The Influence of Elbow Position on the Range of Motion of the Wrist Following Transfer of the Brachioradialis to the Extensor Carpi Radialis Brevis Tendon

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Background: In patients who have an injury of the cervical spinal cord, the brachioradialis tendon may be transferred to the extensor carpi radialis brevis tendon to restore voluntary wrist extension. We hypothesized that the active range of motion of the wrist depends on the position of the elbow after this transfer because the brachioradialis changes length substantially during elbow flexion, which implies the maximum force that the muscle can produce varies with elbow position. The objectives of this study were to determine whether the position of the elbow influences the range of motion of the wrist following transfer of the brachioradialis to the extensor carpi radialis brevis tendon and to evaluate the effect of surgical tensioning.

Methods: The range of motion of eight wrists was assessed after brachioradialis transfer. Two positions of the elbow were tested, the passive limit of elbow extension and 120° of flexion. The range of motion of the wrist was also simulated with use of a biomechanical model. Using the model, we compared the active range of motion of the wrist, with the elbow at 0° and 120° of flexion, following three different approaches to surgical tensioning. The simulations were also repeated to evaluate how muscle strength influences outcomes.

Results: Wrist extension decreased and passive flexion increased when the elbow was flexed. Maximum wrist extension was significantly correlated with passive flexion in all subjects ($r = 0.95$ and $p < 0.001$ when the elbow was extended and $r = 0.82$ and $p < 0.03$ when the elbow was flexed). The biomechanical model suggested that tensioning the tendon transfer so that the fibers of the brachioradialis do not become excessively short when the elbow is flexed may improve outcomes. The simulations also revealed that it is more difficult to maintain a consistent wrist position with the elbow in different postures when a weaker muscle is transferred.

Conclusions: The model suggests that altering the surgical tension could improve wrist extension when the elbow is flexed. However, the ultimate result is sensitive to the strength of the brachioradialis.

Clinical Relevance: The brachioradialis is the donor muscle most commonly used to restore the function of the wrist and hand in tetraplegia. Because many self-care activities involve acquiring an object at a distance from the body and then bringing the object close to the body, it is important to consider the influence of the position of the elbow on the function of the transferred brachioradialis.

The ability to extend and flex the wrist is considered a critical component for restoration of hand function after paralysis of the upper extremity[1-4]. Because of the passive forces developed by the muscles of the fingers and thumb, wrist extension closes the hand and wrist flexion opens the hand, providing a means to grasp and release light objects[5]. Individuals with a spinal cord injury at the fifth cervical segment have severely weakened or paralyzed wrist extensors and paralyzed wrist flexors. Surgical transfer of the distal tendon of the brachioradialis, a nonparalyzed elbow flexor, to the distal tendon of the extensor carpi radialis brevis, a paralyzed wrist extensor, restores active extension of the wrist[6]. With active extension restored, gravity provides passive flexion of the wrist.

Functionally, it is important to be able to extend and flex the wrist over a broad range of elbow postures because many self-care activities (e.g., eating and grooming) involve acquiring an object at a distance from the body and bringing it close to the body. However, it has been suggested that function that is restored by brachioradialis transfer is weak with the elbow in

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TABLE I Data on the Subjects

Limb	Gender, Age *(yr)*	Side	Motor Level	Modified International Classification*[17]	Type of Accident That Caused Injury	Time from Injury to Surgery *(yr)*	Neuroprosthesis
A†	F, 37	Right	C5	0:1	Motor vehicle	1.8	Yes
B‡	M, 30	Left	C6	0:2	Diving	2.0	Yes
C	M, 31	Left	C5	OCu:1	Diving	3.7	No
D	M, 47	Left	C5	0:1	Motor vehicle	15.3	Yes
E	M, 35	Right	C5	OCu:1	Diving	13.9	Yes
F‡	M, 30	Right	C5	0:1	Diving	2.0	No
G	M, 43	Right	C5	0:1	Motor vehicle	6.0	No
H†	F, 37	Left	C5	0:1	Motor vehicle	1.8	No

*O = ocular sensibility, Cu = cutaneous sensibility, 1 = brachioradialis, and 2 = brachioradialis and extensor carpi radialis longus. †A and H are the right and left arms of one subject. ‡B and F are the left and right arms of one subject.

flexed postures[5,7]. While the maximum force that a muscle can produce is proportional to its cross-sectional area[8], the force that a muscle generates also varies as a function of its length[9] and the surgeon chooses the length of the brachioradialis (i.e., tensions the transfer) intraoperatively when attaching it to the extensor carpi radialis brevis. Thus, the surgical technique influences the force-generating properties of the transferred brachioradialis, which suggests that adjusting the tensioning is a potential means of improving outcomes[10,11]. Currently, surgeons rely primarily on their experience and intuition when deciding the length at which muscles are attached during a tendon transfer. There is evidence that donor muscles are being tensioned inadequately for maximum active force generation[12].

We hypothesized that the motion of the wrist depends on the position of the elbow after transfer of the brachioradialis to the extensor carpi radialis brevis tendon and that surgical tensioning of the transfer can be optimized to provide better function with the elbow in flexed postures. The objectives of this study were to quantify the effect of the position of the elbow on active motion of the wrist in individuals with a transferred brachioradialis and to determine if the force-length properties of the transferred brachioradialis could explain the range of motion measured in the wrist postoperatively. We used a biomechanical model to evaluate theoretically how the force-length properties of the transferred brachioradialis impact the range of motion of the wrist at different elbow positions and to determine if surgical tensioning of the transfer could be designed to improve surgical outcomes.

TABLE II Summary of Preoperative and Postoperative Manual Muscle-Testing

		Strength on Manual Muscle-Testing*				
		Preoperative		Postoperative		
Limb	Duration of Follow-up *(mo)*	Brachioradialis	Wrist Extension†	Wrist Extension†	Elbow Extension‡	Source of Elbow Extension
A	76	4	0	4	1	Transfer of posterior part of deltoid to triceps, transfer of biceps to triceps
B	63	5	3	3+	2–	Transfer of posterior part of deltoid to triceps
C	50	4	2	4	2–	Transfer of posterior part of deltoid to triceps
D	58	4	1	3–	2–	Transfer of posterior part of deltoid to triceps
E	36	4	2	2	2–	Triceps
F	63	5	2+	2+	1	Triceps
G	15	4	2–	2–	1+	Triceps
H	76	4	0	1+	2–	Transfer of posterior part of deltoid to triceps, transfer of biceps to triceps

*A grade of 0 indicated no contraction; 1, a flicker or trace of contraction; 2, active movement with gravity lessened; 3, full range of motion against gravity; 4, full range of motion against gravity and resistance; and 5, normal contraction. Plus or minus grades denote varying degrees of resistance or motion. For example, 3+ indicates full of range of motion against gravity with slight resistance. †Wrist extension includes the extensor carpi radialis longus and brevis preoperatively and the brachioradialis-extensor carpi radialis brevis transfer and extensor carpi radialis longus postoperatively. ‡As indicated, elbow extension is provided by either residual triceps function or by transfer of the posterior part of the deltoid to the triceps tendon. In addition to the transfer of the posterior part of the deltoid, one subject (limbs A and H) also had a transfer of the biceps to the triceps tendon in both arms.

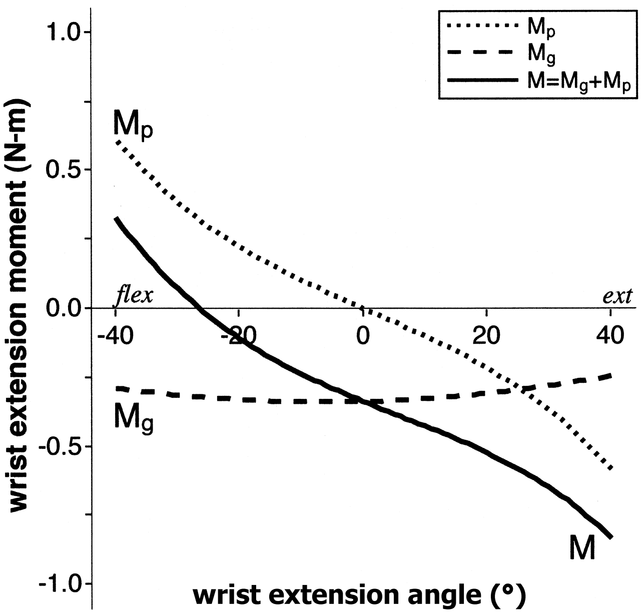

Fig. 1

The passive properties of the wrist joint as a function of the position of the wrist. The positive numbers indicate extension of the wrist, and the negative numbers indicate flexion. The total passive moment (M) at the wrist joint includes a gravitational wrist flexion moment imposed by the weight of the hand (M_g) and the passive moment produced by the structures and muscles that cross the joint (M_p), measured in an individual with tetraplegia at the fifth cervical segment[22]. The position at which the total passive moment is zero (26° of flexion) is the most flexed posture of the wrist that can be achieved unassisted when the wrist flexors are paralyzed. The passive properties of the wrist joint that are shown do not include the passive wrist extension moment produced by the tendon transfer.

Materials and Methods

The transfer of the brachioradialis to the extensor carpi radialis brevis tendon is performed with the patient under general anesthesia, with the elbow positioned at 90° of flexion and the wrist in neutral position after a pneumatic tourniquet at 250 mm Hg is placed on the upper extremity. The surgical procedure for the transfer involves an incision over the radial border of the forearm[6], approximately 5 to 15 cm in length, depending upon the length of the extremity and the depth of the subcutaneous fat layer. The incision is centered on the middle third of the radius. The brachioradialis and extensor carpi radialis brevis are identified, and the radial sensory nerve is identified and protected. The brachioradialis is released from its distal attachment and is mobilized from the fascial attachments along its length until maximum passive excursion is achieved[7]. The brachioradialis tendon is attached to the tendon of the extensor carpi radialis brevis with use of the side-weave technique described by Pulvertaft and clamped in place[13]. Tension is set by applying intraoperative electrical stimulation with use of an insulated needle within the brachioradialis muscle. The adequacy of the contraction for extension of the wrist is also evaluated with the elbow in different positions. The limitations of this technique include the possibility that the electrical stimulation may also activate the upper motor-neuron-innervated wrist extensors or it may not recruit the brachioradialis fully. After tensioning, the tendons are secured with use of braided nonabsorbable sutures on tapered needles. All patients are managed with immobilization of the wrist in a cast for three weeks postoperatively, followed by one to two weeks of inpatient rehabilitation and training in use of the transfer.

Transfer of the brachioradialis to the extensor carpi radialis brevis is often performed in conjunction with other surgical procedures. Additional procedures that are commonly performed include split flexor pollicis longus tenodesis (to the extensor pollicis longus insertion), transfer of the posterior part of the deltoid to the triceps tendon, and implantation of an upper extremity neuroprosthesis[14,15]. Patients who do not receive the neuroprosthesis often undergo flexor pollicis longus tenodesis[16] and extensor pollicis longus tenodesis.

Clinical Assessment of the Range of Motion of the Wrist

Active range of motion of the wrist was evaluated in six individuals (eight limbs) with a transferred brachioradialis. Injury levels, categorized with use of the International Classification for Surgery of the Hand in Tetraplegia[17], were obtained from medical records (Table I). The active motion of the wrist was evaluated with the arm in a posture in which gravity opposes wrist extension; the shoulder was abducted 90°, and the forearm was in mid-pronation-supination (neutral position). The most extended position and the resting position of the wrist were measured with the elbow at the passive limit of extension (which ranged from 0° to 10° of elbow flexion among the subjects) and 120° of flexion. These data were collected by an occupational therapist with use of a hand-held goniometer. While the resting position against gravity (i.e., passive flexion angle) is determined solely by the passive properties of the wrist and not by active muscle contraction, we defined "active" range of motion to be the difference between the most extended wrist angle and the passive flexion angle. This measure represents the range of motion available to the individual for functional activities. Two-tailed paired-difference t tests were performed to evaluate whether maximum extension and passive flexion of the wrist changed with elbow posture.

The range of motion of the wrist and the manual muscle grades for the brachioradialis-extensor carpi radialis brevis transfer and the extensor carpi radialis longus together were determined at an average of fifty-five months (range, fifteen to seventy-six months) postoperatively (Table II). Elbow extension strength was also graded postoperatively because active elbow extensors are necessary to stabilize the elbow during wrist extension after a brachioradialis transfer[16,18]. Postoperative manual muscle grades were assessed by an occupational therapist. Preoperative manual muscle grades for the brachioradialis and the wrist extensors (the extensor carpi radialis brevis and longus) were assessed retrospectively from medical records. All subjects provided informed consent; the human subjects protocol was approved by the Institutional Review Board of the hospital where the study was conducted. All of the data in the present study represent each individual's voluntary capabilities. That is, none of the subjects who were tested used a neuroprosthesis during the clinical assessments.

Computer Simulation of the Range of Motion of the Wrist

Using a computer-graphics-based model of the upper extremity[19,20], we simulated the active range of motion of the wrist after the transfer of the brachioradialis to the extensor carpi radialis brevis tendon. The computer model allows the calculation of muscle lengths, forces, moment arms, and joint moments (the product of muscle force and moment arm) as a function of both elbow and wrist position[21]. Like the data obtained clinically, the range of motion of the wrist was simulated with the shoulder abducted 90° and the forearm in neutral position. In each simulation, we assumed that the brachioradialis was fully activated (i.e., producing the maximum force possible) and that elbow extension strength was sufficient to balance the elbow flexion moment that is produced by the transferred brachioradialis when it is activated to extend the wrist.

In order to achieve a given wrist position, the transferred brachioradialis must be able to produce a wrist extension moment (i.e., torque) that can balance the wrist flexion moment imposed by the weight of the hand and the passive moments generated by muscles and joint structures. Thus, to simulate active range of motion following the transfer of the brachioradialis to the extensor carpi radialis brevis, we first calculated the total passive moment at the wrist joint when the arm is oriented so that gravity opposes wrist extension (Fig. 1). The total moment was estimated by combining the passive moment produced at the wrist by a subject with tetraplegia at the fifth cervical segment[22] with the wrist flexion moment imposed by the weight of the hand. We estimated the gravitational wrist flexion moment on the basis of regression equations that defined the mass and the center of mass of the hand for a 75-kg, 180-cm-tall male[23]. On the basis of these data, the resting position of the wrist against gravity (the wrist position at which the net passive moment at the wrist joint equals 0 N-m) is 26° of flexion. When the wrist is more extended than 26° of flexion, a passive wrist flexion moment is produced. To maintain a more extended position, the transferred brachioradialis must produce a wrist extension moment equal to the passive wrist flexion moment at that position.

Using a computer model, we estimated the range of motion of the wrist with the elbow at 0° and 120° of flexion following three different approaches to surgical tensioning (described below). In each condition, the active range of motion was determined by identifying the range of wrist positions in which the brachioradialis-extensor carpi radialis brevis transfer could produce a wrist extension moment that balanced the passive properties of the wrist.

Our model assumes that the line of action of the transfer is identical to the path of the brachioradialis at the elbow joint and identical to the path of the extensor carpi radialis brevis at the wrist. Thus, it combines the elbow flexion moment arm of the brachioradialis[19,24] with the wrist extension moment arm of the extensor carpi radialis brevis[25]. The isometric force-generating properties of the transfer were derived from muscle architecture[26,27]. Three architectural parameters of the muscle that are necessary to estimate isometric force were determined for the brachioradialis in a previous study[28]. These three parameters include physiological cross-sectional area, optimal fiber length (the fiber length at which the muscle produces its maximum force), and pennation angle.

Tendon slack length, the fourth parameter that is neces-

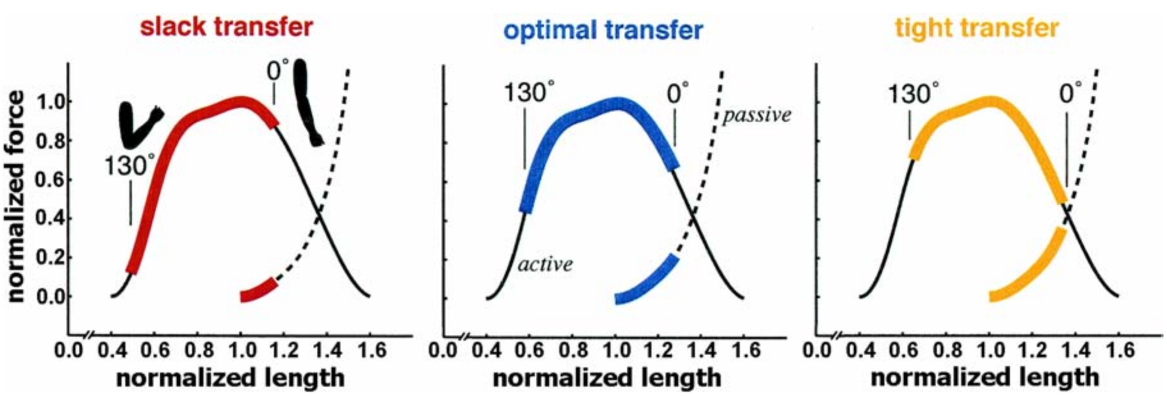

Fig. 2

The model estimate of the operating range of the brachioradialis-extensor carpi radialis brevis tendon transfer between full extension of the elbow (0°) and 130° of flexion for the slack transfer (red), optimal transfer (blue), and tight transfer (yellow) with the wrist in neutral position. The fiber lengths calculated with use of the model were normalized by the optimal fiber length and were superimposed on active (solid thin line) and passive (dashed thin line) isometric force-length curves[29] to illustrate how length changes that occur with elbow flexion influence each transfer's force-generating capacity in different joint postures. In this figure, muscle force is normalized to peak isometric force. As indicated in this figure, our model assumes that muscle develops passive force when it reaches fiber lengths that are greater than optimal length. When the muscle is fully activated, the total force produced by the transfer is the sum of the active and passive forces. Note that for any given joint position, the slack transfer operates at the shortest fiber length and the tight transfer operates at the longest length.

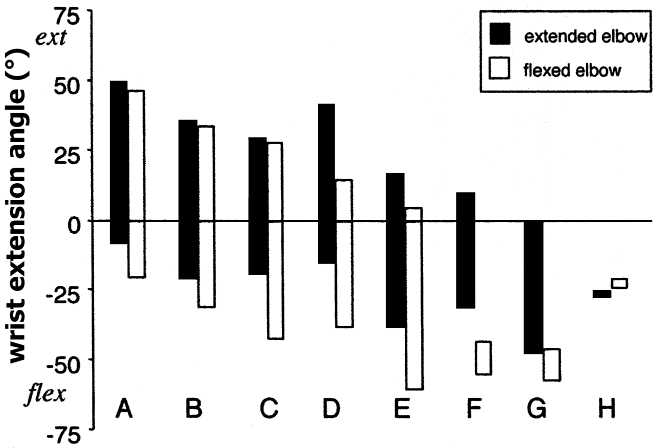

Fig. 3

The active range of motion of the wrist measured in eight wrists with the elbow extended (filled bars) and flexed 120° (open bars). The positive numbers indicate extension of the wrist, and the negative numbers indicate flexion of the wrist. Each bar indicates the resting position (bottom) and the most extended position (top) of the wrist against gravity.

sary to estimate isometric force, was adjusted to simulate three different approaches to surgical tensioning of the transfer: an optimal transfer, a slack transfer, and a tight transfer. The operating ranges (how much and what portion of the isometric force-length curve that the transfer uses during joint rotation) of the optimal, slack, and tight transfers differ from each other (Fig. 2). The portion of the isometric force-length curve that the transfer uses during joint rotation is calculated with use of the model and is based on the moment arms of the transfer at the elbow and wrist, the optimal fiber length of the brachioradialis, and the tendon slack length[28,29]. The tendon slack length of the optimal transfer was chosen so that the transfer operated on the portion of the force-length curve that maximized active range of motion with the elbow at full extension (0°) and 120° of flexion, essentially the same positions at which the range of motion of the wrist was assessed clinically. For the slack transfer, the tendon length was increased by 1.7 cm relative to the optimal transfer, causing the slack transfer to operate at shorter muscle fiber lengths over the same range of motion (Fig. 2). For the tight transfer, the tendon length was decreased by 1.3 cm relative to the optimal transfer, and the tight transfer operated at longer fiber lengths during elbow rotation.

The maximum isometric force that the brachioradialis can produce was estimated as the product of physiological cross-sectional area and maximum muscle stress, which we defined as 50 Ncm^{-2}. While this value is larger than those generally reported for individual muscle fibers or motor units[30], it has been shown that a larger value is often required when estimating the force-generating capacity of whole muscles with use of physiological cross-sectional area data obtained from cadavers[26]. Previous studies[20,25,26,31,32] have described scaling of the cross-sectional areas of the upper extremity muscles by factors ranging from 25 Ncm^{-2} to >100 Ncm^{-2}. Because a broad range of values has been reported for maximum muscle stress, there is some degree of uncertainty in our estimate of peak brachioradialis force. To address this uncertainty, we performed a second set of simulations to evaluate the effect of brachioradialis strength on surgical outcome. In these simulations, we scaled the physiological cross-sectional area by 25 Ncm^{-2}, reducing the force-generating capacity of the brachioradialis (and the moment-generating capacity of the transfer) in the model by 50%. When compared with the original simulations, the results from the second set of simulations illustrated how surgical outcome is influenced when a given tensioning approach is implemented with a weaker muscle.

Results

The active range of motion of the wrist depends on the position of the elbow after the transfer of the brachioradialis to the extensor carpi radialis brevis tendon. Seven of the eight wrists were able to extend from the resting position, but the arc of motion varied among the limbs (Fig. 3). In these seven, the wrist position that could be maintained against gravity was less extended when the elbow was flexed ($p < 0.05$). On

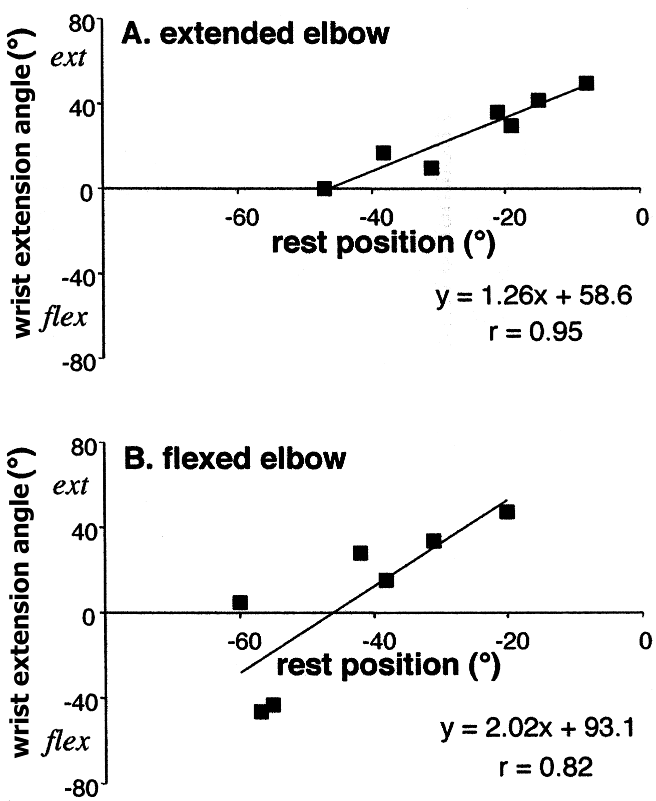

Fig. 4

The maximum extension of the wrist that could be achieved against gravity versus the resting position of the wrist against gravity when the elbow was extended *(A)* and when the elbow was flexed *(B)*. In the seven wrists in which the tendon transfer provided active extension of the wrist, the extension was significantly correlated to the resting position (passive flexion angle) of the wrist.

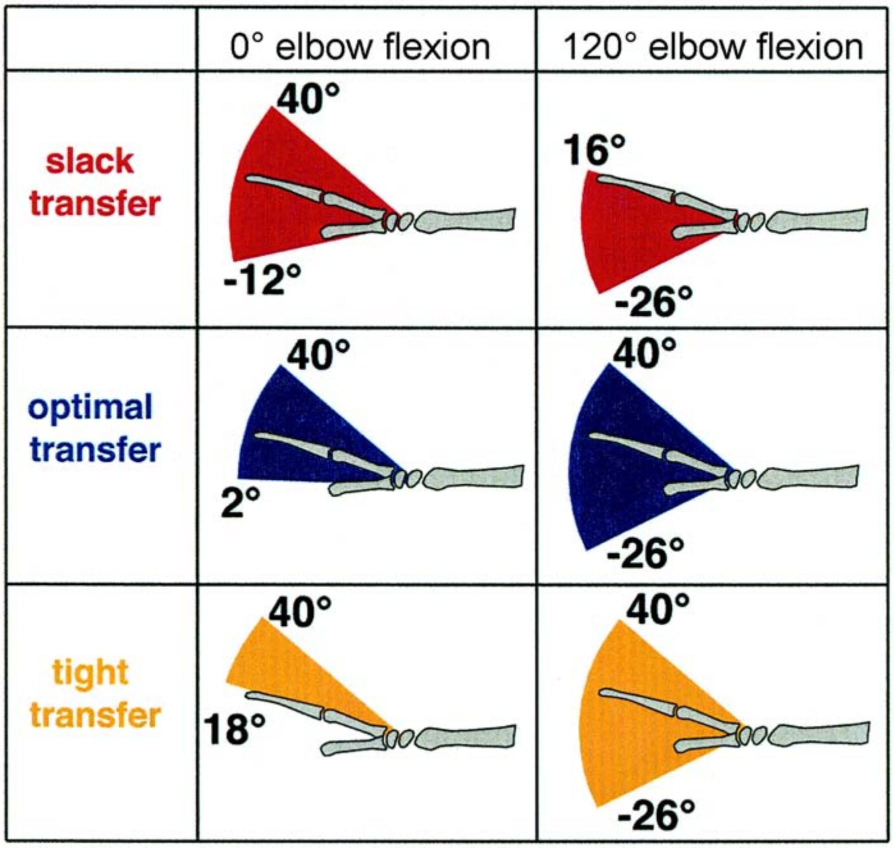

Fig. 5

Computer simulations of the active range of motion of the wrist against gravity for the slack (red), optimal (blue), and tight (yellow) transfers with the elbow in two postures. The bottom arc of each shaded region corresponds to the resting position of the wrist against gravity; the top arc corresponds to the most extended position that can be maintained against gravity.

the average, the extension of the wrist was reduced 21° (range, 2° to 53°) when the elbow was flexed. Also, more passive flexion was achieved when the elbow was at 120° of flexion than when it was at the passive limit of extension ($p < 0.001$). The resting position of the wrist was an average of 18° (range, 10° to 24°) more flexed when the elbow was flexed.

The data illustrate a strong relationship between active wrist extension and passive wrist flexion following the transfer. Increased passive flexion was associated with decreased active extension in the seven wrists that were able to extend from the resting position postoperatively (Fig. 4). This was true both when the elbow was extended ($r = 0.95$, $p < 0.001$) and when the elbow was flexed ($r = 0.82$, $p < 0.03$). The resting position of the wrist against gravity is determined by the passive properties of the wrist joint. Thus, these data imply that passive properties have a strong influence on the outcome of the transfer.

The biomechanical model indicated that surgical tensioning of the transferred brachioradialis influences both active wrist extension and passive flexion. Elbow flexion compromised active wrist extension after the slack transfer but not following the optimal or tight transfer in the model (Fig. 5). For all three tensioning approaches, the wrist rested in a more flexed posture when the elbow was flexed. Passive flexion was severely limited by the tight transfer when the elbow was extended.

Comparisons of the simulations with different brachioradialis strengths indicated that the weaker muscle generally achieved less extension of the wrist (Fig. 6). In addition, maximum extension of the wrist decreased with elbow flexion in all three tensioning conditions when the weaker transfer was simulated. With the elbow extended, the weaker muscle achieved more passive flexion for all three tensions than did the original simulations. In both sets of simulations, the tight transfer resulted in the greatest restriction of passive flexion.

Discussion

The inability of patients with an injury of the cervical spinal cord to achieve a consistent wrist posture in different elbow positions could influence pinch force and could limit their ability to acquire, hold, or release objects. In particular, difficulty extending the wrist when the elbow is flexed may limit independence because many important daily activities require the use of the hand close to the body. Our clinical assessments of eight wrists indicated that maximum extension of the wrist can decrease substantially with flexion of the elbow following the transfer of the brachioradialis to the extensor carpi radialis brevis (Fig. 3). Our computer simulations suggested that it may be possible to address this deficit by tensioning the transfer so that the fibers of the brachioradialis do not become excessively short when the elbow is flexed. The biomechanical model implied that relatively small changes in tensioning (e.g., pulling 1 to 2 cm more of the brachioradialis tendon through the extensor carpi radialis brevis) may put the transfer at a more advantageous portion of the isometric force-length curve when the elbow is flexed. However, it is important to note that the model also indicated that this type of adaptation could reduce passive flexion when the elbow is extended. We caution surgeons to evaluate the trade-off between improving extension of the wrist (which closes the hand) and limiting flexion of the wrist (which opens the hand) when considering adaptations to current surgical techniques.

The computer model also revealed that, for a given surgical approach, a weaker muscle is less likely to provide consistent extension of the wrist with the elbow in different postures (Fig. 6). Unfortunately, because manual muscle tests only provide a subjective measure of strength, it is unlikely that preoperative assessments of brachioradialis strength are sensitive enough to predict whether a surgical candidate will achieve strong wrist extension postoperatively. For example, all eight limbs tested in this study had grade-4 or 5 brachioradialis strength, and preoperative muscle grades did not distinguish the four wrists that achieved at least grade-3 extension postoperatively from the four that did not (Table II). While intraoperative measures of the force that the brachioradialis produces in response to electrical stimulation could provide useful information[33,34], these measurements are difficult to obtain and are not standard clinical practice. Notably, we found that maximum extension of the wrist was strongly correlated with the resting position of the

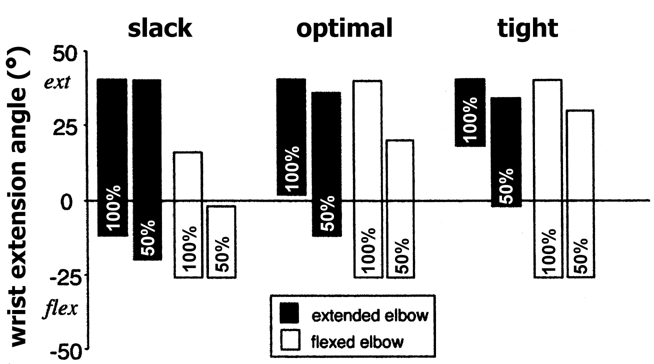

Fig. 6

The active range of motion of the wrist estimated with use of the original model (the bars labeled 100%) and with the brachioradialis strength reduced in the model by 50% (the bars labeled 50%). The filled bars indicate the range of motion of the wrist estimated with the elbow at 0° of flexion (full extension), and the open bars indicate the range of motion estimated with the elbow at 120° of flexion. The positive numbers indicate extension of the wrist, and the negative numbers indicate flexion. Each bar indicates the resting position (bottom) and the most extended position (top) of the wrist against gravity. The weaker muscle was less able to maintain extension of the wrist across elbow postures.

wrist (Fig. 4). These data suggested that preoperative and intraoperative assessments of passive flexion could potentially provide an indicator of how effectively the transfer of the brachioradialis to the extensor carpi radialis brevis will restore wrist extension in a particular surgical candidate.

Three important limitations of the biomechanical analysis should be noted when evaluating the conclusions drawn from our computer simulations. First, this study did not take into account the potential impact of sarcomere adaptations that may occur after tendon transfer. For example, data from a study involving the hind limbs of rabbits have suggested that if donor muscles are attached at fiber lengths that are too long, muscle adaptations may occur that reduce sarcomere number and fiber length and limit muscle excursion[35]. Little is known about how human muscle adapts after a tendon transfer. However, if substantial sarcomere adaptations occur postoperatively, the biomechanical simulations in the present study may not adequately represent how adjustments to surgical tensioning impact clinical outcomes. Second, we assumed that the passive properties of the wrist joint remained constant in different elbow postures. Because some muscles that cross the wrist originate from the humerus, changing the position of the elbow may also change the passive properties of the wrist joint. Since voluntary strength and function are restricted in tetraplegic patients, improving the characterizations of passive joint properties should be a priority in future studies. Third, this study only evaluated how elbow and wrist position affect the primary function of the wrist after the brachioradialis-extensor carpi radialis brevis transfer. This transfer may also influence other degrees of freedom of the upper extremity, such as radial deviation or forearm rotation. Because individuals with tetraplegia have minimal control over antagonists that can stabilize the arm, these factors may also play a role in the function of the hand postoperatively.

Other clinical issues that were not evaluated in this study could influence surgical outcomes. Weak elbow extensors will limit the ability of the patient to fully activate the transferred brachioradialis if the elbow extensors are not strong enough to balance the elbow flexion moment that the brachioradialis produces[18]. The source of elbow extension varied among the subjects in our study (Table II) and was generally weak in all subjects. It is unclear if this weakness influenced the range of motion of the wrist in any of our subjects. Similar to weak elbow extensors, muscle denervation or difficulty learning to voluntarily activate the brachioradialis as a wrist extensor could affect the wrist extension provided by the tendon transfer. In addition, the formation of scar tissue or adhesions could prevent the transmission of force across the wrist, resulting in diminished function[36,37]. While we did not evaluate the importance of these factors in our subjects, we acknowledge their capacity to influence the outcomes after tendon transfer.

To our knowledge, this work is the first to document how wrist function varies with elbow position following the transfer of the brachioradialis to the extensor carpi radialis brevis tendon. In addition, the biomechanical analysis in the present study illustrates that surgical tensioning can directly influence the restored range of motion and suggests that adapting the surgical technique may be a means to address postoperative limitations in extension of the wrist. We believe that the integration of biomechanical modeling with quantitative assessments of postoperative function provides a novel opportunity to better understand surgical outcomes and, ultimately, to improve surgical results. ■

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