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Original Research

Opposition Transfer Using the Extensor Indicis Muscle and the Extensor Pollicis Brevis Tendon

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Purpose: This study aimed to introduce a novel technique using the extensor pollicis brevis and extensor indicis proprius tendons as power sources for thumb opposition reconstruction in cases of severe carpal tunnel syndrome (CTS) associated with thenar muscle atrophy. Furthermore, the efficacy of this novel method and the traditional Camitz technique was compared.
Methods: Patients with severe CTS and thumb opposition dysfunction who underwent surgery using the novel technique ($n = 7$ and 9 surgeries) or the Camitz technique ($n = 8$ and 8 surgeries) were included in the analysis. The pre- and postoperative palmar abduction angle, thumb-ring finger opposition angle, and Kapandji score were assessed. The repeated measures analysis of variance and the Mann-Whitney U test were used for statistical analysis.
Results: The novel technique was associated with a significant postoperative improvement in palmar abduction angle, thumb-ring finger opposition angle, and Kapandji score. In particular, the thumb-ring finger opposition angle of patients who underwent surgery using this technique was superior to that of patients who underwent surgery using the Camitz technique. Therefore, the novel technique was highly effective in improving thumb pronation.
Conclusion: The novel technique using the extensor pollicis brevis and extensor indicis proprius tendons is promising for thumb opposition reconstruction in severe CTS cases. Unlike the traditional Camitz technique, this approach promotes stable thumb opposition function without requiring a pulley, thereby yielding satisfactory outcomes. Nevertheless, further studies with a larger sample size should be conducted to validate these findings.
Type of study/level of evidence: Therapeutic 4; Surgical technique.

Carpal tunnel syndrome (CTS) is a compressive neuropathy of the median nerve in the carpal tunnel.[1,2] Patients with CTS commonly respond well to conservative treatments, thereby preventing surgery. For patients who resist conservative treatment, carpal tunnel release is usually the procedure of choice and provides symptomatic relief in most patients. However, in CTS with severe thenar muscle atrophy, various impairments may occur due to thumb opposition dysfunction.[3] In such a case, thumb opposition reconstruction surgery and carpal tunnel release are recommended.[4]

Several methods have been used for thumb opposition reconstruction. Nevertheless, they vary in terms of the muscle used as the power source, course of the transferred tendon, and insertion site of the transferred tendon. The Camitz technique using the palmaris longus (PL) is the most commonly used method, as reported by Bunnell[5] and popularized by Camitz[6] (Fig. 1A). However, although such a technique offers satisfactory acquisition of palmar abduction of the thumb due to the strength and course of the PL, it has limitations. That is, it cannot adequately provide the acquisition of thumb pronation.[7] To overcome this issue, various modifications have been made. These include alterations in the course

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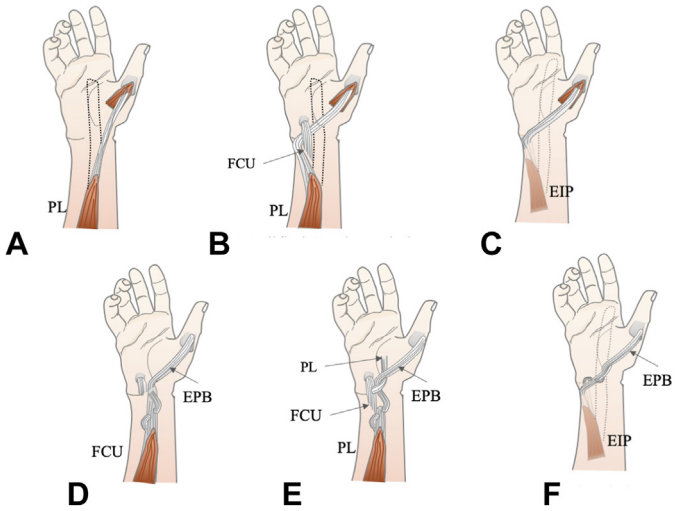

Figure 1. Various thumb opposition reconstruction techniques. **A** Camitz technique, **B** modified Camitz technique, **C** Burkhalter technique, **D** Phalen and Miller technique, **E** Kimori technique, and **F** novel technique.

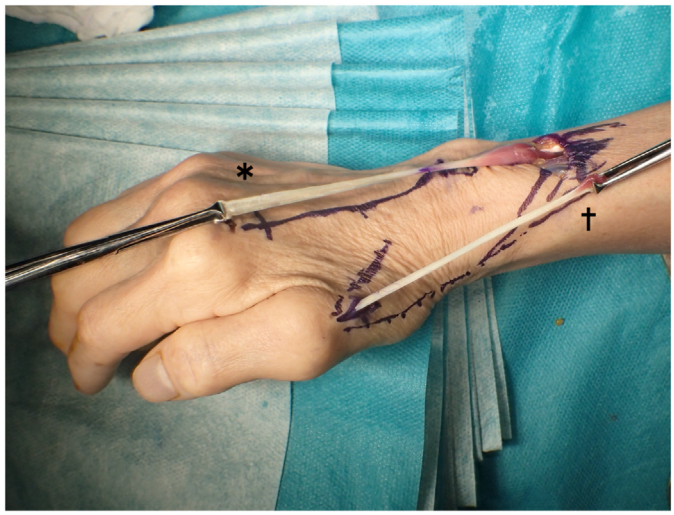

Figure 2. Harvesting the transposed tendons. *EIP † EPB. The extensor indicis proprius tendon was detached distally, and the extensor pollicis brevis tendon was severed at the musculotendinous junction.

of the PL tendon and its suture site. Nevertheless, sufficient acquisition of thumb pronation could still not be achieved (Fig. 1B).[8–17]

The Burkhalter technique, which was first reported by Burkhalter, uses the extensor indicis muscle as a mover, thereby rotating the radial side to reconstruct thumb opposition[18] (Fig. 1C). Previous studies have reported that this method can effectively reconstruct thumb abduction and pronation. Hence, it has significant benefits.[19–23] For example, the tendon graft runs in a straight line without passing through a pulley, and the direction of the traction is at the most distal, unlike in various opposition reconstruction techniques wherein it is located near the pisiform bone.[24]

Although there are various methodologies regarding the insertion site of the tendon, as mentioned earlier, the extensor tendon hood is thin at the transition point. Hence, sufficient initial strength is challenging to achieve, and prolonged postoperative fixation is required. Phalen and Miller[25] have developed a technique in which the extensor pollicis brevis (EPB) tendon is detached at the musculotendinous junction and is rerouted radially using the flexor carpi ulnaris for traction. Moreover, they have reported positive outcomes (Fig. 1D). Komori et al[26] have developed a technique wherein the EPB tendon is rerouted radially and sutured to the PL tendon (Fig. 1E). This method requires a radial pulley. Furthermore, similar to the Camitz technique, it uses the PL tendon as a power source.

Our study developed a novel technique for thumb opposition reconstruction using the EPB tendon, which does not require an attachment to the abdcutor pollicis brevis (APB) tendon, and the EIP as a power source, which is based on the Burkhaltar method that does not require a pulley (Fig 1F). Furthermore, the surgical procedure in this novel thumb opposition reconstruction was discussed, and the postoperative outcomes of the novel technique and the traditional Camitz technique were compared.

Indication and contraindication

Low-level median nerve paralysis in CTS is an optimal indication for this technique. The other thumb opposition reconstruction techniques, namely, the Camitz (PL) and Bunnell (flexor digitorum superficialis) methods, use muscles innervated by the median nerve. However, these procedures use the innervation provided by the radial nerve (specifically, the posterior interosseous nerve), making it applicable for thumb opposition reconstruction in the context of high-level median nerve paralysis. Nevertheless, it is not suitable for patients with concurrent radial nerve (posterior interosseous nerve) paralysis, those who present with concurrent thumb carpometacarpal (CM) joint pathology, those with limited range of motion in the thumb CM joint, or those with thumb adduction contractures who cannot maintain thumb opposition passively.

Surgical anatomy

The presence of the extensor indicis proprius (EIP) and EPB tendons with a sufficient thickness is essential for tendon transfer. Previous studies have shown that the incidence rates of absent EIP and EPB tendons are approximately 3% and 7.6%, respectively.[27,28] Prior to surgery, the presence of the EIP and EPB tendons should be confirmed on ultrasonography or magnetic resonance imaging. In cases where suitable tendons cannot be obtained for transfer, alternative surgical approaches should be considered. The EPB tendon is commonly believed to terminate at the base of the proximal phalanx bone. However, previous reports have shown that in 20% to 70% of specimens, the EPB extends to the base of the distal phalanx.[29–31] The termination of the EPB tendon at the distal phalanx may result in an extensor force acting on the interphalangeal joint during thumb opposition. This is typically not problematic due to the muscular strength of the flexor pollicis longus. Nonetheless, caution might be necessary for patients requiring specific thumb interphalangeal joint flexion. Sugiura et al[32] focused on the widening of the extensor tendon at the center of the thumb proximal phalanx. Furthermore, they reported that if the tendon's width is >8 mm on ultrasonography, the EPB tendon terminates at the distal phalanx. Thus, it is important to preoperatively assess the tendon's width via ultrasonography.

Surgical technique

Surgery is performed under general anesthesia, axillary brachial plexus block, or wide-awake local anesthesia no tourniquet. Unless

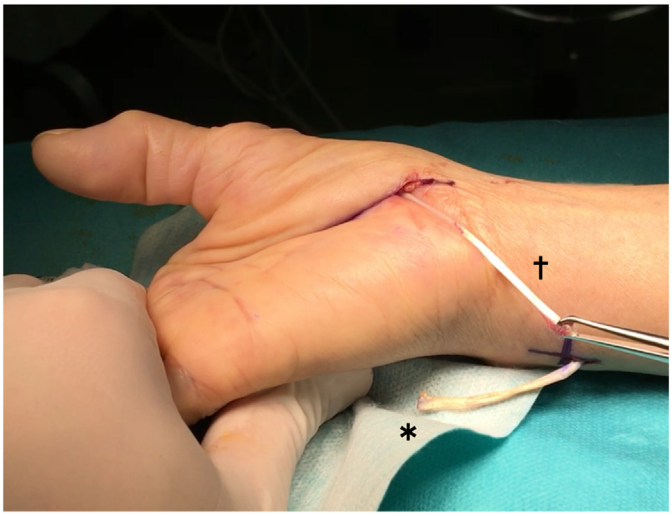

Figure 3. Tendon rerouting. *EIP † EPB. The extensor pollicis brevis tendon was rerouted via the thenar muscles and on the palmar side of the flexor retinaculum. The extensor indicis proprius tendon was passed through the ulnar side, traversing the palmar side of the extensor carpi ulnaris tendon and the flexor carpi ulnaris tendon, and was rerouted on the palmar side of the flexor retinaculum.

there is a specific reason, such as the need to check active movement intraoperatively or a strong patient preference for general anesthesia, we typically employ the axillary brachial plexus block and perform the surgery under a tourniquet.

Initially, the carpal tunnel is opened in accordance with the standard carpal tunnel release. Considering that the tendon will be sutured at the end of the procedure within the surgical field of carpal tunnel release, the proximal skin incision is oriented toward the ulnar side. The EIP tendon, which will be the power source, is then harvested. The EIP tendon, which is located on the ulnar side of the second extensor digitorum communis at the proximal of metacarpophalangeal (MP) joint of the index finger, is identified. It is separated proximally with caution to prevent damaging the extensor tendon hood. It is once drawn out distal to the extensor retinaculum, further dissected to the musculotendinous junction, and then pulled out onto the skin (Fig. 2).

Next, the EPB tendon is harvested. The musculotendinous junction of the EPB is identified in the vicinity of the EIP muscle belly via the same skin incision, and the tendon is separated. A cut is made distal to the first compartment of the extensor retinaculum to dissect the EPB tendon. Ultimately, the tendon is drawn out to the dorsal side of the MP joint (Fig. 2).

A vertical incision is made on the ulnar side of the pisiform bone, and the EIP tendon is passed under the extensor digitorum communis tendon and above and subcutaneously to the extensor carpi ulnaris tendon and pulled out through the skin incision on the ulnar side of the pisiform. It is further guided subcutaneously near the anterior part of the pisiform and runs to the front of the carpal tunnel (Fig. 3).

The EPB tendon, which has been pulled out to the thumb MP joint, is routed inside the thenar muscles and pulled out on the palmar side of the severed transverse carpal ligament, completely across the carpal tunnel (Fig. 3). Underneath the skin at the front of the carpal tunnel, the EIP and EPB tendons are robustly sutured together with 3 to 4 weaves using an interlacing suture (Fig. 4). The tendons are sutured in the wrist's neutral position and at the thumb's maximum opposition. Taking into account that the suture tension may loosen after surgery, they are sutured with maximum tension.

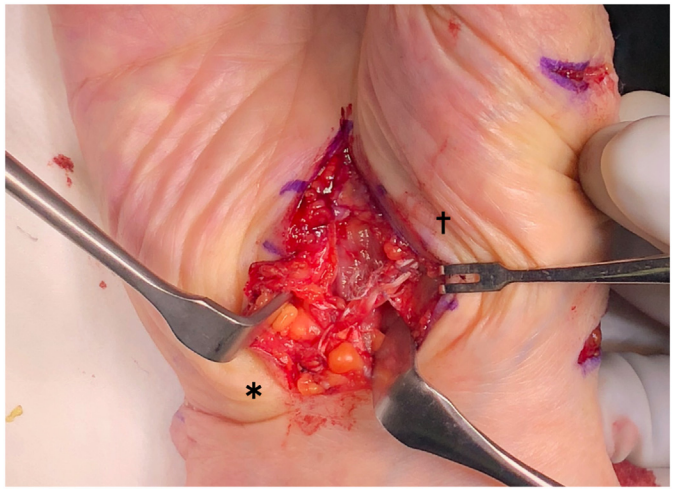

Figure 4. Interlacing suture of the tendons. Interlacing suturing was performed between the rerouted extensor pollicis brevis and extensor indicis proprius tendons.

Postoperative management

Postoperative management involves a 3-week period of immobilization using a thumb spica splint, which is removed during rehabilitation sessions to facilitate early range of motion exercises. Subsequently, the device is removed as necessary, allowing its use whenever appropriate. By the 2-month mark postsurgery, all restrictions are lifted, and unrestricted use is permitted.

Material and Methods

Subject

The current study included patients with severe CTS who received treatment after June 2015. We obtained ethical approval for this study from the Ethics Review Committee, and the patients provided consent. During the same period, some patients underwent surgery using the modified Camitz technique with flexor carpi ulnaris tendon pulley. The inclusion criteria were patients with significant atrophy in the APB, those with evident opposition impairment of the thumb, those with either nonderivable or significantly reduced compound muscle action potential in the APB during preoperative motor nerve conduction velocity measurement, and those with complaints of opposition dysfunction who wanted to undergo reconstructive surgery. The type of surgical procedure was selected according to the surgeon's preference.

Evaluation items

The following variables were evaluated: age at surgery, duration of surgery, time of final follow-up, palmar abduction angle at the time of final follow-up, nail tip angle of the thumb-ring finger opposition (T-R angle), Kapandji score, Semmes-Weinstein monofilament test, and postoperative complications (Fig. 5). The palmar abduction angle was defined as the angle created by the thumb MP joint, thumb CM joint, and index MP joint (Fig. 6A). The T-R angle was defined as the nail angle when the ring finger was placed in opposition (Fig. 6B).[33] Each of these parameters was compared between patients who underwent surgery using the novel technique (the novel technique group) and those who underwent surgery using the Camitz technique (the Camitz technique group). The novel technique group underwent preoperative measurements,

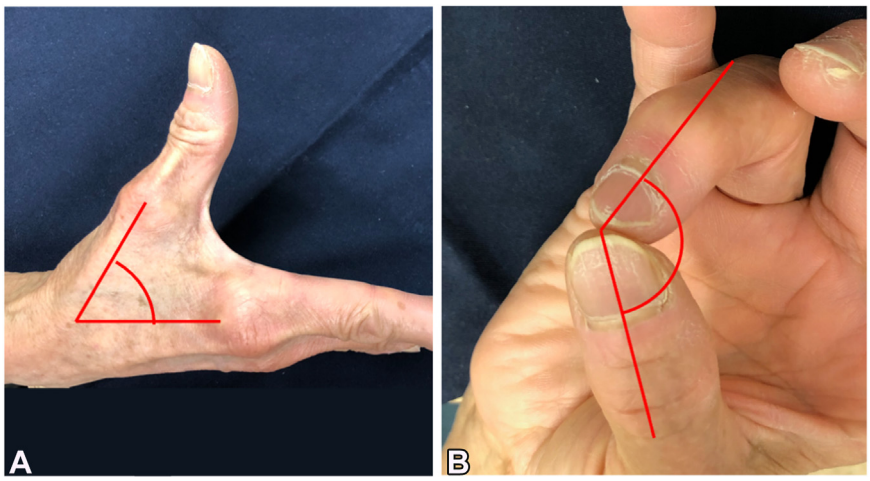

Figure 5. Angle measurement method. **A** Palmar abduction and **B** thumb-ring angle.

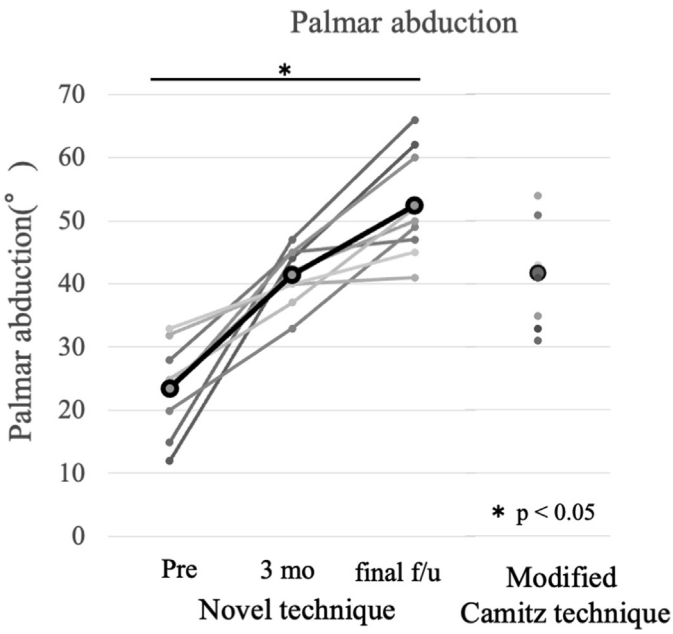

Figure 6. Palmar abduction.

thereby allowing a comparative study between preoperative, 3 months after postoperative, and final follow-up parameters.

Statistical analysis was conducted using repeated measures analysis of variance to compare the preoperative data with the data collected 3 months after surgery and at the final follow-up. The Bonferroni correction was applied for multiple comparisons. Meanwhile, the Mann-Whitney U test was used to compare groups who underwent different surgical procedures. A P value of $< .05$ was considered statistically significant.

Results

Characteristics of the patient

The current study included two male and 13 female patients. The participants were then divided into the novel technique group ($n = 7$ and 9 surgeries) and the Camitz technique group (n = 8 and 8 surgeries). The average ages during surgery were 76.3 years (range: 63–88) in the novel technique group and 75.1 years (range: 65–85) in the Camitz technique group. The average surgical durations were 96.3 minutes (range: 78–114) in the novel technique group and 91.0 minutes (range: 67–147) in the Camitz technique group. The average postoperative observation periods were 32.6 months (range: 4.4–61.5) in the novel technique group and 20.8 months (range: 5.1–44.7) in the Camitz technique group (Tables 1 and 2). There were no significant differences between the two groups in terms of the aforementioned parameters. Sensory disturbances were reduced in all patients, but sensory-related symptoms remained in all patients. There were no cases of postoperative complications.

Palmar abduction

There was significant improvement in the preoperative, 3 months after postoperative, and final follow-up palmar abduction angles of the novel technique group (23.6° ± 7.1°, 41.4°± 4.4°, and 53.6° ± 9.1°) ($P < .0001$; Fig. 6) The postoperative palmar abduction angle of the Camitz technique group was 41.6° ± 8.3°. Hence, the postoperative palmar abduction angle between the Camitz technique group and the novel technique group did not significantly differ ($P = .13$).

T-R angle

There was significant improvement in the preoperative, 3 months after postoperative, and final follow-up T-R angles of the novel technique group (97.4° ± 9.5°, 140.2° ± 13.5°, and 135.6° ± 9.3°, respectively) ($P < .0001$; Fig. 7). In contrast, the T-R angle in the Camitz technique group was 124.9° ± 13.7°, the novel technique group demonstrated a significant acquisition of thumb pronation movement ($P = .017$).

Kapandji score

There was significant improvement in the preoperative, 3 months after postoperative, and final follow-up Kapandji scores of the novel technique group (7.0 ± 1.0, 9.9 ± 0.4, and 9.9 ± 0.4, respectively; Fig. 8). Hence, there was a significant improvement in Kapandji scores ($P < .0001$). In addition, the Kapandji score of the Camitz technique group was 9.4 ± 0.76. Thus, there was no significant difference in terms of the Kapandji score between the Camitz and novel technique groups ($P = .15$).

Table 1
Patients Who Underwent Surgery Using the Novel Technique

Pt	Sex	R/L	Age (y)	APB CMAP	Surgical Time (Min)	F/U Time (Mo)	Palmar Abduction			T-R Angle			Kapandji Score			S-W Test	
							Presurgery	3 mo	Final F/U	Presurgery	3 mo	Final F/U	Presurgery	3 mo	Final F/U	Presurgery	Final F/U
Pt N1	F	R	70	N/E	114	55.3	12	44	62	96	121	145	7	10	10	Red 4.56	Blue 3.61
		L	73	N/E	101	18.2	15	47	66	90	160	135	7	10	10	Red 6.65	Blue 3.61
Pt N2	F	R	84	N/E	89	61.5	28	45	47	90	149	141	5	10	10	Purple 4.31	Blue 3.61
		L	86	N/E	78	40.3	20	33	49	90	158	130	8	10	10	Purple 4.31	Blue 3.61
Pt N3	F	R	80	N/E	85	23.5	23	45	60	90	136	143	7	10	10	Red 4.56	Blue 3.61
Pt N4	F	R	66	N/E	107	17.0	24	42	50	112	127	118	7	10	10	Red 4.56	Green 2.83
Pt N5	F	R	71	N/E	100	12.6	32	40	41	114	130	137	6	9	9	Red 4.56	Green 2.83
Pt N6	F	R	88	N/E	107	4.4	25	37	52	95	140	123	8	10	10	Red 6.65	Purple 4.31
Pt N7	F	R	63	N/E	92	19.0	33	40	45	100	141	132	8	10	10	Red 4.56	Green 2.83
Average			76.3		96.3	32.6	23.6	41.4	53.6	97.4	140.2	135.6	7.0	9.9	9.9		

F/U, follow-up; S-W test, Semmes-Weinstein monofilament test; T-R angle, the nail tip angle of the thumb-ring finger opposition.

Table 2
Patients Who Underwent Surgery Using the Modified Camitz Techniques

Pt	Sex	R/L	Age (y)	APB CMAP	Surgical Time (Min)	Follow-Up Time (mo)	Postsurgery		
							Palmar Abduction	T-R Angle	Kapandji Score
Pt C1	F	R	75	N/E	147	57.4	33	105	9
Pt C2	M	R	76	N/E	71	44.7	54	137	9
Pt C3	F	R	85	N/E	100	10.5	51	124	8
Pt C4	F	R	76	N/E	80	24.2	31	127	9
Pt C5	F	R	65	N/E	80	6.2	43	150	10
Pt C6	M	L	75	N/E	92	5.1	35	117	10
Pt C7	F	L	79	N/E	67	6.6	45	122	10
Pt C8	F	R	71	N/E	91	11.8	41	117	10
Average			75.8		91.0	20.8	41.6	124.9	9.4

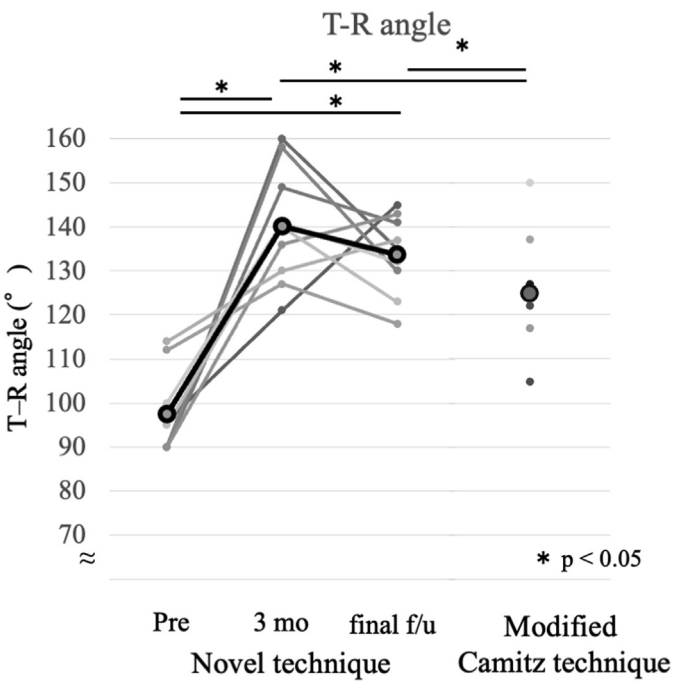

Figure 7. Thumb-ring angle.

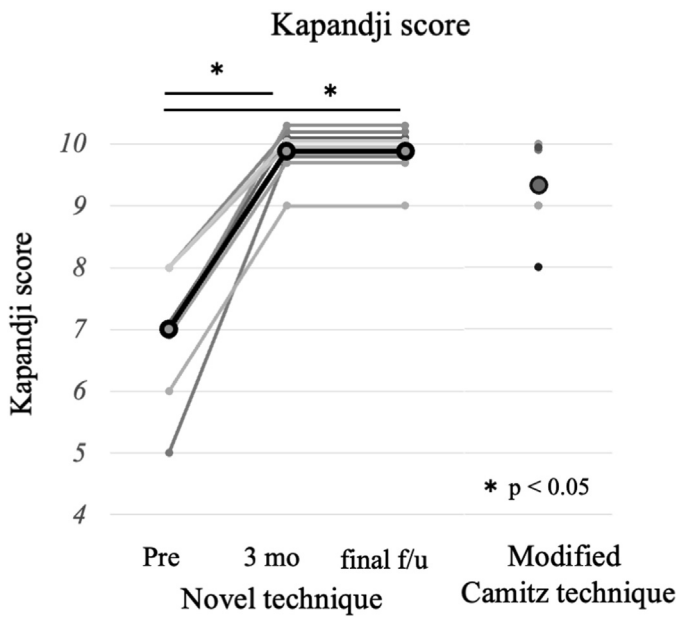

Figure 8. Kapandji score.

Discussion

The opposable thumb is one of the most important aspects of hand function, and impairment of this capability indicates a significant functional loss in the hand. Over the years, various surgeries for thumb opposition reconstruction have been attempted and reported.[5–26] However, the motion of thumb opposition is inherently complex, involving simultaneous action of multiple muscle groups. Hence, this motion is challenging to restore via a single tendon transfer. The essential components for thumb opposition reconstruction include the power source, position of the pulley, and site of insertion.[24]

Cooney et al[24] have shown that the APB is the primary mover in thumb opposition movement, and the flexor pollicis brevis and the opponens pollicis are the secondary movers. The muscle length and cross-sectional area of the APB, PL muscle, and EIP muscle are 3.3 cm and 1.7cm^2, 4.9 cm and 1.8 cm^2, and 5.5 cm and 1.7 cm^2, respectively. Considering the source of power, the PL and EIP can have the required excursion and muscular strength for thumb opposition. Therefore, in terms of factors that can make the thumb opposition movement more efficient, the direction of the tendon's action becomes important.

In a pulley system, the torque generated by muscle force is based on two variables (the length of the lever arm and the angle of the fulcrum).[19] That is, if the angle of the fulcrum is closer to a straight line, a lesser force is consumed by the friction of the pulley, which is advantageous for muscle exertion. Conney et al[24] evaluated the traction direction in thumb opposition reconstruction surgery. The results showed that when the direction of the tendon traction is more distal, near the pisiform bone, as in the Burkhaltar method, it is more advantageous for flexion and pronation. By contrast, if the flexor carpi ulnaris is used as a pulley and the direction of the traction is more proximal, it is advantageous for palmar abduction. This study used the EIP to pull EPB tendon toward the pisiform bone. Therefore, the improvement in palmar abduction was potentially unsatisfactory, but the results were comparable with the modified Camitz method and, at the same time, statistically significantly improved pronation.

Similar to the novel technique, the Burkhalter technique using the EIP tendon is an excellent procedure for thumb opposition reconstruction.[19–23] However, the original Burkhalter technique requires the removal of the EIP up to the expansion hood to ensure that it reaches the flexor pollicis brevis attachment site.[4] This requires meticulous repair of the hood. Failed repair may lead to hood rupture, scarring, tight sutures, and, consequently, gliding issues. These complications can result in MP joint dysfunction due to extensor lag of the index finger MP joint.[27] Our method, which uses the EPB tendon, allows for a sufficient length without the need to harvest the EIP up to the expansion hood, thereby preventing extensor lag of the index finger MP joint.

The advantages of using the EPB tendon include the ability to perform sturdy interlacing suturing with 3 to 4 weaves in the palmar area, which allows for joint range of motion training from the early postoperative period. In traditional thumb opposition reconstruction, attempts have been made at various tendon insertion sites such as the attachment site of the APB and the EPB and extensor pollicis longus tendons. However, these structures are all thin, and it is challenging to confirm that they can provide robust insertion sites. The EPB tendon, as used in the studies of Phalen and Miller[25] and Kimori et al,[26] did not require tendon suturing to the MP joint. Hence, it facilitated tendon reconstruction for stable thumb opposition, irrespective of the surgeon's skill level. This, in turn, can help achieve a stable thumb opposition function.

This technique, which uses the EIP tendon controlled by the radial nerve, can address high median nerve paralysis and flexor tendon rupture. Hence, it has a wide application. However, this method has a limitation. That is, it requires two donor muscles, thereby implying a substantial sacrifice. In cases such as rheumatoid arthritis, where there is a high risk of additional tendon transfers in the future, either the Camitz or Bunnel technique should be considered.

The current study had several limitations. That is, the type of surgical procedure was selected based on the discretion of the physicians. Furthermore, the comparative study between the novel technique and the Camitz technique was retrospective in nature.

The preoperative functionality with the Camitz technique was not evaluated. However, thumb opposition reconstruction can be independent of preoperative performance. Thus, postoperative functional evaluation alone is sufficient in comparative studies. Nevertheless, due to the limited number of cases, a study with a large sample size should be performed in the future. This surgical procedure sacrifices the EPB tendon and may decrease the extension force of the thumb MP joint. It may not be used in cases with extensor pollicis longus muscle weakness.

The novel technique using the EPB tendon and EIP muscle is promising for thumb opposition reconstruction in severe CTS cases. This approach promotes stable thumb opposition function, thereby yielding satisfactory outcomes. Nevertheless, further studies with a larger sample size should be conducted to validate these findings.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

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