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The relationship between ultrasound and electrodiagnostic findings in relation of the severity of carpal tunnel syndrome

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Abstract

Introduction Carpal tunnel syndrome is the most common compression neuropathy. Grading the severity of carpal tunnel syndrome is an important factor in deciding on the type of treatment. This study aims to determine the relationships between the findings of the electrodiagnosis and ultrasonography methods based on the severity of carpal tunnel syndrome.

Methods In this prospective clinical study, 50 patients (96 wrists) who were referred to the Physical Medicine and Rehabilitation Department of the Shohada Tajrish Hospital, Tehran, Iran (from March 2021 to November 2022) were studied. All patients with a history and clinical examination related to CTS underwent electrodiagnosis studies. Based on the results of electrodiagnosis, patients were divided into three groups: mild, moderate, and severe. All eligible patients underwent ultrasound at the cross-section of the wrist (at the level of the pisiform bone, the entrance of the canal) and the middle of the forearm.

Results In this study, the cross-sectional area of the median nerve was measured in 96 wrists of 50 patients with a mean age of 51.78 ± 9.80 years. The mean CSA of the median nerve in the mild, moderate, and severe groups was reported as 0.12 ± 0.03, 0.14 ± 0.02, and 0.21 ± 0.06, respectively. The mean WFR in different groups of CTS was reported as 1.85 ± 0.56, 1.93 ± 0.56, and 2.45 ± 0.49, respectively. A significant relationship between ultrasound findings, including CSA-inlet and WFR, and electrodiagnosis findings was presented (P value < 0.05).

Conclusion Based on our findings, there is a statistically significant relationship between the sonographic findings, including the mean CSA-inlet and WFR, and the severity of CTS based on the electrodiagnosis study. Our findings revealed that as disease severity increases, sonographic parameters also increase significantly.

Keywords Carpal tunnel syndrome, Electrodiagnosis, Ultrasound

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Introduction

Carpal Tunnel Syndrome (CTS) is a prevalent neuropathy, which accounts for 90% of neuropathies, and is caused by compression of the median nerve at the wrist [1–4]. Clinically, CTS manifests as pain, paresthesia, and numbness in the hands, with symptoms predominantly occurring at night [5]. The prevalence of CTS is reported to range from 3.8 to 7.8% within the general population. It is more prevalent in females than in males, with a ratio that varies from 3 to 10 times. CTS is also commonly detected in occupations involving the use of high-force or repetitive pressure. Several studies have indicated that factors such as pregnancy, childbirth, and the presence of diseases like diabetes, amyloidosis, hypothyroidism, and joint rheumatism can increase the risk of developing CTS [6–8]. This syndrome leads to increased absenteeism, mortality, and significant economic impacts [9].

Several diagnostic methods, in addition to clinical signs and symptoms, are routinely applied in CTS diagnosis, including nerve conduction studies (NCS), magnetic resonance imaging (MRI), and ultrasonography (US). The current reference standard for CTS diagnosis involves evaluating clinical symptoms and their location in combination with abnormal median nerve function based on electrodiagnostic studies (EDX) [10, 11]. The diagnostic accuracy of EDX has been reported to range between 49% and 84%, with a specificity exceeding 95%. Although electrodiagnostic tests are considered the gold standard for diagnosing CTS, they have some disadvantages, such as invasiveness and patient discomfort [1, 12–14].

Recently, advancements in ultrasound technology have prompted researchers to explore its efficacy in diagnosing CTS. Ultrasound has several advantages, including painlessness, non-invasiveness, accessibility, relatively good diagnostic power, and cost-effectiveness [15–20]. Grading the severity of CTS is crucial for decision-making in selecting the appropriate treatment. However, to date, no standard system has been introduced for evaluating the severity of CTS using ultrasound. Furthermore, several previous studies have been performed to investigate the correlation between electrodiagnostic and ultrasonographic findings in carpal tunnel syndrome. However, controversial results have been presented. This study aimed to determine the relationship between findings from the electrodiagnosis method and findings from the ultrasound method based on the severity of CTS.

Methods

This prospective chart review clinical study was conducted on patients diagnosed with CTS who were referred to Shohada Tajrish Hospital between March 2021 and November 2022. The study received approval from the research deputy of Shahid Beheshti University of Medical Sciences, Tehran, Iran (IR.SBMU.MSP.REC.1401.558). Informed consent was obtained from all eligible individual participants who subsequently enrolled in the study.

Patients aged over 18 years, regardless of sex, exhibiting clinical symptoms of CTS and confirmed by an electrodiagnosis study, were considered eligible and included in the study. However, patients diagnosed with systemic diseases such as diabetes, rheumatoid arthritis, thyroid diseases, chronic kidney diseases, acromegaly, and gout were excluded. Additionally, patients with neuropathies other than CTS, including radiculopathy, plexopathy, and polyneuropathy, were also excluded. Furthermore, patients with a history of fractures in the distal radius and wrist, a history of surgery or corticosteroid injection for CTS treatment, pregnant patients, and those who did not consent to continue participation were not included in the study.

An electrophysiological examination was performed by a physiatrist using a Natus device under standard conditions. The examination included an assessment of the median and ulnar nerves using a standard technique with supramaximal stimulation and surface electrodes, according to the standard criteria of the American Association of Neuromuscular & Electrodiagnostic Medicine (AANEM) [21]. The device settings for examining the sensory nerve action potential (SNAP) included a sensitivity of 20 microV/Div and a sweep speed of 2 ms/Div, while for the compound muscle action potential (CMAP), the sensitivity of 5000 microV/Div and a sweep speed of 5 ms/Div were used. Distal motor latency, nerve conduction velocity (NCV), and Needle EMG were also performed for the upper limb. CTS was confirmed if the peak latency of the SNAP of the median nerve (MN) to finger 3 at a distance of 14 cm was greater than 3.6, the distal motor onset latency of the median nerve to the thenar region at a distance of 8 cm was greater than 4.2, and the difference in peak latency of SNAP between the median and ulnar nerves to finger 4 was greater than 0.5. Patients were divided into three groups (mild, moderate, and severe) based on these electrophysiological findings and according to Dimitrov's criteria [22, 23].

Ultrasonography was performed by a specialist in physical medicine and rehabilitation who had completed a musculoskeletal sonography course and was blind to the electrophysiological data. To perform the sonography, the patient sat in front of the physiatrist with their forearm in supination, their wrist in a neutral position, and their fingers in a semi-extended position on the table. In this study, all examinations were performed with a high-frequency linear-array transducer with an optimized musculoskeletal setting (HD11XE Philips, 14-MHz). The probe was placed on the wrist without any pressure in a completely perpendicular position to the forearm to locate the nerve. After placing the probe

Table 1 Baseline characteristics of patients

	Range	Min	Max	Mean ± SD
Patient's Age (year)	44	28	72	51.78 ± 9.80
Mean of CSA	0.28	0.07	0.35	0.15 ± 0.05
Mean of WFR	3.63	0.17	3.80	2.01 ± 0.59
Qualitative Variables			**N (%)**	
Patient's Sex	Female		45 (95)	
	Male		5 (5)	
CTS Severity	Mile		27 cases (28.1%)	
	Moderate		50 cases (52.1%)	
	Severe		19 cases (19.8%)	

longitudinally on the wrist, the longitudinal view of the nerve was observed. Then the probe was placed at the wrist in a transverse position to capture the short-axis view and measure the cross-sectional area (CSA). CSA of the median nerve at the level of the pisiform bone at the entrance to the canal was measured in square millimeters by placing an electronic caliper around the nerve using a direct technique. It should be mentioned that we captured the long view to confirm the pathology in two perpendicular planes by observing the notch sign.

In this study, the CSA was measured from just inside the hyperechoic rim using the trace function of the US machine. This method ensures that the CSA measurement includes the nerve fibers but excludes the surrounding protective sheath. Each measurement was performed three times, and their average was calculated and analyzed. Additionally, to calculate the ratio of the CSA of the median nerve to the wrist, the CSA of the median nerve in the forearm at the point where the middle third and distal third of the forearm intersect was measured twice by drawing a continuous line around its inner epineurium. Demographic information of patients (patient's age and sex) and their clinical characteristics, such as EDX and US findings, were recorded through a pre-designed checklist.

Statistical analysis

Data were analyzed using SPSS version 22 for Windows (IBM Inc, NY). In this study, continuous data (such as age, mean of CSA, mean of sensory latency, sensory amplitude, motor latency, and motor amplitude) were expressed as mean±standard deviation (SD), and categorical data (like patient's sex) as frequency counts (percentages). ANOVA and post-hoc analyses were used to compare the mean of outcomes between groups. Pearson coefficient correlation was used to check the correlation between ultrasound and electrodiagnosis findings. A p-value equal to or less than 0.05 is considered statistically significant.

Results

In this study, 50 patients (96 wrists), 45 women and 5 men, diagnosed with CTS, with a mean age of 51.78 ± 9.80 (range: 28 to 72 years), were enrolled. Of the total number of 96 wrists, 27 cases (28.1%) were reported with mild CTS, 50 cases (52.1%) with moderate CTS, and 19 cases (19.8%) with severe CTS (Table 1). According to our study findings, the mean CSA of the median nerve in the wrist area in mild, moderate, and severe levels were reported to be 0.12 ± 0.03, 0.14 ± 0.02, and 0.21 ± 0.06 cm [2], respectively. A significant difference was observed between the mean CSA of the median nerve in the wrist area in different CTS severity (P value: 0.001) (Table 2). Additionally, the mean wrist to the forearm (WFR) in mild, moderate, and severe levels of CTS were reported to be 1.85 ± 0.56, 1.93 ± 0.56, and 2.45 ± 0.49, respectively. A significant difference was observed between the mean CSA of the median nerve in the wrist area across different severities of CTS (P value: 0.001) (Table 2).

This study examined the relationship between sonographic parameters, the mean CSA and WFR, and findings obtained from electrodiagnosis, which include sensory latency, sensory amplitude, motor latency, and motor amplitude. Based on the study results, significant correlations were reported between the mean CSA of the median nerve at the wrist and the following parameters: sensory latency (P value < 0.001, r: 0.53), sensory amplitude (P value < 0.001, r: –0.39), motor latency (P value < 0.001, r: 0.50), and motor amplitude (P value < 0.001, r: –0.27). The relationships between the mean CSA of the median nerve and electrodiagnostic parameters were reported in Table 3 in detail.

Table 2 The Mean ± SD CSA and WFR based on the CTS Severity

		N	Range	Minimum	Maximum	Mean	SD	95% CI		P value
								Lower Bound	Upper Bound	
Mean of CSA	Mild	23	0.14	0.07	0.21	0.12	0.03	0.11	0.13	0.001
	Moderate	45	0.11	0.09	0.20	0.14	0.02	0.13	0.14	
	Severe	19	0.22	0.13	0.35	0.21	0.06	0.17	0.24	
	Total	96	0.28	0.07	0.35	0.15	0.05	0.14	0.16	
Mean of WFR	Mild	23	2.56	0.31	2.87	1.85	0.56	1.62	2.08	0.001
	Moderate	45	2.71	0.17	2.88	1.93	0.56	1.77	2.10	
	Severe	19	2.04	1.76	3.80	2.45	0.49	2.20	2.69	
	Total	91	3.63	0.17	3.80	2.01	0.59	1.89	2.13	

Table 3 Correlation between Ultrasound and Electrodiagnosis findings

		Pearson Correlation	*P* value
Mean of CSA	Sensory Latency	0.53	< 0.001
	Sensory Amplitude	-0.39	< 0.001
	Motor Latency	0.50	< 0.001
	Motor Amplitude	-0.27	< 0.001
Mean of WFR	Sensory Latency	0.22	0.05
	Sensory Amplitude	-0.19	0.08
	Motor Latency	0.40	< 0.001
	Motor Amplitude	-0.07	0.48

There were significant correlations between the mean WFR with sensory latency (P value: 0.05, r: 0.22), and motor latency (P value < 0.001, r: 0.40). No significant correlations were reported between the mean WFR with sensory amplitude (P value: 0.08, r: -0.19) and motor amplitude (P value: 0.48, r: -0.07). The relationships between the mean WFR and electrodiagnostic parameters were reported in Table 3 in detail.

In this study, the relationship between sonographic findings and the severity of CTS was evaluated. According to these findings, there was a significant difference between the mean CSA of the median nerve among different severity groups (P value: 0.001). In the post-hoc analysis, pairwise comparisons were made between groups, and the study findings showed that there was a significant difference between the mean CSA of the median nerve in the mild and severe groups (P value < 0.001) and the moderate and severe groups (P value < 0.001). No significant difference was reported between the mean CSA of the median nerve in the mild and moderate groups (P value: 0.09).

Furthermore, there was a significant difference between the mean WFR among different severity groups (P value: 0.001). The study findings showed a significant difference between the mean WFR index in the mild group compared with the severe group (P value: 0.001), and the moderate group compared with the severe group (P value: 0.001). There was no significant difference between the mean CSA of the median nerve in the mild and moderate groups (P value: 0.56). Pairwise comparisons between the study findings in different groups of CTS severity were presented in Table 4 in detail.

Discussion

The severity grading of CTS is a critical factor in determining the appropriate treatment, necessitating a diagnostic test before treatment (14). This study aims to determine the relationships between the findings of the electrodiagnosis and ultrasonography methods in terms of the severity of carpal tunnel syndrome.

Several sonographic parameters have been assessed in various studies for the diagnosis of CTS. The measurement of the cross-sectional area of the median nerve is the most significant and commonly used sonographic parameter for diagnosing CTS (8). The CSA of the median nerve at the inlet, the level of the pisiform bone, is the most frequently measured parameter due to the clear visibility of tunnel contents in this area and a specific bony landmark [24]. Given that the CSA of the median nerve at the canal entrance may be influenced by various factors such as the study population, measurement technique, patient weight, etc., some researchers prefer to use the ratio between the median nerve size in the mid-forearm (proximal) and the median nerve size in the carpal tunnel (distal), known as the WFR [25], for diagnosing CTS. In this context, this study examined the correlation between sonographic findings, including the CSA-inlet (median nerve CSA at the wrist) and the WFR ratio (median nerve CSA at the wrist to the forearm), and electrodiagnosis findings in terms of the severity of CTS.

In studies conducted to date on the grading of CTS using sonography, a correlation has been observed between sonographic and electrodiagnostic findings. A study by Lee and colleagues demonstrated that the size of

Table 4 Pairwise comparisons between Ultrasound and Electrodiagnosis findings based on the CTS Severity

			Mean Difference	Std. Error	95% CI		P value
					Lower Bound	Upper Bound	
Mean of CSA	Mild	Moderate	– 0.016	0.009	-0.03	0.002	0.09
		Severe	-0.08	0.01	-0.10	-0.06	0.001
	Moderate	Mild	0.16	0.009	-0.002	0.03	0.09
		Severe	-0.06	0.01	-0.09	-0.04	0.001
	Severe	Mild	0.08	0.01	0.06	0.10	0.001
		Moderate	0.06	0.01	0.04	0.09	0.001
Mean of WFR	Mild	Moderate	-0.07	0.13	-0.35	0.19	0.56
		Severe	-0.60	0.17	-0.93	-0.25	0.001
	Moderate	Mild	0.07	0.13	-0.19	0.35	0.56
		Severe	-0.51	0.15	-0.81	-0.21	0.001
	Severe	Mild	0.60	0.17	0.25	0.93	0.001
		Moderate	0.51	0.15	0.21	0.81	0.001

the median nerve at the canal inlet (CSA inlet) in sonography correlates well with electrodiagnostic findings [26]. Another study by Habashy and colleagues showed that the examination of the CSA of the median nerve at the wrist (CSA-inlet) and the ratio of the CSA of the median nerve at the wrist to the forearm has a significant correlation with electrodiagnostic findings [27]. The present study revealed a statistically significant relationship between the mean CSA of the median nerve (CSA-inlet) and WFR across disease severity groups.

In another study conducted by Moschovo and colleagues, the results demonstrated that CSA-inlet and WFR are excellent criteria for diagnosing and grading CTS in patients under 65 years old [28]. The study revealed a statistically significant difference between the mean indices of the median nerve CSA at the inlet region and the mean WFR index among different groups based on disease severity. Another study by Abrishamchi and colleagues indicated that as disease severity increases, CSA-inlet and WFR indices also increase (25). According to their findings, there was no statistically significant difference between the mild and moderate groups in terms of the WFR index. However, this difference was reported to be statistically significant between the mild and severe groups, as well as the moderate and severe groups. In terms of the mean median nerve CSA parameter among different groups based on disease severity, no statistically significant difference was observed. On the contrary, the present study observed a statistically significant difference between the mean CSA of the median nerve and the WFR parameters among different groups based on disease severity. According to the post-hoc test findings, this difference was reported to be statistically significant between the mild and severe groups, as well as between the moderate and severe groups. However, no significant differences were reported between the mean CSA of the median nerve and the WFR parameters between the mild and moderate groups. This finding implicated that ultrasound may not be a sensitive test to differentiate between mild and moderate CTS.

In contrast to these studies, there are studies by Yin Ting and Moran, based on their findings, suggest that sonography cannot differentiate between different severities of CTS (29, 30]. Yin Ting's study is the only one that compares CSA-inlet, WFR, and Delta CSA with different electrodiagnostic grading criteria (CSI and Bland criteria) and has not found a significant difference in any of the sonographic parameters in the mild, moderate, or severe groups based on electrodiagnosis, which may be due to different electrodiagnostic criteria [30]. It may be due to different electrodiagnostic criteria. The choice of electrodiagnostic criteria could potentially influence the study's findings.

In a study conducted by Moran, CSA-inlet, and CSA-outlet parameters were initially examined, but due to the unreliability of measurements at the outlet section, it was not continued. In examining the relationship between the inlet parameter and the Padua electrodiagnostic criterion, although the cross-sectional area of the median nerve at the inlet region increased with increasing disease severity, no significant correlation was observed between any of the mild, moderate, or severe groups (29).

The findings of our study, which was conducted on a total of 96 wrists with CTS, showed that there is a statistically significant correlation between the mean CSA of the median nerve at the inlet of the canal and the WFR index with CTS severity determined by electrodiagnostic findings. The findings of our study indicate that as disease severity increases (based on Dimitro criteria), the mean median nerve cross-sectional area and WFR ratio also increase significantly, which is consistent with the mentioned studies.

According to our findings, there was a significant difference between the mean median nerve cross-sectional area at the wrist region among different groups in terms of CTS severity. Our findings were consistent with those of Karadag and colleagues [31]. In their study, the range of the mean median nerve CSA at the wrist region in mild, moderate, and severe levels was reported to be 10 to 13 mm^2, 13 to 15 mm^2, and more than 15 mm^2, respectively [20]. In Moschovo's study and colleagues [28], the mean median nerve CSA in mild, moderate, and severe levels was reported to be 1.9 ± 10.8 mm^2, 1.8 ± 11.4 mm^2, and 1.5 ± 12 mm^2, respectively. In their study, like ours, there was a statistically significant difference between the mean median nerve cross-sectional area at the wrist region and disease severity. In contrast to these studies, based on Moran's findings and colleagues, there is no statistically significant difference between the mean median nerve cross-sectional area at the wrist region with disease severity [29].

The study explores the relationship between sonographic parameters and electrodiagnostic findings, which include sensory latency, sensory amplitude, motor latency, and motor amplitude. The principal findings are as follows:

There exists a positive, moderate correlation between the mean CSA of the median nerve at the wrist region and both sensory latency and motor latency. A negative, relatively weak correlation is observed between the mean CSA of the median nerve at the wrist region and both sensory amplitude and motor amplitude. As the mean CSA of the median nerve increases, both sensory amplitude and motor amplitude parameters decrease. These findings align with those of Habashy and colleagues [27]. Regarding the increase in CSA as the latency increases and as the amplitude decreases, one possible explanation could be that as the severity of the condition increases (reflected by increased latency and decreased amplitude), there may be an associated increase in nerve swelling or hypertrophy, which could result in an increased CSA. However, this is a hypothesis that would need to be tested in future studies.

Additionally, a positive, moderate correlation is found between the WFR index and both sensory latency and motor latency. However, no significant relationship is found between the mean WFR index and both sensory amplitude and motor amplitude. It suggests that these variables are not strongly associated. In other words, changes in sensory or motor amplitude do not consistently correspond to changes in the mean WFR index. The lack of significant correlation could be due to a variety of factors, including the inherent variability in these measurements, the sample size of our study, or the specific characteristics of our patient population. However, this is an area that requires further investigation.

Based on previous studies, as mentioned in the introduction section, several diagnostic methods, in addition to clinical signs and symptoms, are routinely applied in CTS diagnosis. The current reference standard for CTS diagnosis involves evaluating clinical symptoms and their location in combination with abnormal median nerve function based on electrodiagnostic studies (EDX). While electrodiagnostic (EDX) studies can provide valuable information about the severity of carpal tunnel syndrome (CTS), and rule out other mimicking pathologies; they are not always a routine part of the management of CTS. Many surgeons indeed rely on clinical findings to guide their treatment decisions, including the decision to proceed with carpal tunnel release (CTR) surgery. However, in many cases, surgeons and non-surgeon physicians utilize electrodiagnostic tests and/or ultrasonography for diagnosis and prognostication of CTS. It's important to note that the use of EDX and ultrasound in our study does not imply that these investigations are mandatory in the management of CTS. They are tools that can complement clinical findings and help guide treatment decisions, but the decision to use them should be individualized based on the specific circumstances of each patient.

In this study, we measured the CSA at the carpal tunnel inlet at the pisiform level. As mentioned above, it is because of the CSA of the median nerve at the inlet, the level of the pisiform bone, is the most frequently measured parameter due to the clear visibility of tunnel contents in this area and a specific bony landmark. In addition, based on recent studies, the CSA of the median nerve at the inlet, the level of the pisiform bone has the highest diagnostic accuracy for diagnosing CTS [32–34]. However, this is not a strict rule because, in clinical practice, the maximum nerve enlargement may not always be found at the inlet. Sometimes, it can be located at the outlet or even in the palm. Therefore, the current recommendation is to measure the nerve CSA at the site of maximum enlargement, which may not necessarily be at the inlet [35, 36].

Unfortunately, in our current study, we could not assess other parameters, such as echotexture and vascularity which may also vary with the severity of the CTS. This indeed represents a limitation of our study. In future studies, these parameters could potentially enhance understanding of the disease and improve patient management. In addition, in this study, we did not perform the correlation with conduction velocity, and ROC curve analysis to provide cut-off values for inlet CSA and WFR which can be used to determine the grade of severity. We acknowledge this as a limitation in our current study. Incorporating ROC curve analysis into future studies may lead to a more comprehensive understanding of the relationship between CSA, WFR, and disease severity. In this study, we did not evaluate the relationships between the US findings and the severity of the clinical symptoms. It should be considered in future studies to provide more information about the relationship between the ultrasound parameters and the patient's clinical condition.

As for the implications of our findings, they suggest that ultrasound parameters such as CSA could potentially serve as useful non-invasive markers for assessing disease severity in patients with this condition. However, as our study has shown, the relationship between these ultrasound parameters and traditional electrophysiological measures is complex and warrants further investigation.

Conclusion

Based on our findings from this study, there is a statistically significant correlation between the sonographic findings, including the mean CSA-inlet and WFR, and the severity of CTS based on the electrodiagnosis study. Our findings revealed that as disease severity increases, sonographic parameters also increase significantly.

Abbreviations

CTS	Carpal Tunnel Syndrome
NCS	Nerve conduction studies
MRI	Magnetic resonance imaging
US	Ultrasonography
EDX	Electrodiagnostic studies
SNAP	Sensory Nerve Action Potential
CMAP	Compound Muscle Action Potential
MN	Median Nerve
WFR	Wrist to Forearm Ration

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Author contributions

S.M.R and R.M. and K.A. and F.N. contributed to the conception of the work. S.M.R. and R.M. and K.A. contributed to the design, and acquisition of data. K.A. contributed to the data analysis and interpretation of data. S.M.R and R.M. and K.A. and F.N. contributed to drafting the work and revising it critically. In addition, all authors contributed to final approval of the manuscript and final agreement on the work.

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Data availability
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All patients signed written informed consent before enrollment. The Ethics Committee approved the study protocol of Shahid Beheshti University of Medical Sciences. In this study all methods were based on relevant guidelines and regulations (declaration of Helsinki).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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