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Biomechanical assessment of brachioradialis pronatorplasty

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Objective: Transfer of the brachioradialis muscle, proposed by Özkan et al. can be applied to cases, in which, the biceps rerouting technique is not appropriate for the correction of forearm supination contracture and restoration of active pronation. We have aimed to assess the biomechanical effects of the brachioradialis transfer.

Methods: Pronation strength was acquired in nine fresh-frozen cadaver forearms by applying rerouting of the brachioradialis muscle through interosseous membrane (Group 1) or transferring the same muscle to the distal insertion of extensor carpi ulnaris (ECU) (Group 2). Then, a force of 5 to 35 N was applied to the muscle and the range of forearm rotation and rotation strength were measured. The normalities of the data were analyzed by Shapiro-Wilk test. Comparisons between the groups were made with independent-sample t-test and comparison of the data, obtained from the same group, was carried out with paired-sample t-test and Bonferroni correction.

Results: A maximum of 74° (with a mean of 61°) gain of pronation with rerouting and a maximum of 72° (with a mean of 65°) gain with ECU transfer of brachioradialis muscle were observed. A significant regression was also found in the first group. Regression constant was -9.59 ($p = 0.001$, 95%: -13.20; -6.00) for the applied force of 2.06 N ($p = 0.001$, 95%: 1.90; 2.22). Furthermore, a significant regression was found in the second group. Regression constant was -9.73 ($p = 0.001$, 95%: -13.13; -6.34) for the applied force of 1.91 N ($p = 0.001$, 95%: 1.76; 2.06).

Conclusion: The brachioradialis muscle works as a pronator in full forearm supination. However, when the forearm comes close to the neutral rotation, due to the lateral location of the proximal insertion, the brachioradialis muscle loses this pronator effect. The additional release or lengthening of contracted soft tissues increases the range of pronation.

Key words: Brachial plexus palsy; brachioradialis; cerebral palsy; supination; pronation.

Supination contracture of the forearm can occur as a result of the unopposed action of the biceps brachii and supinator muscles in traumatic or obstetric lower brachial plexus palsy, or polio.[1,2]

The correction of the rotational forearm deformities is extremely difficult. Several treatment methods have been proposed: sectioning of the dominating supinator muscle described by Steindler, osteoclasis, proximal radial osteotomy, the rerouting of the biceps tendon of Zancolli, and one-bone forearm fusion. More recently, Özkan et al. described rerouting of brachioradialis tendon and transferring the brachialis muscle to forearm muscles to restore the forearm's pronation and supination.[3] The brachioradialis muscle is used with success for the restoration of supination in pronation deformities. The effectiveness of this technique was proved by the biomechanical study of Cheema et al.[4]

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Özkan et al. changed the vector of the brachioradialis by rerouting through the intermuscular septum. After the exposure and release of the brachioradialis muscle, they lengthened its tendinous portion by 5 cm with Z-lengthening. Then, they passed the distal end of the tendon between the radius and the ulna, through the interosseous membrane in volar-to-dorsal and ulnar-to-radial direction and fixed it to the proximal tendon end.[5]

The supination contractures in neuro-muscular disorders, where supinator muscles are stronger compared to pronator muscles, have a negative effect on hand and all upper-body functions. Full supination is not an effective hand position for daily activities. Therefore, it is crucial to correct the supination contracture to obtain a functional hand.[6]

Tendon transfers are more appropriate for mild to moderate soft tissue contractures without any accompanying bone deformity and joint dislocation.[7] The triceps muscle must be intact to successfully perform the "rerouting" operation on the biceps, in order to restore pronation.[8]

The brachioradialis muscle is a good option in forearm muscle transfers, due to its anatomical position and strength.

The purpose of this biomechanical study was to analyze the effectiveness of the rerouting of the brachioradialis muscle and to assess the power of pronation after insertion of brachioradialis into different locations.

Materials and methods

Above-elbow upper extremities of nine fresh-frozen adult cadavers (age range, 65-75 years; 5 female, 4 male) were used for this study. All skin and subcutaneous fatty tissue were removed, and special care was taken for the preservation of the brachioradialis muscle and its attachments.

Each cadaveric specimen was verified to have at least 90° of passive pronation and supination. Specimens with gross deformity, or obvious evidence of previous injury or surgery were excluded from the study.

All the soft tissue cover of the proximal part of the humeral shaft was removed and the exposed humerus shaft was secured into a steel pipe. A threaded Kirschner wire and cement were used for fixation of the humeral shaft into the pipe. The Kirschner wire, with a diameter of 2 mm, was passed from each side of the pipe to cross the bone transversally at 1 cm from distal end of the pipe. After the wire fixation, the space between the pipe and the bone was filled with cement to prevent all possible movements.

The distal attachment of brachioradialis muscle was carefully preserved and fascial attachments around the muscle belly were stripped off. The muscle was freed from all its connections with the technique, described by Özkan. The distal brachioradialis tendon was cut at its musculotendinous junction as proximally as possible. Vicryl sutures (no. 2) were passed from the tendon with Krackow technique to form a secure pull-out cord at the proximal end of the brachioradialis (Fig. 1a). The proximal end of the free tendinous portion of the brachioradialis muscle was passed through interosseous interval in the volar–to-dorsal and ulnar-to-radial direction (Fig. 1b). With this rerouting, the proximal end of the distal brachioradialis tendon was taken to the dorsal and ulnar side of the shaft of the radius.

The wrist's ulnar extensor muscle was freed (Fig. 1c). This tendon was cut at the insertion of the distal and middle one-third of the forearm. Again, a no. 2 vicryl suture was used with the Krackow technique for pull-out cord (Fig. 2).

Separate cords were applied on the rerouted distal brachioradialis and ECU tendons. Then these cords were passed through a pulley on the mid-point of the proximal insertion of the brachioradialis muscle (Fig. 1d). Thus, the brachioradialis muscle had two new distal routes. In group 1, brachioradialis muscle was rerouted through interosseous membrane, while in group 2, it was transferred to the distal tendon of extensor carpi ulnaris (ECU). As we did this, we tried to simulate rerouting and transfer to ECU. The cords were then loaded vertically with 5, 10, 15, 20, 25, 30 and 35 N loads, respectively and the degree of pronation was recorded for each loading. The movements were initiated with full supination and 90° supination was accounted for 0°.

The rotational force, created during 35 N loading, was measured with a torque-meter (Digital Dial Torque Wrench ed 1-75i) (Fig. 3).

The normality of data was assessed with Shapiro-Wilk test. Independent sample t-test was used for the comparison between the two groups, and paired

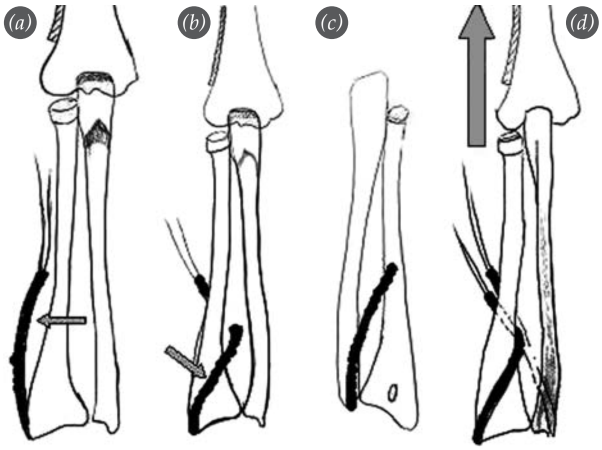

Fig. 1. **(a)** Brachioradialis tendon was freed proximally. **(b)** Brachioradialis tendon passed through interosseous membrane. **(c)** Extensor carpi ulnaris was freed. **(d)** Extensor carpi ulnaris was carried to radio-dorsal. Short arrows: brachioradialis, ECU: extensor carpi ulnaris.

sample t-test with Bonferroni correction, for the comparisons in the same group. Linear regression analysis was used for the comparison of the load and the degree of rotation.

Fig. 2. Brachioradialis and extensor carpi ulnaris carried dorsally and radially.

Results

While the rotation in 5 N loaded cadavers was noted as 3.5 degrees in average, it was 3.8 degrees in cadavers with ECU transfer. With the maximal load of 35 N, a 60.7 degree rotation was obtained, whereas with transfer to ECU the rotation was 64.9 degrees. With loading, pronating force could only bring the forearm to a slightly supinated position. After brachioradialis transfer, we observed that while forearm pronation could not be achieved, the pronating force decreased the degree of supination.

The torque was found to be 465.6 nm in rerouting and 526.7 in ECU transfer. In summary, transfer to ECU at each load level was found to be more effective (Table 1).

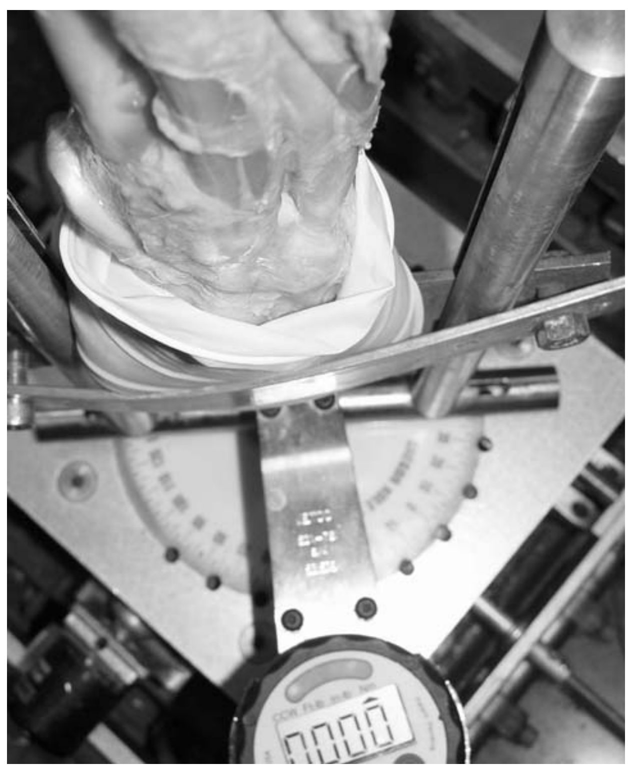

Fig. 3. Device used for free rotation of the forearm.

Table 1. Table of applied forces and rotation obtained.

Cadaver no	muscle	5n Motion	10n Motion	15n Motion	20n Motion	25n Motion	30n Motion	35n Motion	Torque
793l	br-ecu		4	13	41	53	63	67	480
793r	br-ecu	0	9	12	23	28	42	50	300
750r	br-ecu	8	20	19	35	47	53	68	700
795l	br-ecu	0	7	12	23	34	55	67	450
779l	br-ecu	0	12	23	26	35	55	69	500
750l	br-ecu	15	18	20	25	28	50	63	510
795r	br-ecu	7	19	25	30	41	54	68	550
779r	br-ecu	0	9	20	32	40	55	60	580
781l	br-ecu	0	10	23	35	44	57	72	670
.		3.75	12	18.556	30	38.889	53.778	64.89	526.7
793l	br rerouting	0	12	14	22	36	47	63	620
793r	br rerouting	5	10	13	27	34	49	64	300
750r	br rerouting	6	12	15	26	32	47	57	650
795l	br rerouting	4	11	14	29	38	50	61	510
779l	br rerouting	7	10	25	27	43	58	70	480
750l	br rerouting	5	10	20	28	50	56	74	390
795r	br rerouting	0	11	21	24	26	48	53	440
779r	br rerouting	0	7	11	21	28	46	54	350
781l	br rerouting	5	9	14	19	23	41	50	450
.		3.5556	10.222	16.333	24.778	34.444	49.111	60.67	465.6

br: brachioradialis; ecu: extensor carpi ulnaris; l: left; r: right

In each of the two groups, there were statistically significant changes in the degree of forearm rotation after loading ($p<0.005$). With regression analysis there was significant regression in the first group [Constant -9.59 (p=0.001, 95% safety rate: -13.20; -6.00), load applied 2.06 (p=0.001, 95% safety rate: 1.90; 2.22)].

In the second group there was significant regression [Constant -9.73 (p=0.001, 95% safety rate: -13.13; -6.34), load applied 1.91 (p=0.001, %95 safety rate: 1.76; 2.06)].

Regression analysis showed that the reaction we had was proportional to the forces applied. We observed that the pronation angle increased together with the force applied.

Discussion

Özkan et al. obtained a pronation gain of 49 degrees with brachioradialis rerouting and interosseous membrane release, in patients with a mean supination deformity of 28 degrees.[3]

In our study, an active and sufficient forearm pronation couldn't be achieved with brachioradialis rerouting and ECU transfer, because after 60 degrees of pronation this muscle starts to lose its "pronator" effect. The loadings of 5 to 35 N resulted in a pronation gain of 3.5 to 60.6 degrees. In brachioradialis - ECU transfer, the mean gain of pronation was found to be greater for every load, with the maximum gain being 64.9 degrees.

In both transfers, some pronation could be given to the forearm in full supination, yet, the pronation gained was not enough to bring the forearm to neutral position. In this study, we concluded that brachioradialis transfer may counter maximum supination contracture of the forearm, but could not provide a pronation beyond the neutral position. Even with the pronating power, gained by the transfer of the brachioradialis, the forearm remained in 25 to 30 degrees of supination.

Why has this technique been found to be biomechanically unsuccessful, despite its promising clinical results? The rotation of the forearm is the movement of the radius on a stable ulna and in order to achieve this movement, a muscle must exert a rotational force. Pronator teres, the most important forearm pronator, is located between medial epicondyle and 1/3 dorsoradial portion of the radial shaft. When facing a person with his right elbow in 90 degrees flexion, the contraction of pronator teres will pronate the forearm, bringing the thumb from 9 to 3 o'clock position, with the ulna, acting as the center of the hour dial (Fig. 4).

The proximal attaching midpoint of brachioradialis muscle, which is the main subject of our study here, is in 11 o'clock position. When the forearm is in neutral position, the proximal attachment of the muscle and the distal attachment midpoint are in parallel; therefore, there is not any rotation in neutral position (Fig. 5).

The distal attachment point moves to 12 o'clock position in pronation and to 6 o'clock position in supination of the forearm (Fig. 6). Thus, the brachioradialis can exert its rotational function when the forearm is in supination, and it works as a supinator when the forearm is in pronation.

In summary, the brachioradialis tries to bring the distal attachment point into the same axle with the proximal one. By bringing the brachioradialis from dorsal to volar to achieve supination, the distal attachment point is then in volar position, as the distal attachment point moves to 1 o'clock position, and explaining schematically, supination is achieved with a counter-clockwise rotation, as the supinator force in pronation status also increases. But if the distal attachment point of brachioradialis is moved to dorsal, this time it is in 5 o'clock position; and this achieves a rotation that is a pronation.

In the process of passing the brachioradialis muscle from volar to dorsal, through interosseous interval, in order to gain pronator force in supination deformity, the distal attachment point is taken to dorsal, which in turn gives way to a pronation increase (Fig. 7).

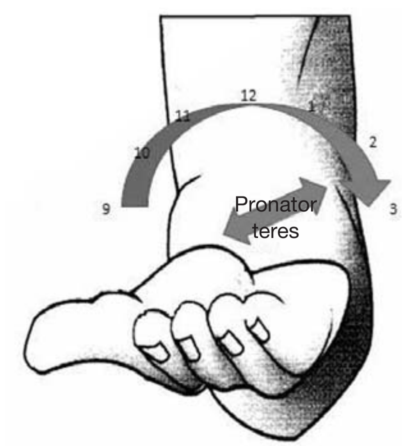

Fig. 4. Direction of pronator teres pull and rotational movement at full supination.

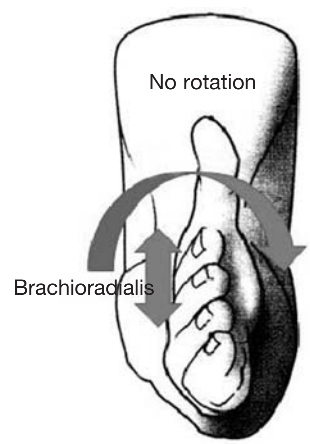

Fig. 5. Direction of brachioradialis pull at neural position. No further pronation.

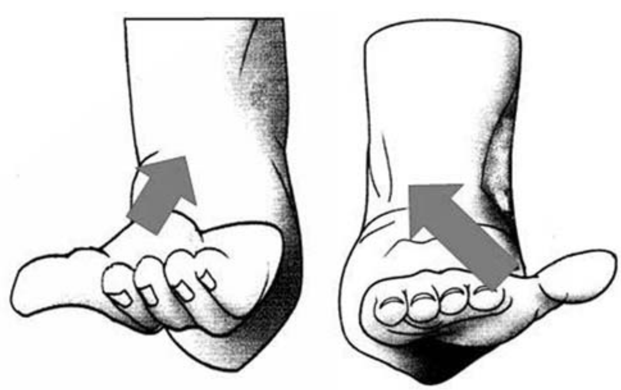

Fig. 6. Brachioradialis pronator at full supination, supinator at full pronation.

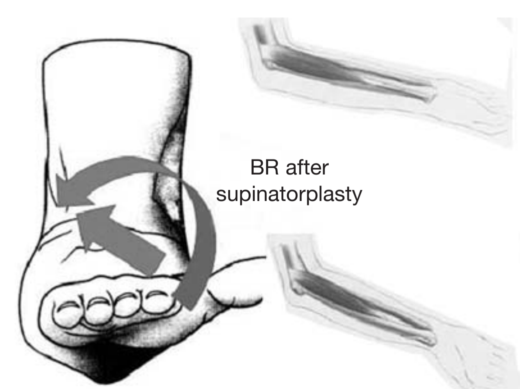

Fig. 7. Brachioradialis function after rerouting. BR: brachioradialis.

We believe that if we transfer brachioradialis to ECU, this will move the attachment point even closer to dorsoulnar; and thus, the rotation will be bigger and stronger. But at the end of this biomechanical study, we observed that, with ECU transfer in the forearm, a pronation of 64.8 and with rerouting, a pronation of 60.6 degrees, in average, could be achieved. More strength was achieved by transfer of brachioradialis to ECU. However, in neither of the techniques, pronation that exceeded neutral position could be obtained. Rotation ended in supination of 90-64.9=25.5 or 90-60.7= 29.3 degrees.

As with all motions, the force in the same axle must be continuous in order for the continuous rotation motion of the forearm. If the direction of the force, starting the motion, and the direction of the motion are same, the motion continues. However, since the brachioradialis muscle is attached to lateral epicondyle, when the forearm comes close to neutral rotation, the pronation vector disappears. If this muscle is used for supination in a pronated forearm; as the distal insertion will be in ulnar and volar position, relative to the proximal attachment; the supination force will continue even though in full supination. Therefore, transferring of the brachioradialis muscle cannot be a good pronator force, due to position of proximal attachments.

The positive clinical results of Özkan et al. may be related to the local effect of soft tissues releases and to the active pronator triggering effect of the transferred brachioradialis muscle. In our opinion, the proximal attachment of brachioradialis must be medialized, in order to use the muscle as an effective pronator. Although it is a good source for supination, the brachioradialis muscle can possess a limited functionality as a pronator, due to anatomical location of the proximal brachioradialis attachment.

Conflicts of Interest: No conflicts declared.

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