All parts of the distal median nerve in the hand and wrist can be found damaged. Sometimes the injuries are combined with vascular lesions to the superficial arterial arch. Partial laceration and blunt injury to the main trunk of the median nerve at a wrist or proximal palm level indicates injury with the endoscope or trocar (slotted cannula of biportal system) during insertion or dilatation. Blunt, not focally confined, extensive lesions point toward "ramming" of these instruments. Most likely, difficulties were encountered in finding the proper sagittal plane, or the instrument angle was too steep, so the nerve was hit directly with the tip of the instrument. This situation can occur if the flexor synovium between the nerve and retinaculum is not carefully separated from the nerve before insertion of the release instruments. It is essential to hyperextend the hand over a fulcrum placed underneath the wrist to ease advancement of the endoscope. Another source of damage is direct attack of the median nerve during entry port dissection, even before insertion of the instruments. In this case, the median nerve forearm sheath obviously has not been clearly identified as such and separated well enough from the median nerve. A partial or complete transection of the median nerve main trunk close to the entry port indicates a direct blade injury. This finding, in turn, implies that either the blade/trocar must have been turned around the longitudinal axis pointing downwards if the instruments were in the right axial and sagittal planes, or the instruments were passed through a plane underneath or parallel to the nerve. Damage of a palmar common digital nerve or one of its distal branches indicates that the endoscope or slotted cannula was advanced too far in the wrong plane, and beyond the retinaculum's distal edge. Not infrequently, these injuries are combined with lacerations of the superficial arterial arch. This situation is preventable if those palpable landmarks that outline the distal border of the retinaculum (hook of hamate, ridge of trapezium) are respected.[34]

Different terms are used to denote the roof of the carpal tunnel. Cobb and colleagues[35] refer to the "central portion of the flexor retinaculum" as the transverse carpal ligament, which is different from the 1989 Nomina Anatomica.[36] It is defined by its bony attachments to the pisiform bone, hook of hamate, tuberosity of the scaphoid, and ridge of the trapezium. Regardless of term preference (classic flexor retinaculum, transverse carpal ligament, central portion of the flexor retinaculum), these bony attachments delineate the roof of the anatomic carpal tunnel. They are easily palpable on a skin level (see later discussion). The first common digital nerve branches from the main median trunk at the level of the distal margin of the retinaculum. Apart from these palpable skin level landmarks, the end of the retinaculum should be visible with the camera. The retinaculum is readily identifiable because of its typical transverse fiber direction. The transverse fiber direction cannot only be seen with the endoscope (monoportal technique), but before scope insertion it can be palpated as a "rugged washboard texture," when a dilator is used. The emergence of a yellow fat pad additionally marks the distal end of the carpal tunnel, when the monoportal technique is applied. Incomplete release at the distal retinacular end indicates that the view was not good enough to recognize details, because complete transection can be nicely visualized in most instances. A dirty lens from fatty films or fluids might be the reason for a restricted, blurred view, if the scope is placed correctly within the carpal tunnel. In this case, the endoscope needs to be removed and cleaned. This requirement mainly applies to the monoportal techniques because the scope lens gliding in the slotted cannula of the biportal instrumentarium will be more protected.

CRUCIAL PROCEDURAL STEPS

For us, the best way to prevent complications with such a variety of hand morphology (eg, size of hands, thickness and rigidity of layers, subcutaneous fat at entry port, diameter of tendons and ease with which they can be shifted away from the forearm fascia) is to adhere to the same crucial steps in each case. In essence, these steps are as follows:

Identification of Landmarks on Skin Level

Their quick palpation leaves no doubt about the confines of the retinaculum, and defines the area that the endoscope should not leave (**Fig. 2**). It also allows for a good approximation of the distal end of the retinaculum.

The distal volar flexion crease crosses the proximal end of the scaphoid and pisiform bone and identifies the proximal edge of the flexor retinaculum. The pisiform bone is palpable on the far ulnar side distal to the flexor crease. Radial to it, the ulnar nerve and artery enter into the hand. The pisiform bone and hamate hook define Guyon's canal and thus the course of the ulnar nerve and artery. Consequently, the slit cannula or endoscope always has to pass on the radial side of the hamate hook, rather than blindly aiming toward a certain finger. The position of the hamate hook[37] can be variable in different hands but it is palpable. The ulnar nerve will pass on its ulnar side.

Fig. 2 illustrates where one can palpate the hook of hamate and trapezium bone on skin. These bony eminences mark the distal end of the retinaculum. Kaplan's cardinal line has been defined in various ways[38,39] but its overall clinical significance has been controversial. However, it can serve to raise the awareness of an area where the thenar motor branch will most likely be located.[40] In addition, staying proximal to Kaplan's line will definitely avoid the superficial palmar arterial arch. We trace Kaplan's line as an oblique from the apex of the interdigital fold between the thumb and index finger toward the ulnar side of the hand and the hamulus (hook of hamate).[37] The most frequent localizations of the thenar motor branch have been found within an obliquely oriented oval with vertical and horizontal diameters of 10 and 15 mm, respectively, ulnar and slightly proximal to the intersection of Kaplan's line and the middle finger radial side lines.[40] It is generally accepted to stay ulnar to the lifeline of the thumb (linea vitalis) to avoid injury to the thenar motor branch with open incisions for open carpal tunnel surgery and with the endoscopic technique.

Positioning

For us, it is essential to hyperextend the hand over a rolled towel placed under the wrist. The hyperextended hand position greatly eases the insertion, alignment, and manipulation of the instruments.[41]

Meticulous Proximal Port Dissection

Meticulous proximal port dissection enables secure identification of the forearm fascia, which can then be lifted away from the nerve to allow

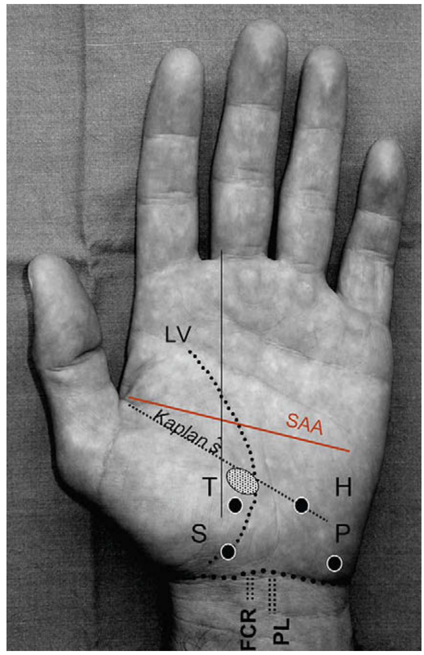

Fig. 2. Skin level landmarks for CTR. The flexor retinaculum inserts on the pisiform bone (P) on the ulnar side and the ridge of the scaphoid bone (S) on the radial side/thenar eminence. After about 2.5 cm, it will attach to the hook of hamate (H) on the ulnar side and on the trapezium (T) on the radial side. It converges from proximal to distal. The "loge de Guyon" (Guyon's canal), which contains the ulnar nerve and artery, runs between the hamate and pisiform bone. The flexor retinaculum, which is the roof of the carpal tunnel, builds the floor of the loge. A line through the hamulus and trapezium marks the distal end of the flexor retinaculum. Although Kaplan's cardinal line is inconsistently defined and cannot predict the thenar motor branch takeoff, it helps to define a corner roughly that is the distal end of an area, where this branch will be found with high likelihood (*stippled oval proximal to Kaplan's line and medial to intersection with straight elongation of radial side of middle finger*). Palmar incisions for open CTR are recommended ulnar to the hyperthenar lifeline (LV, linea vitalis), to avoid the thenar motor branch and a palmar cutaneous branch. The superficial arterial arc (SAA) is distal to Kaplan's on a line that runs from the first web space in a more horizontal direction. The distal flexor crease of the forearm (*dotted line*) marks the beginning of the flexor retinaculum. It helps incision planning for open CTR (distal to it) and endoscopic CTR (proximal to it). The courses of this subject's flexor carpi radialis (FCR) and palmaris longus tendons (PL) are marked out with dotted double contours.

for progressive dilator insertion (we use two sizes) and separation of the flexor synovium. We prefer to place this transverse incision in a skin fold slightly proximal to the distal flexor crease. It is thus easier to dislocate the flexor tendons on the radial aspect of the median nerve (flexor carpi radialis) and the more ulnar aspect (palmaris longus) away from the underlying nerve. It also allows for ample free room to navigate the instruments into the tunnel, as compared with a more distal incision, where the tendons are much more fixed in place because of the proximity of their respective insertion points.

Dissection and Dilation of Tunnel

To dissect the flexor synovium away from the median nerve, two conical dilators of progressive size are used. This procedure first creates and then widens a tunnel for the endoscopic instruments. At the same time, it supplies haptic information about the tightness of the canal. The correct plane should be reconfirmed by palpating with the smooth, broad dilator tip for the washboard texture of the retinaculum. The distal end of the retinaculum can also be felt in most instances.

Unrestrained View

It is paramount to maintain a good view, and thus to clean the optic lens whenever fatty films or liquids (local anesthetic) blur the vision. We prefer to clean the created tunnel with a rolled pointed swab to remove any fluid before insertion of the endoscope (eg, installed local anesthetic). At the same time, this procedure flattens any fat tissue remnant onto the canal wall. The endoscopic view should clearly allow identification of the retinaculum according to its color and transverse fiber orientation (**Fig. 3**A) and its distal end by emergence of a fat flap. Successful transection can be confirmed by the appearance of red muscle (**Fig. 3**B) or in very atrophied hands, subcutaneous palmar fascia (longitudinal fiber direction).

INCOMPLETE RELEASE

Two forms of incomplete release should be differentiated:

1. Failure to cut the distal portion of the retinaculum
2. Failure to transect the full thickness of the retinaculum

With the first form, the situation of the nerve will immediately be worsened because this form creates constriction and partial herniation of the nerve over the remaining edge, resulting in pronounced venous congestion and edema, which will create a vicious circle leading to more compression. With the second form, failure to transect, more space is created initially but in a triangular, cross-sectional shape. The retinaculum is left intact on the palmar surface and the full thickness will likely be reunified by fibrous proliferation exerting at least the same amount of compression as before. These patients typically complain that their symptoms never, or only initially, improved before they worsened again. On open revision, these cases logically appear as if the retinaculum has never been touched before because it was incompletely cut from the underside, leaving the surgeon's facing palmar upper side intact.

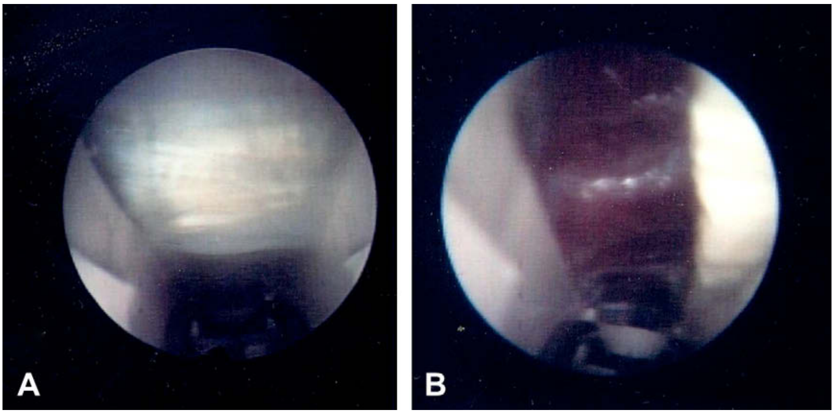

Fig. 3. Endoscopic view of carpal tunnel roof. (*A*) Before transection of the flexor retinaculum, its transverse fiber orientation can clearly be identified. (*B*) After complete flexor retinaculum transection, the overlying muscle can be seen. A view like this clearly rules out a "partial thickness" transection in the coronal plane and incomplete transection along the longitudinal axis of the endoscope.

In sharp contrast, acute new deficit and pain after CTR unequivocally delineates direct nerve injury and necessitates early open revision. Because grafting or at least an operating microscope frequently will be necessary, we prefer to do this type of reexploration under general anesthesia. Unimproved symptoms and later progression will more likely be associated with failure to transect the retinaculum, in which case a conventional reexploration with ligament transection under local anesthesia might be sufficient.

NECESSARY CONVERSION TO OPEN PROCEDURE

It is rare that a carpal tunnel will indeed be too tight to allow insertion of a slotted cannula or the combined endoscope and knife of a monoportal system. Still, every nerve surgeon applying the method will encounter situations where he or she quickly has to assess if the tunnel allows for insertion or not (eg, with a slightly different insertion angle, or another dilatation maneuver to free adhesions). It is natural that the prudent novice will thus have a higher conversion rate to open surgery. In fact, if not, the surgeon might risk complications. For the inexperienced surgeon, it is difficult to judge whether increased resistance, and maybe even sudden pain during trocar insertion, is the first sign of nerve damage or just an irritation of the nerve by the properly introduced trocar in a narrow carpal tunnel that is not fully anesthetized. It also depends on individual preferences for instillation of the local anesthetic (eg, local instillation versus plexus block). With progressive experience, conversions will actually be rare, but are still necessary at times. Our departmental conversion rate is likely between 0.5% and 2%. If the local anesthetic is injected properly, and a conventional carpal tunnel set is always in the room and thus can be opened without delay, one can easily proceed with an open procedure in the same setting. In consideration of this, the patient has given consent for this eventuality before surgery. The arm pressure cuff is usually tolerated continuously for 15 to 20 minutes without a problem. It is psychologically important to have this option readily available to avoid overriding reasonable decision making by stress and "pressure to perform" (with a patient who is awake). By hyperextension, the superficial palmar arch and the median and third common digital nerve are displaced in a dorsal and more distal direction.

SUMMARY

Endoscopic CTR is a good technique to lessen initial scar and wound pain, and to improve initial pinch and grip strength. However, it bears substantial risks for neurovascular injury. Respecting some basic anatomic and technical considerations can minimize the occurrence of adverse events. The cases of CTR-related neurovascular injuries we reexplored and repaired seemed related to inappropriate technique, rather than anatomic variations. We think that experience with median nerve exploration is an important factor to use this technique successfully.

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