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ORIGINAL RESEARCH

Electrodiagnostic, Sonographic, and Clinical Features of Carpal Tunnel Syndrome with Bifid Median Nerve

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Purpose: A bifid median nerve (BMN) is not a rare variant. This study aimed to investigate the features of carpal tunnel syndrome (CTS) accompanied by BMN.

Patients and Methods: In this retrospective study, we defined a BMN group as CTS with BMN and a non-bifid median nerve (NMN) group as CTS without BMN. All hands were assigned to four severity grades according to the findings of electrodiagnosis (EDx): very mild, mild, moderate, and severe. The cross-sectional area (CSA) of the median nerve, palmar bowing of the flexor retinaculum, and persistent median artery (PMA) were assessed by ultrasonography. Numerical pain rating scale (NRS) and symptom duration were assessed as clinical variables.

Results: Sixty-four hands (57 patients) and 442 hands (341 patients) were enrolled in the BMN and the NMN groups, respectively. BMN was prevalent in 12.6% of all CTS hands. The distribution of EDx severity grade was milder in the BMN group than in the NMN group ($P<0.001$). The CSA of the BMN group was 16.2±4.1 mm^2, slightly larger than 15.1±4.2 mm^2 in the NMN group ($P=0.056$). The BMN group showed higher NRS than the NMN group (5.5±1.5 and 4.4±1.7, respectively; $P<0.001$). In the subgroup analysis, NRS was significantly higher in the BMN group than in the NMN group at all EDx severity grades. In the BMN group, the PMA group showed greater EDx severity ($P=0.037$) and higher NRS (6.0 and 5.0, respectively; $P=0.012$) than the non-PMA group. The radial side branch's CSA was larger than that of the ulnar side branch (10.0 mm^2 and 6.0 mm^2, respectively; $P<0.001$).

Conclusion: CTS with BMN presented more severe symptoms and relatively milder EDx severity. When assessing the severity of CTS with BMN, the clinical symptoms should primarily be considered, as well as we should complementarily evaluate the EDx and ultrasonography.

Keywords: carpal tunnel syndrome, bifid median nerve, electrodiagnosis, diagnostic ultrasound, pain measurement

Introduction

Carpal tunnel syndrome (CTS) is one of the most common entrapment neuropathies.[1] Its diagnosis is generally based on the patient's clinical history, electrodiagnosis (EDx), and ultrasonography (US).[2] In particular, EDx has been employed as a key diagnostic tool for CTS because it can objectively confirm CTS and identify disease severity.[3–5] US can identify structural changes of the carpal tunnel and the median nerve passing through it. Unlike EDx, it is non-invasive and, as an advantage, does not cause discomfort to the patient, making it a major diagnostic tool in patients with CTS.[6]

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A bifid median nerve (BMN) is an anatomic variation described by Lanz[7] in 1977. Following the introduction of imaging techniques such as US and magnetic resonance imaging (MRI) for CTS diagnosis, the frequency of identifying cases with BMN has increased. Previous studies have reported that BMN was detected by US in 8%−20% of patients with CTS.[8,9] This is much higher than the percentage reported by surgical exploration studies (3%), which were conducted before imaging techniques were being fully utilized.[7,10] BMN has also been found in 9% −15% of healthy adults. Studies have differed in the assessment of whether BMN acts as a risk factor for CTS.[9,11]

Even though BMN is not a rare variation, previous studies have focused on reporting radiological and anatomical features and prevalence.[12–14] Few studies have examined the clinical features and EDx findings of CTS with BMN.[15] Thus, this study aimed to comprehensively investigate the electrodiagnostic, ultrasonographic, and clinical features of CTS with BMN. We subsequently identified the characteristics of CTS accompanied by BMN and conducted a comparative analysis between CTS patients with and without BMN.

Patients and Methods

Patient Inclusion and Clinical Assessments

This study was reviewed and approved by the Institutional Review Board of Pohang Stroke and Spine Hospital (approval no. PSSH0475-202101-HR-001-01). Informed consent was waived given the retrospective nature of the study. The Pohang Stroke and Spine Hospital's medical information department provided the researcher with the dataset necessary for this study while removing the medical records that had personal information before being provided for the study. The dataset was managed by the research director and stored in a password-protected database. Access to the database was restricted to the authorized researcher. Patient confidentiality was thus guaranteed. This study was conducted in compliance with both the Declaration of Helsinki and the International Conference on Harmonization-Good Clinical Practice Guideline.

Patients diagnosed with CTS by EDx from January 2016 to June 2020 at a single hospital were included. CTS hands were divided into two groups based on the presence of BMN identified through US: those with BMN were allocated to the BMN group, and those without a median nerve variant were placed in the non-bifid median nerve (NMN) group.

Exclusion criteria were as follows: central nervous lesion; lower cervical radiculopathy; other peripheral nerve lesions; peripheral vascular disease; arthritis or other musculoskeletal diseases of the hand and wrist; previous surgery on the wrist or hand; pregnant women; and systemic diseases such as tumors, thyroid diseases, fibromyalgia, and diabetes mellitus.

The patient's subjective numerical pain rating scale (NRS) and symptom duration (SD) were measured before the EDx. The NRS is a unidimensional measure of pain intensity; it is an 11-point numeric scale which ranges from 0 to 10, where 0 represents no pain and 10 represents the worst pain imaginable.[16] Meanwhile, we defined SD as the time that elapsed from when the patient first experienced symptoms to the time of EDx. Further, we confirmed whether decompression surgery was decided within 6 months after EDx confirmed CTS. Currently, decompression surgery for CTS is decided upon at our hospital in the following cases: 1) in the presence of either atrophy or weakness of the thenar muscles or 2) when CTS has been categorized as moderate or greater severity by EDx, and when, despite conservative care for three months, intractable pain persists.[17,18] The flow chart of this study is shown in Figure 1.

Electrodiagnostic and Sonographic Evaluations

All EDx were performed using Sierra®wave (Cadwell, Kennewick, WA, USA). The temperature in the examination room was maintained at 23−25°C. All tests were conducted with the patient in the supine position.

For the measurement of the median compound motor nerve action potential (CMAP), the recording electrodes were positioned at the abductor pollicis brevis muscle. Then, stimulation was applied at the 8-cm mark. The following instances were defined as abnormal: onset latency >4.0 ms, or amplitude <5 mV. The recording electrodes were placed on the second digit to measure the median sensory nerve action potential (SNAP); stimulation was applied at the 14-cm mark. Abnormal scope was defined as follows: onset latency >3.5 ms, or amplitude <20 μV. To test for transcarpal latency (TCL), additional testing was conducted at the 7-cm mark from the SNAP recording site. An abnormal scope was defined as ≥1.7 ms. As sensitivity tests, the lumbrical-interossei

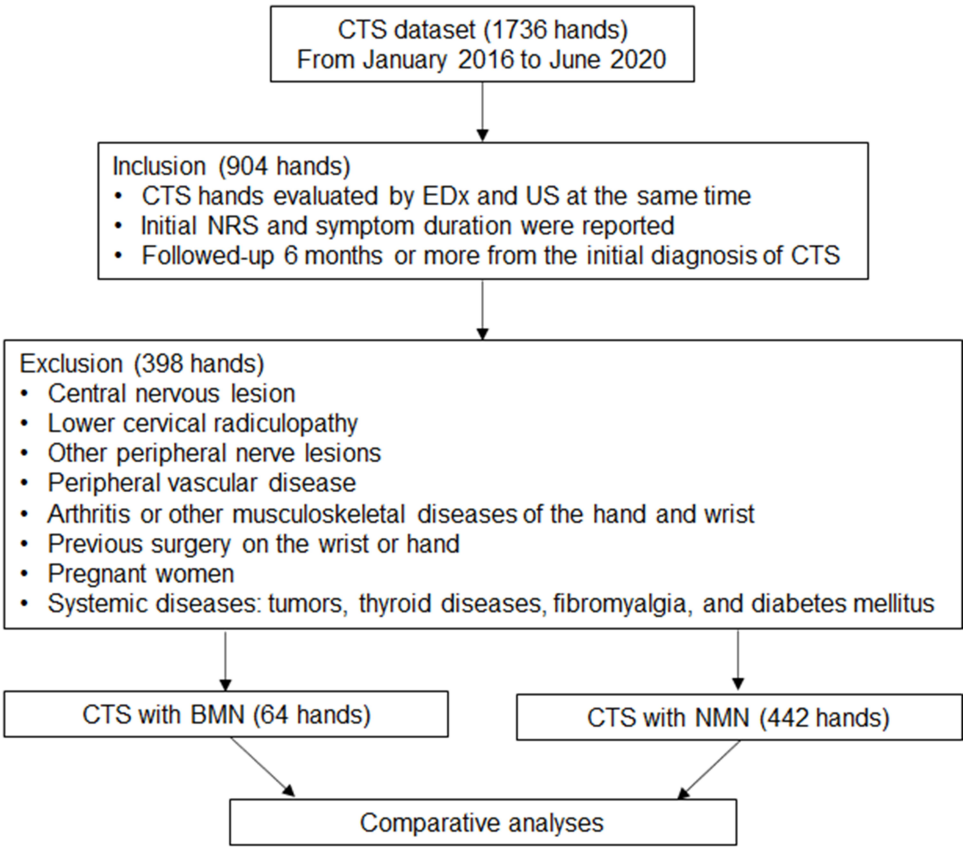

Figure 1 Flow chart of this study.
Abbreviations: CTS, carpal tunnel syndrome; EDx, electrodiagnosis; US, ultrasonography; BMN, bifid median nerve; NMN, non-bifid median nerve.

comparison study and the ring finger study were carried out. For the lumbrical-interossei comparison study, an active recording electrode was placed at the midpoint of the third metacarpal bone and a reference recording electrode at the second proximal interphalangeal joint. Then, the median nerve and ulnar nerve of the wrist were stimulated individually. When the onset latency between two recordings was >0.4 ms, such instances were defined as abnormal. We recorded at the fourth digit for the ring finger study, where we individually stimulated the median nerve and the ulnar nerve at the 14-cm mark. An onset latency between two recordings of ≥0.6 ms was defined as abnormal.[19] To exclude possible differential diagnoses, nerve conduction studies were performed on not only the median nerve but also the ulnar and radial nerves.

Moreover, needle electromyography (EMG) was performed on the muscles corresponding to each cervical root level. The muscles primarily evaluated in the upper extremity are as follows: deltoid, biceps brachii, flexor carpi radialis, triceps brachii, extensor digitorum communis, first dorsal interosseus, and abductor pollicis brevis. Then, if needed, additional EMG evaluation was performed on other related muscles. The following were defined as positive findings on needle EMG: 1) when increased insertional activity or denervation potentials were seen in the resting state or 2) when polyphasic, long duration, and large amplitude motor unit action potential was seen during volition.[19]

CTS severity was graded based on the EDx results, modifying the classification introduced by Stevens.[4] CTS severity was assigned with four grades: very mild, mild, moderate, and severe. The very mild (S1) group was composed of patients with no abnormalities in the routine SNAP and CMAP, who showed abnormal findings in either the TCL or sensitivity tests. The mild (S2) group was composed of patients with either delayed TCL or abnormal findings in the sensitivity tests, and abnormal findings in onset latency or amplitude of the median SNAP. For the moderate (S3) group, included patients had the following conditions: 1) delay in TCL or abnormal findings in sensitivity tests, 2) abnormal findings in CMAP, and 3) negative findings in needle EMG. Finally, patients with the following conditions

were assigned to the severe (S4) group: 1) abnormal findings in either SNAP or CMAP and 2) those who showed positive findings in the needle EMG.

US evaluations were performed using iU22 (Philips, Bothell, WA, USA). A linear 12–5 MHz probe was used. All patients underwent US immediately after the EDx. For US, patients were instructed to sit upright and to flex their elbows to 90° while their wrists were supinated and in a neutral position. We visualized the pisiform and scaphoid directly proximal to the carpal tunnel level and obtained transverse images. Afterwards, we measured the cross-sectional area (CSA) of the median nerve.[20] For the BMN group, we measured the CSA of both the ulnar and radial side branches and defined the sum as the CSA of the BMN group (Figure 2).[21] Subsequently, we visualized the trapezium and the hook of the hamate at the distal carpal tunnel level and measured the palmar bowing (PB) of the flexor retinaculum (Figure 3).[22] For the BMN group, we identified the presence of the persistent median artery (PMA) that passes through the two median branches (Figure 4).

The experienced physiatrist team of our hospital interpreted the EDx and US findings; D Park, BH Kim, and S-E Lee have had 11, 14, and 18 years of experience, respectively, in EDx and US on entrapment neuropathies.

Statistical Analysis

Categorical variables were expressed as frequency and proportion. They were analyzed using the Chi-squared test, Fisher exact test, or Cochran-Armitage test for trends.

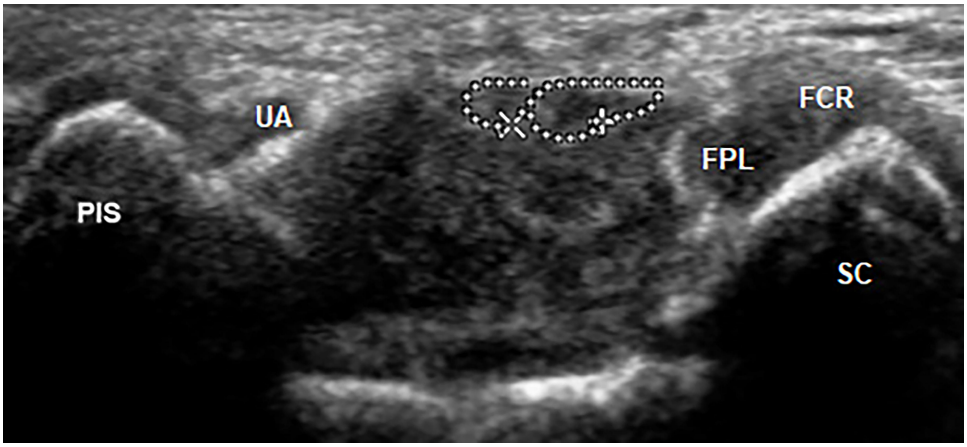

Figure 2 CSA measurement of the bifid median nerve at the scaphoid and pisiform level. After detecting the scaphoid and pisiform bones, the CSA measurement (dotted lines) is carried out at the proximal carpal tunnel level.
Abbreviations: CSA, cross-sectional area; UA, ulnar artery; FCR, flexor carpi radialis; FPL, flexor pollicis longus; PIS, pisiform bone; SC, scaphoid bone.

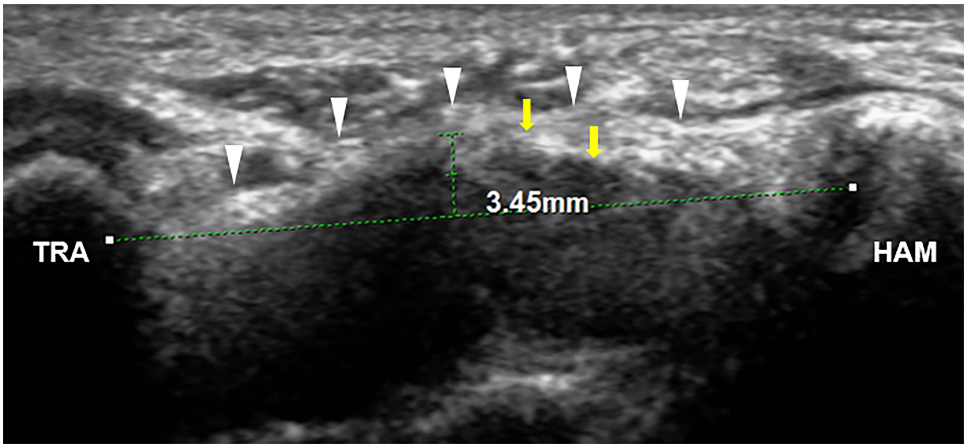

Figure 3 Measurement of flexor retinaculum bowing (arrow heads). After drawing a line connecting the hook of the hamate and tubercle of the trapezium where the flexor retinaculum is attached (transverse dotted line), the distance from the line to the top of the flexor retinaculum is measured (vertical dotted line). The radial and ulnar sides branch of the bifid median nerve (arrows) passes beneath the flexor retinaculum.
Abbreviations: TRA, trapezium; HAM, hamate.

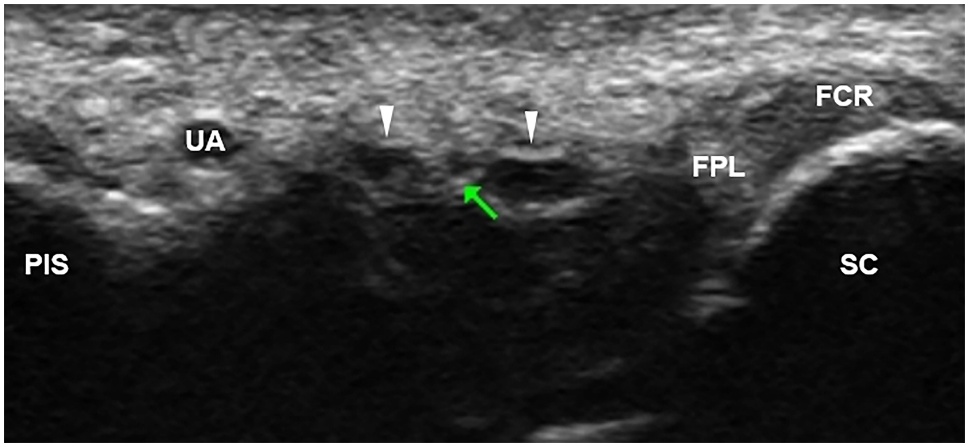

Figure 4 Identification of the persistent median artery (arrow) between the radial and ulnar sides branch of the bifid median nerve (arrow heads) by ultrasonography.
Abbreviations: UA, ulnar artery; FCR, flexor carpi radialis; FPL, flexor pollicis longus; PIS, pisiform bone; SC, scaphoid bone.

For continuous variables, the Shapiro–Wilk test was performed to verify normality when the number of samples was less than 50. Parametric data were expressed as mean ± standard deviation. Non-parametric data were expressed as median (interquartile range [IQR]). Two-sample *t*-test was used for parametric tests, and Wilcoxon rank-sum test with continuity correction was used for nonparametric tests. Wilcoxon signed-rank test was used for the CSA comparison between the radial and ulnar side branches of BMN. Statistical significance was confirmed as *P*-value<0.05. All statistical analyses were performed using R software version 4.0.4 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline Characteristics

A total of 64 hands from 57 patients were included in the BMN group; 442 hands from 341 patients were enrolled in the NMN group. BMN prevalence in all CTS hands was 12.6%. The average age of the BMN group was 57.1±11.5 years, 45.6% were male, and 51.6% were right hands. The average age of the NMN group was 58.7±10.6 years, 33.7% were male, and 50.7% were right hands. No significant differences were found between the two groups in terms of age, sex, or involved side (Table 1).

Electrodiagnostic, Sonographic, and Clinical Features

Table 2 presents a summary of the examined parameters between the BMN group and NMN group.

The unrecordable rates of SNAP and CMAP were not significantly different between the groups (P = 0.294 and P>0.999, respectively). The BMN group had significantly shorter onset latency and TCL than the NMN group (P<0.001 and P=0.001, respectively). The BMN group also showed larger SNAP amplitude than the NMN group; however, the difference was not significant (P=0.247). For the CMAP comparison between the two groups, the BMN group showed significantly shorter onset latency and larger amplitude than the NMN group (P<0.001 and P=0.041, respectively). The two groups displayed significant differences in EDx severity distribution (P<0.001). S4 was most prevalent in the NMN group, accounting for 33.7%, followed by S1 (30.6%). Meanwhile, S1 was dominant in the BMN group with 54.7%; S2, S3, and S4 showed similar distribution levels.

US findings revealed the CSA of the BMN group to be 16.2±4.1 mm^2, slightly larger than that of 15.1±4.2 mm^2 in the NMN group. The BMN group's PB was 2.5±1.1 mm and slightly smaller than the NMN group's 2.6±2.6 mm. However, those differences were not significant (P=0.056 and P=0.413, respectively).

Table 1 Baseline Characteristic of Patients

Variables	NMN Group	BMN Group	*P*-value
Patients, n	341	57	
Age (year), mean±SD	58.7±10.6	57.1±11.5	0.297
Male, n (%)	115 (33.7)	26 (45.6)	0.112
Hands, n	442	64	
Right side, n (%)	224 (50.7)	33 (51.6)	>0.999

Abbreviations: NMN, non-bifid median nerve; BMN, bifid median nerve; SD, standard deviation.

Table 2 Electrodiagnostic, Sonographic, and Clinical Features of Each Group

Variables	NMN Group	BMN Group	*P*-value
Unrecordable SNAP, n (%)	34 (7.7)	2 (3.1)	0.294
Unrecordable CMAP, n (%)	9 (2.0)	1 (1.6)	>0.999
SNAP (n=408:62)			
Onset Latency (ms)	3.5±0.7	3.1±0.5	<0.001
Amplitude (μV)	22.5±21.6	24.5±10.6	0.247
TCL (ms)	2.2±0.6	2.0±0.3	0.001
CMAP (n=433:63)			
Onset Latency (ms)	4.3±1.3	3.9±0.7	<0.001
Amplitude (mV)	7.4±2.5	8.0±2.3	0.041
Severity, n (%)			<0.001
S1	135 (30.6)	35 (54.7)	
S2	58 (13.1)	8 (12.5)	
S3	100 (22.6)	11 (17.2)	
S4	149 (33.7)	10 (15.6)	
CSA, mm^2	15.1±4.2	16.2±4.1	0.056
PB, mm	2.6±2.6	2.5±1.1	0.413
NRS	4.4±1.7	5.5±1.5	<0.001
SD, months	7.7±8.4	9.6±11.0	0.177
Decision of OP, n (%)	104 (23.5)	18 (28.1)	0.518
OP in S3, n (%)	5 (4.8)	8 (44.4)	<0.001
OP in S4, n (%)	99 (95.2)	10 (55.6)	

Note: All continuous values are expressed as mean±standard deviation.
Abbreviations: NMN, non-bifid median nerve; BMN, bifid median nerve; SNAP, sensory nerve action potential; CMAP, compound motor nerve action potential; TCL, transcarpal latency; CSA, cross-sectional area; PB, palmar bowing; NRS, numerical pain rating scale; SD, symptom duration; OP, operation.

The BMN group scored significantly higher NRS than the NMN group (5.5±1.5 and 4.4±1.7, respectively; *P*<0.001). The BMN group's SD was 9.6±11.0 months, which is slightly longer than the NMN group's 7.7±8.4 months (*P*=0.177). In the BMN group, a total of 18 (28.1%) hands were selected for surgical treatment within 6 months; of those, eight (44.4%) hands were S3 and 10 (55.6%) hands were S4. Conversely, in the NMN group, 104 (23.5%) hands were selected for surgical treatment within 6 months; 5 (4.8%) hands were S3 and 99 (95.2%) hands were S4. No significant difference was found between the two groups in terms of the decision ratio for surgical treatment (*P*=0.518); however, there was a significant difference between the two groups in terms of severity grade distribution in hands with surgical decision (*P*<0.001).

Subgroup Analysis Based on Electrodiagnostic Severity Grades

US features revealed that the BMN group had a larger CSA than the NMN group in S1, S2, and S3. Significance could only be confirmed for S1 and S3 (*P*=0.001, and *P*=0.010, respectively). The BMN group's PB was higher in S1, S2, and S4; however, the differences in PB between the two groups were not significant in all severity grades. Regarding NRS, the BMN group showed significantly higher points in all EDx severity grades (*P*<0.001, *P*=0.002, *P*<0.001, and *P*=0.010; S1−4, respectively). The BMN group also showed longer SD than the NMN group in all severity grades; however, significance was only identified in S1 and S4 (*P*=0.037 and *P*=0.034, respectively) (Table 3).

Additional Features in CTS with BMN

PMA was observed in 39 hands among all CTS hands (7.7%). Of the CTS hands with BMN, 60.9% presented PMA. The PMA group was significantly older than the non-PMA group (*P*=0.049). The PMA group showed a higher EDx severity grade distribution than the non-PMA group (*P*=0.037). The NRS of the PMA group was significantly higher than that of the non-PMA group (*P*=0.012). The proportion for selection for decompression surgery within 6 months was 15 (38.5%) hands in the PMA group, compared with 3 (12.0%) hands in the non-PMA group (*P*=0.044). In terms of sex, CSA, PB, and SD, we did not find any significant difference between the two groups (Table 4). The CSA of the radial side branch was 10.0 mm^2 (IQR, 7.1−12.8) and that of the ulnar side branch group was 6.0 mm^2 (IQR, 4.0−7.8) (*P*<0.001) (Figure 5).

Discussion

In this study, we presented electrodiagnostic, sonographic, and clinical features of CTS with BMN, not a rare variant among entire CTS hands. As most previous studies only focused on morphological features and its prevalence, the fact that we focused on CTS with BMN in diverse ways is a strength of our study. From this, we provided the results that physicians and surgeons could practically apply to assess the severity of CTS with BMN. Further, to the best of our knowledge, our study enrolled the largest number of CTS hands with BMN among related studies published thus far.

Our study's most noticeable result was that the measured EDx severity grade was relatively mild compared

Table 3 Subgroup Analysis of Sonographic and Clinical Parameters According to the Electrodiagnostic Severity Grades

Variable	Group	Severity Grade			
		S1	S2	S3	S4
CSA, mm^2	NMN	13.0 (11.0–15.0)	13.0 (12.0–14.0)	14.0 (13.0–16.5)	17.0 (15.0–20.0)
	BMN	15.0 (12.5–18.0)	15.5 (12.5–20.0)	17.0 (15.5–20.0)	17.0 (16.0–20.0)
	P-value	0.001	0.063	0.010	0.989
PB, mm	NMN	1.9 (1.4–2.5)	1.8 (1.4–2.6)	2.3 (1.7–3.0)	2.8 (2.2–3.6)
	BMN	2.0 (1.6–3.0)	2.0 (1.4–2.8)	2.3 (1.8–2.8)	3.0 (1.9–3.7)
	P-value	0.313	0.867	0.847	0.929
NRS	NMN	3.0 (2.0–4.0)	3.0 (3.0–4.0)	5.0 (3.0–5.0)	5.0 (5.0–7.0)
	BMN	5.0 (4.0–5.5)	5.0 (5.0–5.0)	7.0 (6.0–7.0)	7.0 (6.0–8.0)
	P-value	<0.001	0.002	<0.001	0.010
SD, months	NMN	2.0 (1.0–4.0)	3.0 (1.0–4.0)	4.0 (2.0–9.0)	12.0 (6.0–15.0)
	BMN	3.0 (2.0–5.0)	8.0 (2.5–18.0)	10.0 (5.5–12.0)	19.0 (12.0–36.0)
	P-value	0.037	0.061	0.059	0.034

Note: All continuous values are expressed as median (interquartile range).
Abbreviations: CSA, cross-sectional area; PB, palmar bowing; NRS, numerical pain rating scale; SD, symptom duration; NMN, non-bifid median nerve; BMN, bifid median nerve.

Table 4 Characteristics of Carpal Tunnel Syndrome with Bifid Median Nerve According to the Presence of Persistent Median Artery

Variables	Non-PMA	PMA	*P*-value
Patients, n	23	34	
Age, year[a]	53.5±11.3	59.6±11.1	0.049
Sex, male (%)	14 (60.9)	12 (35.3)	0.103
Hands, n	25	39	
Side, right	14 (56.0)	19 (48.7)	0.755
Severity, n (%)			0.037
S1	18 (72.0)	17 (43.6)	
S2	3 (12.0)	5 (12.8)	
S3	1 (4.0)	10 (25.6)	
S4	3 (12.0)	7 (17.9)	
CSA, mm^{2a}	17.3±4.4	15.5±3.8	0.091
PB, mm[b]	2.1 (1.5–3.3)	2.1 (1.8–3.0)	0.620
NRS[b]	5.0 (4.0–6.0)	6.0 (5.0–7.0)	0.012
SD, months[b]	5.0 (2.0–10.0)	6.0 (2.5–12.0)	0.365
Decision of OP, n (%)	3 (12.0)	15 (38.5)	0.044

Notes: [a]mean±standard deviation, [b]median (interquartile range).
Abbreviations: PMA, persistent median artery; CSA, cross-sectional area; PB, palmar bowing; NRS, numerical pain rating scale; SD, symptom duration; OP, operation.

with the symptom severity expressed by the patients in the BMN group. This suggests that, even if one of the two branches in CTS with BMN causes clinical symptoms due to compression, the other branch is relatively spared, which may be reflected in the EDx result.[8,15] In our

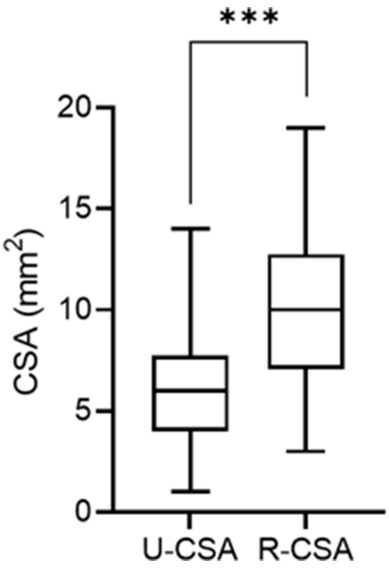

Figure 5 Comparison of CSA between the radial and ulnar side branches of the median nerve. The radial branch shows a significantly larger CSA than the ulnar branch. ***Means *P*-value <0.001.
Abbreviations: CSA, cross-sectional area; U-CSA, cross-sectional area of the ulnar side branch; R-CSA, cross-sectional area of the radial side branch.

results, the EDx findings of the BMN group were far milder than those of the NMN group. Even when the subgroup analysis was conducted after grouping by the same EDx severity grade, the BMN group showed a higher NRS and longer SD than the NMN group. This was not only true for patients in the very mild EDx group but also for those in higher severity groups. In other words, this suggests that patients with CTS with BMN have higher pain intensity and longer periods of disease than those without BMN at the time the disease is confirmed by EDx. This also infers that, if EDx is solely relied upon for CTS diagnosis, patients with BMN may be misdiagnosed with normal findings or their disease severity may be underrated.[21]

Kasius et al[15] reported similar results to ours. In their study, the mean CMAP latency was significantly slower and the SNAP unrecordable rate was significantly higher in the NMN group than in the BMN group; however, they did not find any difference in symptom severity between the two groups. These results differed from ours because our BMN group had significantly higher NRS than the NMN group. This difference was most likely because Kasius et al used clinical symptoms for their CTS inclusion criteria. Because of such criteria, there was a high possibility that they enrolled more patients with relatively severe symptoms in the NMN group. By contrast, our study targeted CTS patients diagnosed with EDx. Therefore, we inferred that, in the NMN group, some patients with subclinical symptoms were also detected with EDx as having CTS.

In our hospital, like in many other studies, the decision for decompression surgery of the carpal tunnel is largely based on EDx findings.[23–25] Our results showed that most patients who were decided to undergo surgery in the NMN group were S4 upon EDx. Contrastingly, only about half of the BMN group were S4 upon EDx. The ratio of needing surgery exceeded 40%, even for S3 patients. Such results suggest that surgeons primarily base their surgical decision upon EDx findings for patients in the NMN group. By contrast, since EDx severity might be underestimated for the BMN group, clinical symptoms could more readily affect decision making. Further, for S3 patients, we could infer that the proportion of patients responding to conservative treatment was lower in the BMN group than in the NMN group. We also speculate that this phenomenon might be associated with longer SD in the BMN group.

We defined the decision for decompressive surgery, not the patient who underwent the surgery, as the endpoint. This considers the fact that compliance may vary depending on the patient, even if the surgeon decides to perform the surgery. The surgeon's decision is made on an objective basis; however, the patient's compliance with that decision can be greatly influenced by the threshold for pain, resistance to surgery, or occupational and social environment. Therefore, the ratio of surgery taking place may be lower than the ratio of the decision made for surgery. Given this difference, we believed the number of decisions for surgery was a more objective outcome variable than the number of surgeries performed.

Although no significance was found, US findings showed that the overall CSA was slightly larger in the BMN group. Bayrak et al[9] presented CSA cutoff values for CTS diagnosis as follows: 10 mm^2 for the NMN group and 11 mm^2 for the BMN group. This minor difference corresponds to our results. In the subgroup analyses, the CSA value of the BMN group was significantly larger for very mild and moderate severity. Meanwhile, the median CSA of both groups was the same for hands with the highest severity grade. We speculate that this may be because of our measurement methodology. For the BMN group, we measured each branch separately and then added the values to determine the final CSA. Thus, as the severity increased, there was a possibility that CSA was underestimated.[26] Our results also showed that changes in the CSA of the median nerve according to disease severity were more evident in the NMN group than in the BMN group. Therefore, although US is a good evaluation tool to confirm the presence of BMN, there are limitations to interpretation according to disease severity when BMN is involved. Particularly, in the highest severity group, the possibility for underestimation is high.

Based on our findings, we suggest that various evaluations–EDx, US, and clinical findings–must be considered comprehensively and in a complementary fashion to determine the disease severity and corresponding treatment plans for CTS patients. Physicians and surgeons should be reminded that, if the morphologic study is overlooked when CTS is diagnosed, disease severity may be underestimated in patients with BMN, and this underestimation may exceed 10%.[11,27] Thus, when determining disease severity, EDx, US findings, as well as the patient's subjective pain level and duration of clinical symptoms, should all be considered.

When examining patients suspected of peripheral nerve diseases, our hospital conducts EDx and US evaluations in the same room; EDx is conducted first, followed immediately by US. Such a system can detect many morphologic variants and has the advantage of being able to interpret EDx and US findings complementarily. US has advantages compared with MRI, because it is easy for the examiner to perform, can be completed within a short time, and patient discomfort is minimized. Conversely, this system is also the basis of our thinking that our CTS with BMN prevalence is highly accurate, because we were able to perform US evaluations on all hands that belong to the CTS criteria following EDx. In our study, the proportion of CTS accompanied by BMN was 12.6% of all CTS, similar to previous studies.[8,28]

Another US feature of CTS with BMN is PMA. In our study, the PMA prevalence was similar to the prevalence, ie, 3.7%−10%, suggested in previous studies.[12,29] In addition, our results suggest that EDx severity is higher when BMN is accompanied by PMA. In such cases, NRS is also higher, resulting in a higher ratio of patients who are decided to undergo surgery. This means that PMA may be a causative factor in median nerve irritation.[30,31] Therefore, upon examining BMN by US, physicians should consider the possibility of a vascular anomaly accompanying relatively high disease severity. However, since the average age of the PMA group was significantly higher than that of the non-PMA group, caution is needed in the interpretation. Meanwhile, among both branches of the bifid nerve, the CSA of the radial side branch was larger than that of the ulnar side. This is consistent with previous studies showing that the CSA of the radial side branch is larger.[9,12] However, the mechanism by which the radial side branch has a larger CSA and which branch has more influence on symptoms has not yet been clearly revealed in previous studies.[12,32]

Our study has several limitations. This is a single-center, retrospective study. We could not present a healthy control group because our study design only involved patients diagnosed with CTS using EDx. Such enrollment may act as a selection bias for patients who have been clinically diagnosed with CTS or patients who show normal findings on EDx. US evaluations were not performed for such patients at our hospital. Consequently, we could not present the proportion of clinical CTS hands with negative EDx finding, which had BMN out of all CTS patients. If we could present that proportion, we believe our results can be more firmly proven. Our study is also limited in that we only presented NRS, SD, and decision of surgery as clinical variables. NRS and SD are quite subjective parameters; therefore, they might not exactly be reflective of the patient's objective state. In addition, if detailed clinical manifestations such as numbness, night pain, and thenar atrophy or weakness are considered, we believe that the comprehension of CTS with BMN can be heightened. Since we have not been able to present the intra-class and inter-class correlations of US findings, this might lower the reliability of the evaluation results. Although our sample size of the BMN group was the largest ever, the number of hands was still relatively small, especially when conducting subgroup analysis. A large-scale, multi-center study with detailed clinical data is needed in the future.

Conclusion

CTS with BMN is not a rare condition, and EDx severity is relatively underestimated compared with the severity of symptoms. In the same EDx severity grade, the degree of pain was more severe, and the symptom period was longer for CTS with BMN. US evaluation is a good diagnostic tool to confirm BMN; however, it tends to be underestimated compared with NMN in severe CTS. When assessing the severity of CTS with BMN, the clinical symptoms should primarily be considered and the EDx and US should be complementarily evaluated.

Data Sharing Statement

The data supporting this article's conclusions will be made available by the corresponding author without undue reservation.

Ethics Approval and Consent to Participate

This study was reviewed and approved by the Institutional Review Board of Pohang Stroke and Spine Hospital (Approval No. PSSH0475-202101-HR-001-01). Informed consent was waived owing to the retrospective nature of the study. The Pohang Stroke and Spine Hospital's medical information department provided the researcher with the dataset necessary for this study while removing the medical records that had personal information before being provided for the study. The dataset was managed by the research director and stored in a password-protected

database. Access to the database was restricted to the authorized researcher. Patient confidentiality was thus guaranteed. This study was conducted in compliance with both the Declaration of Helsinki and the International Conference on Harmonization-Good Clinical Practice Guideline.

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Disclosure

The authors report no conflicts of interest in this work.

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