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Original Research

Anatomic Variation of the Hamate Hook as a Potential Risk in Endoscopic Carpal Tunnel Release

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Purpose: The purpose of this study was to investigate the incidence of anomalies in patients who underwent endoscopic carpal tunnel release and their relationship with clinical outcomes.
Methods: This retrospective study included 65 hands of 57 patients (8 men and 49 women; mean age, 64.9 years) who underwent endoscopic carpal tunnel release for carpal tunnel syndrome at our hospital between March 2016 and April 2022. The patients were diagnosed with carpal tunnel syndrome based on clinical observations and electrophysiological studies. On T2-weighted magnetic resonance axial images, the height of the hook of the hamate was measured from the bottom to the tip of the hook, and the total height of the hamate was measured from the dorsal surface of the hamate to the tip of the hook. A hook-to-height ratio of less than 0.34 was defined as hypoplastic, and its incidence was investigated. In addition, electrodiagnostic testing of sensory and motor nerve conduction of the median nerve and patient-reported outcome measurements, including Quick Disabilities of the Arm, Shoulder and Hand score, Boston carpal tunnel questionnaire, and visual analog scale score, were investigated at 6 months after surgery. Adverse events were collected from patient records.
Results: The mean hook-to-height ratio was 0.40. Hypoplasia with a ratio $\leq$0.34 was observed in seven hands (10.8%), and adverse events were observed only in the two cases that had a hypoplastic hook of the hamate (3.07%). The patient-reported outcome measurements and the result of electrodiagnostic testing at 6 months after surgery did not correlate with the height of the hook of the hamate.
Conclusions: The incidence of a hypoplastic hook of the hamate is common in patients with carpal tunnel syndrome, and preoperative evaluation of the morphology of the hooks and indications for endoscopic carpal tunnel release in cases of hypoplastic hooks may help predict adverse events.
Type of study/level of evidence: Therapeutic IV.

The carpal tunnel, located within the concave arch of the carpal bones, is encapsulated by the transverse carpal ligament (TCL).[1] The TCL affixes to the pisiform bone and the hook of the hamate on the ulnar side and the scaphoid tuberosity and the crest of the trapezium on the radial side.[2] The hook of the hamate, a curvilinear bony structure emanating from the palmar surface of the body, carries clinical significance for hand surgeons due to its palpable presence on the palmar aspect and its use as a landmark for carpal tunnel release.[3,4]

The surgical management of carpal tunnel syndrome (CTS) primarily entails two procedures: open carpal tunnel release (OCTR) and endoscopic carpal tunnel release (ECTR). In ECTR particularly, the surgeon's field of view is indirect, rendering the strategic placement of skin incision crucial for a safe operation. Consequently, the identification of the hook of the hamate as a landmark on the ulnar side of the carpal tunnel has been highlighted by various authors.[5–7]

Numerous studies have documented variations in the hooks of the hamate (aplastic, hypoplastic, or bipartite).[8–13] A recent study on 2000 cadavers revealed a 3.5% incidence of variations in the hook of the hamate.[4] Furthermore, such variations in the hook of the hamate have been found to be more prevalent in patients diagnosed with CTS.[12,13]

Despite these findings, the influence of these variations on the surgical outcomes of ECTR has only been explored in a handful of

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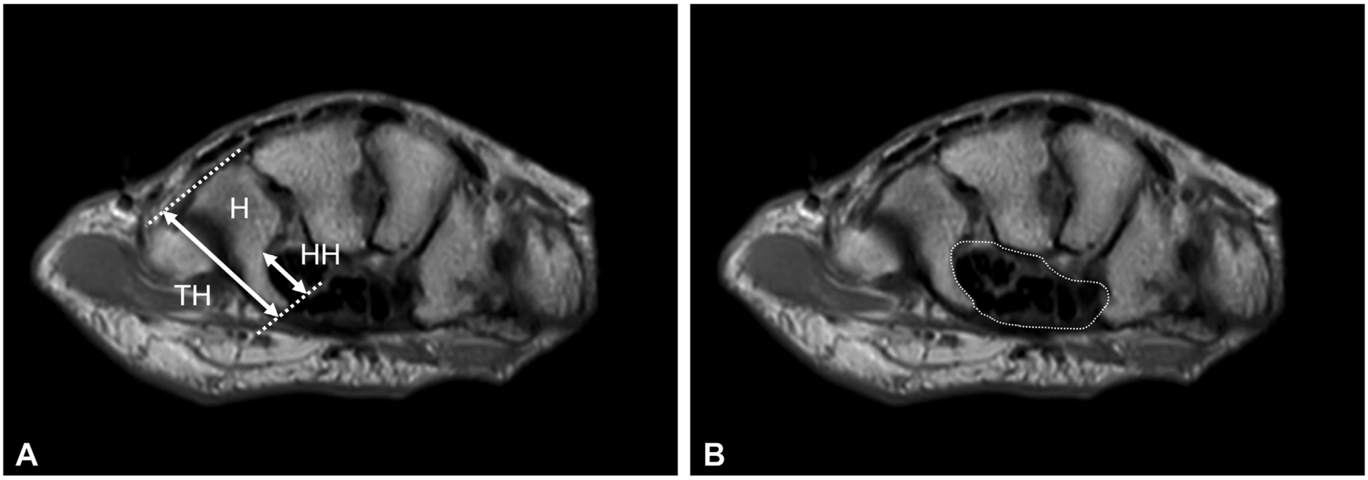

Figure 1. T2-weighted MRI in axial view at the carpal tunnel level. **A** Hamate bone (marked H), HH, and TH. **B** The CSA of the carpal tunnel demarcated by the dotted line.

studies.[13,14] Hence, the primary objective of this research was to ascertain the prevalence of hypoplastic hook of the hamate in CTS patients undergoing ECTR at our institution, along with a comprehensive evaluation of clinical outcomes and the detection of any associated adverse events.

Material and Methods

Participants

This retrospective study involved a cohort of patients who underwent ECTR for CTS between March 2016 and April 2022 at our institution. We included patients diagnosed with CTS who agreed to participate in the study and expressed a preference for undergoing ECTR as the initial carpal tunnel release. We excluded patients with severe CTS, where the compound muscle action potential of the median nerve could not be obtained; those undergoing dialysis; those with recurrent cases; those with a history of wrist surgery, mass lesion, or requiring simultaneous opponoplasty; nonconsenting participants; and those unable to undergo a follow-up of at least 6 months. Carpal tunnel release was performed in 186 hands in this period, and ECTR was performed in 71 hands. This study included 57 patients (8 men and 49 women, with an average age of 64.9 [±12.7] years with at least 6 months of follow-up; 65 hands) who underwent ECTR for CTS. Carpal tunnel syndrome diagnosis was based on clinical observations and electrophysiological examinations. Sensory nerve action potential and motor nerve conduction values of the median nerve were recorded immediately preceding and 6 months after surgery.

Additionally, at the level of the hook of the hamate, specific parameters were measured on axial T2-weighted magnetic resonance images. These parameters included the height of the hook of the hamate (HH), assessed from the base to the apex of the hook, and the total height of the hamate (TH), measured from the dorsal surface of the apex of the hamate (Fig. 1A). The hook-to-height ratio was calculated as the HH/TH ratio. The magnetic resonance imaging (MRI) slices were standardized with a thickness of 3 mm, and serial images were reviewed. The image representing the longest hook of the hamate was selected for analysis.

As previously described, a hamate with a ratio of below 0.34 was defined as the hypoplastic hook of the hamate, and the incidence of such occurrences was documented.[4] The cross-sectional area (CSA) of the carpal tunnel was also measured and demarcated by tracing the boundary between the carpal bones and the dorsal edge of the TCL (Fig. 1B). Three blinded authors (a specialist, a senior resident, and a junior resident) performed the MRI measurements of CSA, HH, and TH three times, and the average values were used for the analysis. The visual analog scale (VAS) was used to evaluate pain and numbness, both before and 6 months after surgery. Furthermore, Quick Disabilities of the Arm, Shoulder, and Hand (*Quick*DASH) scores and the Boston carpal tunnel questionnaire (BCTQ), consisting of the symptom severity scale (SSS) and the functional status scale (FSS), were evaluated likewise. Adverse events were defined as surgical site infection, nerve injury inclusive of transient neurapraxia, tendon injury, arterial arch injury, severe radiating pain during surgery, and pillar pain. A single specialist, using Chow's two-portal technique, performed all the surgeries.[7] Written informed consent was obtained from all participants before the surgery. Patient records served as the data source for this study, which received approval from and was conducted in accordance with the ethical board of our institution.

Statistical analysis

Data are presented as means along with their SD. The Mann-Whitney U test was used to compare the clinical outcomes before and after ECTR and compare the clinical outcomes in patients with and without a hypoplastic hook. Spearman's correlation coefficients facilitated the analysis of correlations between the HH or the HH/HT ratio, the carpal tunnel's CSA, postoperative nerve conduction velocity, VAS, *Quick*DASH, and the BCTQ FSS, and SSS. The correlation strength was categorized as follows[15]: very strong (absolute value, ≥0.8), strong (absolute value, 0.60–0.79), moderate (absolute value, 0.40–0.59), weak (absolute value, 0.20–0.39), and very weak (absolute value, 0.00–0.19). The incidence of complications was compared between cases with and without a hypoplastic hook using Fisher's exact test. Intrarater and interrater reliabilities of the MRI measurements were evaluated using intraclass correlation coefficients, with very good defined as 0.81–1.00, good as 0.61–0.80, moderate as 0.41–0.60, fair as 0.21–0.40, and poor as <0.20.[16] Statistical significance was defined as a *P* value of <.05. All analyses were conducted using R (version 4.2.1; R Foundation for Statistical Computing) and EZR software (Saitama Medical Center, Jichi Medical University).

Results

Hypoplastic hooks of the hamate, defined by a ratio of less than 0.34, were identified in seven hands (10.8%) (Fig. 2). All cases

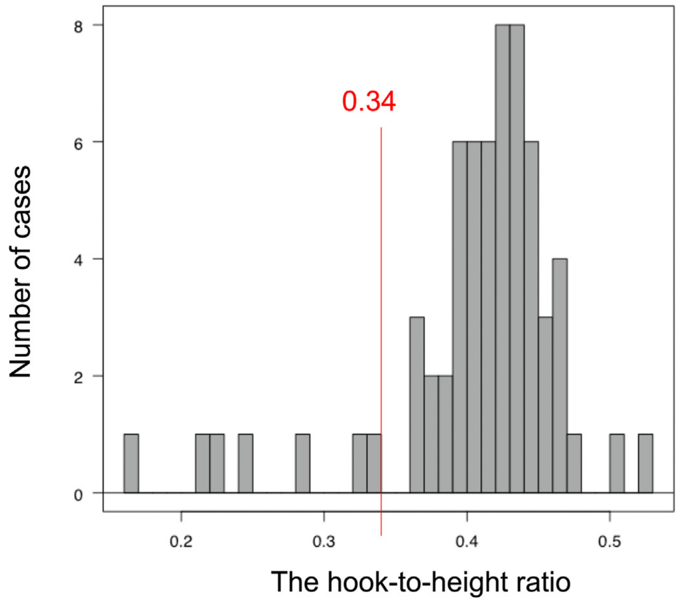

Figure 2. Histogram representing the occurrence rate of hypoplastic hook of the hamate, with a hook-to-height ratio of 10.8% observed in seven hands.

involved women. Table 1 shows the comparison between the outcomes before and after ECTR. The BCTQ, *Quick*DASH, and VAS values significantly improved 6 months after surgery when compared with that before surgery. However, the results of the electrodiagnostic testing did not show any significant changes except for the amplitude of compound muscle action potential. No significant difference was observed in the improvement of outcomes between the cases with a hypoplastic hook and the cases with a normal hook when comparing preoperative and postoperative results (Table 2).

Regarding anatomical parameters, the TH and HH were found to be 19.4 (±2.3) mm and 7.8 (±2.0) mm, respectively. The HH/HT ratio was 0.40 (±0.08), whereas the CSA of the carpal tunnel was measured to be 206.9 (±29.6) mm^2. The mean CSA values were 186.9 (±23.6) mm^2 in patients with hypoplastic hooks and 209.2 (±29.7) mm^2 for those with normal hooks, with a statistically significant difference observed ($P < .05$).

Notably, both the HH and the HH/HT ratio exhibited moderate-to-weak positive correlations with the carpal tunnel's CSA (Spearman's rank correlation coefficient, $r = 0.57$; $P < .01$; $r = 0.35$; $P < .01$, respectively) (Fig. 3). However, no significant correlations were observed between the results of electrodiagnostic testing, VAS, *Quick*DASH scores, BCTQ FSS, and SSS at 6 months after surgery and the HH or HH/HT ratio (Table 3).

Among the patients with a hypoplastic hook of the hamate, two adverse events were recorded: one patient experienced severe pain in the sensory area of the median nerve during trocar insertion, necessitating a switch to OCTR, whereas the other patient-reported postoperative numbness in the ulnar nerve sensory area. Both adverse symptoms were temporary and ameliorated with conservative treatment. No adverse events were observed in cases with a normal hook. The difference in complication rates between cases with and without a hypoplastic hook was statistically significant ($P < .05$). Table 4 shows good to very good intraclass correlation coefficient of both intrarater and interrater reliabilities for the MRI measurements.

Representative case

A 65-year-old woman, who reported experiencing numbness in the median nerve region, was diagnosed with CTS, as evidenced by a prolonged distal motor latency of 5.6 in the median nerve. A plain x-ray radiograph of the carpal tunnel revealed the presence of a hypoplastic hook of the hamate. An MRI confirmed this, displaying a hypoplastic HH/HT ratio of 0.21 (Fig. 4). During trocar insertion, the patient reported severe radiating to the median nerve sensory area, resulting in a transition to an OCTR. The patient reported strong numbness (rated 72 on a VAS) after surgery. However, after 4 months of conservative treatment, the numbness was entirely alleviated. The patient's *Quick*DASH score improved from 56.8 before surgery to 15.9 at 6 months after surgery, whereas BCTQ FSS and SSS scores improved from 2.1 and 1.8 before surgery to 1.0 and 1.0, respectively, at 6 months after surgery.

Table 1
Comparison Between Preoperative and Postoperative Outcomes*

Outcomes	Before Surgery	6 mo After Surgery
CMAP amp (mV)	5.33 (4.40)	8.29 (5.1)†
CMAP terminal latency (ms)	6.23 (2.33)	5.67 (1.54)
SNAP terminal latency (ms)	4.55 (3.21)	3.63 (1.70)
BCTQ FSS	2.73 (0.66)	1.34 (0.27)†
BCTQ-SSS	2.50 (1.1)	1.43 (0.50)†
*Quick*DASH	35.9 (24.4)	12.8 (10.3)†
VAS	45.2 (28.3)	9.7 (8.6)†

amp, amplitude; CMAP, compound muscle action potential; SNAP, sensory nerve action potential.
* Values are represented as mean (SD). Data were calculated using the Mann-Whitney U test.
† Significant difference between the preoperative and postoperative items at 6 months.

Discussion

Endoscopic carpal tunnel release boasts several advantages, including a more rapid return to work and fewer wound healing complications, as a result of its minimally invasive surgical approach.[17,18] Conversely, complications related to ECTR can encompass injuries to the arterial arch, digital nerve, and major nerves.[19] Although most nerve injuries constitute temporary neurapraxia, instances of median nerve transection have also been reported.[20,21]

The hook of the hamate serves as a critical landmark when performing an ECTR, acting as a practical reference for the ulnar protective boundary of the carpal tunnel.[22] Extant research has demonstrated variability in the hook of a hamate.[9,11–13] When the hook of the hamate is not palpable, accurate placement of the skin incision and correct trocar insertion direction are reportedly challenging.[13,14] Previous reports, however, have predominantly been confined to case studies or cross-sectional studies focused on intraoperative data collection. Consequently, the present study aims to assess the relationship between hypoplastic hook of the hamate and clinical outcomes at a 6-month postoperative follow-up. We found that postoperative clinical outcomes, including nerve conduction velocity and patient-reported outcome measurement scores (VAS, *Quick*DASH, BCTQ FSS, and SSS), did not correlate with HH and the HH/HT ratio in our study.

Of note, the only two patients who experienced an adverse event in this study had a hypoplastic hook of hamate. One adverse event was temporary ulnar nerve neurapraxia. The prevalence of ulnar nerve injury is reported to be very rare.[19,23] One reason for the low risk of injury to the ulnar vascular bundle in ECTR is considered to be the contribution of the hook, which blocks the migration of the device toward the ulnar side.[24] It has been noted that ulnar nerve injury in ECTR can occur not only due to unintentional insertion of the device into the Guyon canal but also when properly placed in the carpal tunnel with the interference of the device and

Table 2
Items Compared Between Hypoplastic and Normal Cases*

Variable	Cases With a Hypoplastic Hook	Cases With a Normal Hook	*P* Value
ΔCMAP amp	4.33 (3.3)	3.26 (1.2)	.18
ΔCMAP terminal latency	−2.20 (1.5)	−1.83 (2.1)	.20
ΔSNAP terminal latency	−0.83 (1.1)	−0.99 (1.2)	.33
ΔBCTQ FSS	−1.10 (0.9)	−1.42 (0.7)	.58
ΔBCTQ-SSS	−1.31 (0.5)	−1.13 (1.3)	.38
Δ*Quick*DASH	−19.1 (8.6)	−24.5 (12.4)	.19
ΔVAS	−30.1 (11.1)	−37.5 (13.8)	.29

amp, amplitude; CMAP, compound muscle action potential; SNAP, sensory nerve action potential.
* Values are represented as mean (SD). Data were calculated using the Mann-Whitney U test. The Δ symbol represents the difference between the postoperative and preoperative results.

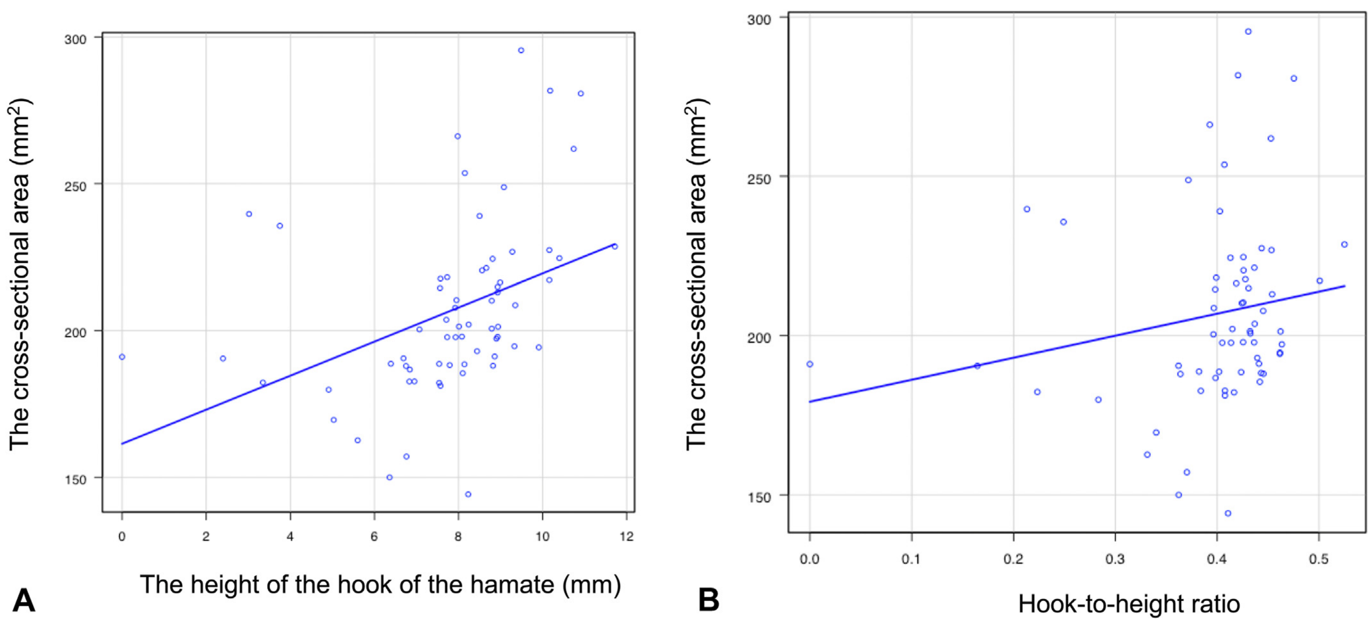

Figure 3. Correlation analyses between CSA and hamate bone measurements. **A** Relationship between CSA and HH (r = 0.57; *P* < .01). **B** Relationship between CSA and hook-to-height ratio (r = 0.35; *P* < .01).

Table 3
Correlations Between CSA or Postoperative Clinical Parameters and the Measurement Items*

Parameters	HH	HH/TH Ratio
CSA	0.57†	0.35†
CMAP amp (6 mo after surgery)	0.44	0.50
CMAP terminal latency (6 mo after surgery)	0.65	0.73
SNAP terminal latency (6 mo after surgery)	0.33	0.45
BCTQ-FSS (6 mo after surgery)	0.60	0.63
BCTQ-SSS (6 mo after surgery)	0.66	0.71
*Quick*DASH (6 mo after surgery)	0.45	0.51
VAS (6 mo after surgery)	0.59	0.46

amp, amplitude; CMAP, compound muscle action potential; SNAP, sensory nerve action potential.
* Data were calculated using Spearman's correlation tests.
† Correlation is significant at the 0.01 level.

Table 4
Intrarater and Interrater Reliability Assessments

Reliability	CSA	HH	HH/TH Ratio
Intrarater reliability (ICC [1.k])			
Specialist	0.88	0.76	0.80
Senior resident	0.90	0.79	0.73
Junior resident	0.83	0.80	0.82
Interrater reliability (ICC [2.k])	0.92	0.90	0.88

ICC, intraclass correlation coefficient.

ulnar nerve.[25–30] A cadaveric study reported that the ulnar neurovascular bundle is located within 7 mm ulnar to 2 mm radial of the hook of the hamate.[31] Although we were unable to confirm the course of the ulnar neurovascular bundle in our case, previous studies have reported that the structures may be located more radially than normal in cases with a hypoplastic hook.[12] Further research is needed on the geometry of the ulnar neurovascular bundle in cases with a hypoplastic hook. The other adverse event involved temporary neurapraxia of the median nerve in the representative case. This study showed that the CSA of the carpal tunnel is narrower in cases with a hypoplastic hook. This suggests that trocar insertion into a narrowed carpal tunnel may increase the risk of median nerve compression. A previous study pointed out that compressing or stretching the median nerve during insertion of the device into the carpal tunnel or increased pressure in the carpal tunnel while the wrist is attached to the hand holder may cause the median nerve injury that occurs during ECTR.[32] Notably, this complication occurred even when performed by experienced hand surgeons and should be considered with caution in their report. In all, surgeons should actively choose to switch to OCTR if the hook cannot be palpated or if resistance exists when inserting the instrument into the carpal tunnel.

Research indicates a higher prevalence of hook of the hamate variations in CTS patients, with an odds ratio 34 times higher than

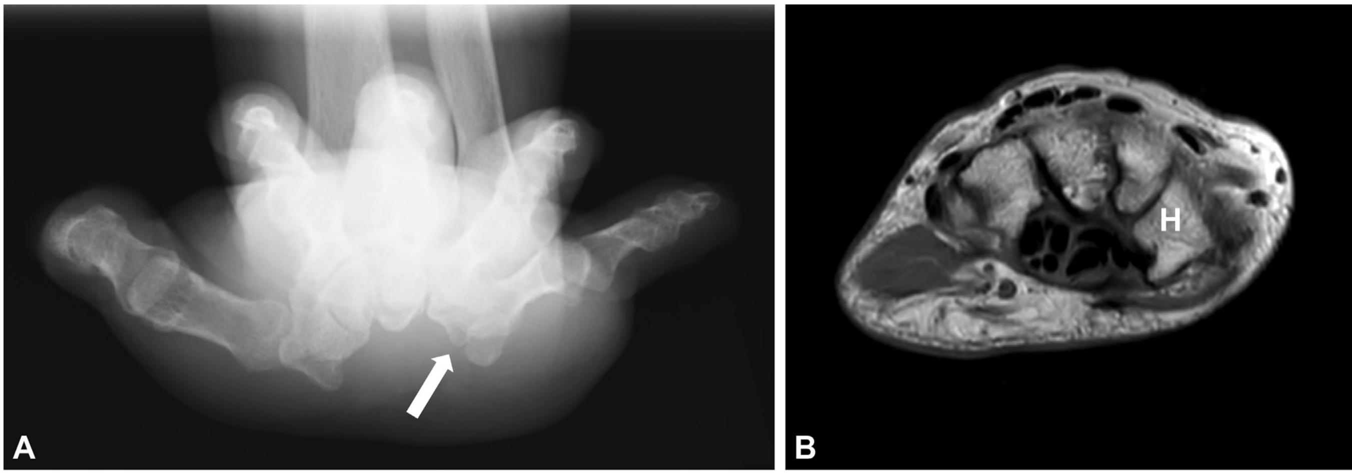

Figure 4. Comparative imaging of a representative case with a hook-to-height ratio of 0.21. **A** X-ray radiograph highlighting the hypoplastic hook of the hamate (indicated by white arrow). **B** MRI image with the same emphasis. H, hamate bone.

that in the general population.[13] A shorter hook is associated with a lower carpal tunnel ceiling because the TCL attaches to the hook of the hamate.[4] The hypoplastic hook of the hamate could affect the carpal tunnel volume and develop CTS.[12] This is consistent with our findings that the HH and the hook-to-height ratio correlated positively with the carpal tunnel's CSA. Huang et al[4] analyzed 2,000 cadaveric hamates focusing on variations in the hook of the hamate in the general population, and they reported that the prevalence of hypoplastic hook was 3.5%. Indeed, the prevalence of the hypoplastic hook of the hamate in our study was 10.8%, higher than that in their studies focusing on the general population. Furthermore, interestingly, they reported that the prevalence is more common in White women. Consistent with this, our findings also indicate that cases of hypoplastic hook are exclusive to women. However, it is important to note that our study was limited to a small sample of East Asian participants.

This study had several limitations. First, it was a single-institution study with a small sample size. However, we consider the comprehensive and accurate collection of all clinical data to be a significant strength. Second, we only registered a single specialist for surgery in this study, thereby invalidating any variations in techniques during surgery that may affect surgical results. Reports suggest that complication rates are comparable when a seasoned surgeon performs the procedure due to the steep learning curve associated with this procedure.[33] Our observed incidence of temporary neurapraxia (3.07%) is considered reliable, falling within the range of nerve injury reported in earlier ECTR studies (from 0% to 18.7%).[34–36] Observer error for MRI measurement might have occurred because the three blinded observers (M.O., M.I., K,S.) individually selected the MRI slice representing the longest hook at the carpal tunnel. However, both the interrater and intrarater reliabilities of the MRI measurement were considered excellent. Furthermore, although it is possible that true values exist between successive slices, the thickness of the slices in this study was unified to be as thin as 3 mm. Finally, this study was retrospective. Therefore, further randomized studies are required to ascertain whether a hypoplastic hook of the hamate is a risk factor for ECTR.

In conclusion, our findings align with those of previous reports, underscoring the importance of caution when performing ECTR on patients with variations in the hook of the hamate.[14] We exclusively observed adverse events in cases featuring a hypoplastic hook of the hamate. Thus, it may be beneficial to evaluate the morphology of the hook of the hamate before surgery and carefully consider the indications for ECTR in such cases.

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