FROM THE ORTHOPAEDIC HOSPITAL IN COPENHAGEN

ELBOW FLEXOR PLASTY IN TENDON TRANSPOSITION

(An analysis of the functional result in 26 patients).

By

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In the years following the great polio epidemic in Denmark in 1952, an increasing number of patients were referred for orthopaedic reconstruction of their paralytic extremeties.

The two main groups of operations applied, were arthrodeses and tendon-muscle transpositions. Frequently a combination of procedures was preferred, since efforts were concentrated on achieving the optimal result with regard to both strength, stability and coordination.

Amongst the aim of reconstructive treatment of upper extremity paralysis was the restoration of active elbow flexion in case of permanent paralysis of the normal elbow flexors (biceps brachii: long and short head, brachialis and brachioradialis). To fulfill this task Steindler's elbow flexor plasty (1) was favoured, whereas the pectoral plasty described by Clare was employed only in a few selected cases.

In 1918 Steindler published the results of his first attempts with his new technique. Steindler's brilliant idea consists of utilising the forearm flexor group as a substitute for the normal elbow flexors by increasing the muscle group's negligeable lever arm on the elbow joint and thus providing the muscles with "a reciprocal task" in addition to the original function in the wrist joint, hand and fingers.

Steindler's operative procedure is performed as follows: A longitudinal incision is made along the medial aspect of the elbow joint from 5 cms. above the joint to the medial epicondyle and from here swinging radially along the radial edge of the pronator teres to about 5 cms. distally of the joint. The skin and subcutaneous tissue are reflected and the ulnar nerve is isolated and drawn carefully aside. The common head of the flexors is then exposed and released subperiosteally from

the epicondyle. In order to obtain sufficient length of the transplant, the muscle group is dissected bluntly as far as this is permissible, bearing in mind the motor nerve branches from the median and ulnar nerves.

Finally the transplant is fixed proximally at the medial rim of the humerus, which is exposed by dissection along the medial intermuscular septum between the brachialis and triceps. The tendon is fixed to the periosteum or through drill holes in the bone with the elbow in flexed position and the forearm in maximal supination.

This position is maintained for 3 weeks in circular plaster of Paris. After this period the plaster is replaced by a dorsal splint furnished with flexible joint. The degree of flexion is gradually diminished and 6 weeks postoperatively exercises is commenced after removal of the splint.

A more detailed analysis of the functional result in a larger series did not emerge until Steindler's own report in 1939 on 29 cases (3). In the following 20 years serial publications revealed the great interest for this intervention (*Carrol & Gartland* 1953 (4), *Mayer & Green* 1954 (5, 6). *Schoettstaedt, Larsen & Bost* 1958 (7) and *Segal, Seddon & Brooks* in 1959 (8)).

The above authors all agree with the premises: a strong forearm flexor group and a good hand function. *Mayer & Green* emphasise the importance of strong wrist joint flexors, since these require the major power of the muscle group.

A hand capable of function is a conditio sine qua non, since the operation would otherwise lack all purpose. In case of impaired hand function several authors recommend a primary reconstruction of hand function. *Steindler & Carroll,* however, preferred inverse sequence, as they point out that the best result of tendon transfer in the hand is achieved, if the origin of the muscles is transposed in advance.

2 important drawbacks of Steindler's operation are some restriction of supination and elbow extension. In case of pronation contracture, tenotomy of pronator teres and/or pronator quadratus may be a good solution, while a threatening contracture with restriction of active supination has in several cases been overcome by tendon transposition reinforcing the supination.

For the latter purpose Steindler perfers a transposition of the flexor carpi ulnaris around the forearm with fixation to the radius, while Tubby has described another method, in which the pronator teres and

flexor carpi radialis are detached distally and brought through the interosseous membrane to the dorsal aspect of the radius.

Segal, Seddon & Brooks attribute the loss of supination to the loss of the main supinator, the biceps, while *Carroll & Gartland*, agreeing with this, point out the importance of adequate exercises of the accessory supinator muscles, particularly the extensor pollucis longus and flexor carpi ulnaris.

The postoperative limitation of extension is by most authors ascribed to a paralytic triceps. Both *Steindler* and *Seddon & Brooks* point out the significance of this loss of antagonistic strength, and the first-named warns against the early onset of contracture.

The importance of an adequate, postoperative retraining of the extension is generally accepted. In case of a weak Triceps, *Mayer & Green* go so far as to remove the plaster after only 2 weeks, and immediately begin exercise with special attention to extension. On the other hand *Schoettstaedt, Larsen & Bost* point out that a complete extension is rarely obtainable and even not desirable, since elbow flexion is facilitated from an initially position of flexion. In agreement with this *Seddon & Brooks* are able to demonstrate a relationship between the flexion power force of the transplant and the degree of restricted extension.

Amongst other attempts to counteract the limitation of extension, primary splinting in a more extended position may be mentioned.

Due to these difficulties and on the basis of a more exact analysis, several authors have tried to modify the operation. Thus *Mayer & Green* fix the common head of the flexors laterally to the anterior aspect of the humerus in an attempt to counteract the pronation tendency and state that they are able to lessen, although not prevent it. The same authors have furthermore attempted to increase strength by a simultaneous transfer of the extensor group, but were compelled to give this up due to the technical difficulty in preserving the motor nerve branches.

Bunnell's lengthening the insertion with fascia lata transplant, Eyler's suggestion of dispensing with the flexor carpi ulnaris in order to obtain better clivage (Henry's internervous plane), and *Mayer & Green's* careful dissection of the flexor group to achieve a higher and more lateral position are all strivings for a more ideal utilisation of Steindler's original idea and a further step towards normal function.

In the same way the present study is a modest attempt to contribute to the solution of these problems.

The following may be mentioned as the most important alternatives to Steindler's operation:

1. Clarc's transposition of the pectoralis major to the biceps. (2).
2. Brook's & Seddon's modification of the above (9).
3. Bunnell's transposition of the sternocleidomastoideus to the biceps using fascia lata transplant for lengthening.
4. Carroll's transposition of the triceps to the biceps.

In addition various forms of pectoralis plasty have been utilised since *Schultze-Berge* in 1917 (12) made use of the muscle for the first time, but it was not until Clarc's modification in 1946 that this form of elbow activation was generally accepted.

A single case in which the pectoralis minor has been used, was published by *E. Spira* from Israel (13).

In the present study we employed Clarc's operation only in individual cases.

Personal series:

26 patients operated for elbow paralysis at The Orthopaedic Hospital in Copenhagen, dept.s I, II and III in the years 1951–59.

22 cases were polioparalysis, 3 trafficlesions of the brachialplexus and a single case a sequence of an obstetric lesion.

1/3 of the operations were performed on women, 2/3 on men, including 2 operations on the same patient with bilateral paresis.

The operations were performed 2–6 years after the first orthopaedic consultation with the exception of single cases in which individual factors in the patients' invalid condition or the treatment became predominant. The premises for operation were generous, so far as the claim for full strength in the transposed muscles was not absolute, whereas the requirement for adequate hand function was decisive. In cases of insufficient hand function the Steindler operation was always preceded by hand reconstruction and the result of this was determining the elbowplastics.

Operative technique:

The technical procedure followed the principle stated by Steindler. Most frequently the common caput of the flexors was detached from the medial epicondyle by chiseling away a small slice of bone a.m. Campell; in individual cases the tendon was freed subperiosteally.

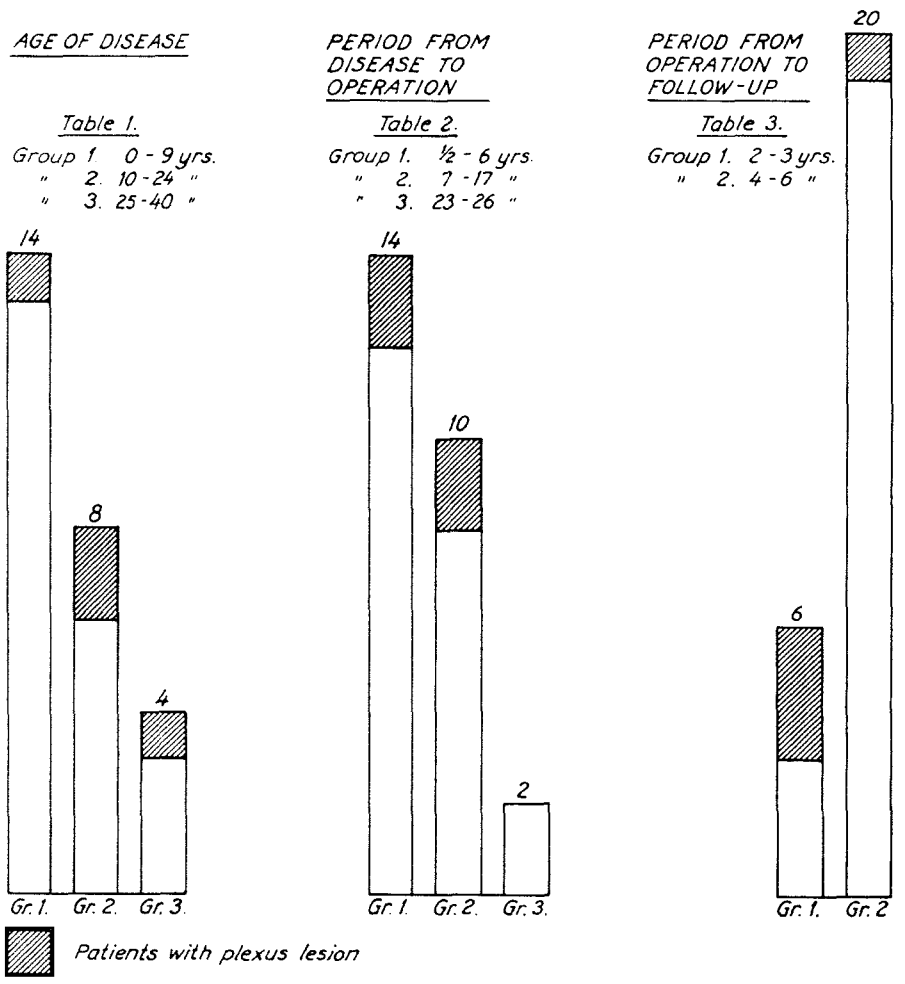

Table 1. The age distribution at the onset of disease or time of lesion. ½ of the patients are previous polio children, who caught their disease during 0–10 years of age.

Table 2. The periods up to the time of operation. More than ½ of the patients were operated on within 6 years after the occurrence of paralyses, 3 within 2 years.

Table 3. The periods from operation to follow-up examination. More than ¾ of the patients were followed up from 4–6 years postoperatively.

Fixation was carried out to the medial border of the humerus from 2–6 cms. proximally, efforts being made to place the fixation as high as possible with the elbow flexed 90 degrees and with the forearm in maximal supination.

ERRATA

In Dr. *Kaare Nyholm's* article in Acta Orthopaedica Scandinavica. vol. XXXIII. fasc. 1, page 35, Fig. 1 is missing. The figure is reproduced here.

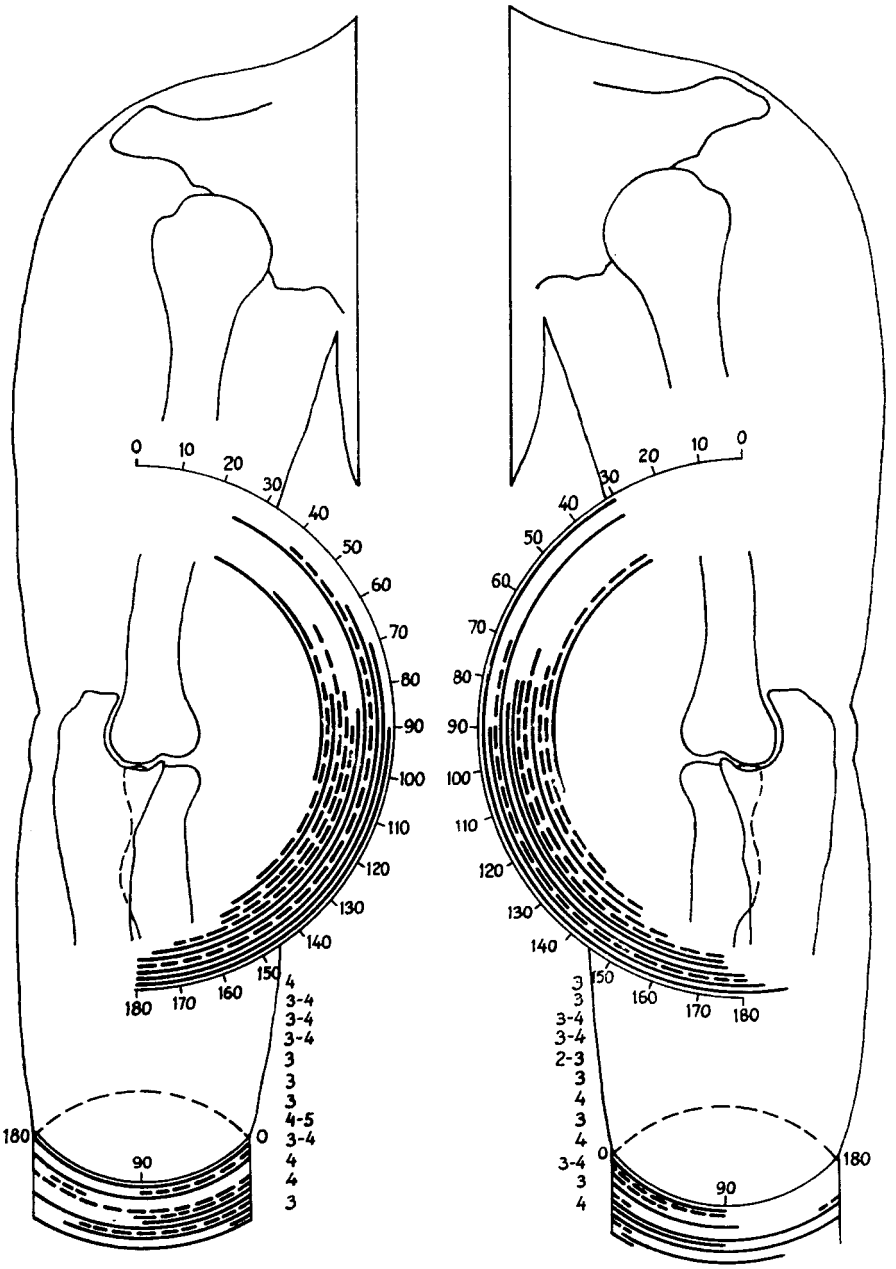

Fig. 1.

Verte

In one single patient the tendon was fixed laterally to the anterior aspect of the humerus a.m. Mayer & Green.

The tendons were firmly fixed by drill holes in the bone or to the periosteum and the intermuscular medial septum.

After the operation the arm was put into a circular plaster of Paris with the elbow flexed 90 degrees and the forearm in maximal supination. 3 weeks later the plaster was changed to a dorsal splint and active excersises of elbow flexion and myotensor treatment were started. After another 3 weeks the splint was removed and physiotherapy commenced.

Avulsion of the transposed tendon from its bed was not observed in any patient.

In 2 patients the classic Steindler operation was supplemented by proximal transposition of muscles from the extensor or radial extensor group. One case is differentiated from the others owing to an isolated transposition of the radial extensor group, as the flexors were found too weak.

RESULTS OF THE FOLLOW-UP EXAMINATION

Steindler-plastics.
Elbow flexion:

All patients, but one, were able to carry out a slow harmonised flexion-extension movement of the elbow corresponding to the number of degrees stated. (Fig. 1). The strength achieved varied from 3–4, while that in 4 out of 5 patients with simultaneous function of the biceps reached at least 4. No one with total paresis of the normal elbow flexors could lift more than 4 pounds.

Fig. 1.

The results of 24 Steindler operations on 23 patients.

The middle curves show the elbow flexion—extension in degrees.

The arrangement of the curves is determined by an increasing extension deficiency centrally. Active supination and pronation can be discovered from the Manchet curves. Maximum pronation: o degrees. Maxium supination: 180 degrees.

The unbroken lines represent movements in patients with fully capable forearm muscles. The dotted lines are equal movements in patients with reduced strength in single or several forearm muscles. (strength below 4).

Elbow flexion strength is stated according to the following grading:

3: flexion to full extent with ½ pound weight in the hand.
3–4: flexion to full extent with ½–2 pound weight in the hand.
4: flexion to full extent with 2–4 pound weight in the hand.
5: flexion to full extent with normal strength.

All patients, except 2, preferred to flex the elbow with pronated forearm and clenched hand. In the 2 exceptions the forearm was in maximal supination, without active pronation.

10 were capable of flexing during unchanged supination or semi-supination, whereas 10 were compelled to pronate during flexion. In 4 cases the forearm was in fixed pronation.

Of the first mentioned 10 patients, 4 had a partially recovered biceps, 2 a supplementing extensor transposition and 2 a supination contracture in the forearm. Of the last 2, one had some function of brachioradialis and the last one a preoperative function of biceps, whereas this function could not be demonstrated at the follow-up examination.

The preferred position of the forearm and hand is a function of the primary action of the now doubly working muscles and demonstrates the functional basis for the Steindler operation. A replacement of the normal flexion-supinating mechanism by a flexion-pronating mechanism, which phylogenetically is probably of an older date.

The same phenomenon is demonstrated during flexion tests with the forearm supinated. Almost all patients with total paresis of the biceps and brachioradialis, and without a supplementing extensor transposition, exhibit such a pronation tendency.

A shoulder arthrodesis was performed in 6 patients. Among the other 18 patients 4 showed fairly slight atrophy and instability in the shoulder, while 14 had severely paralysed shoulder girdle with subluxation of the joint during elbow flexion.

A study of the preoperative elbow bending capacity showed that 10 patients at that time were able of trick movements, in which the elbow could be flexed utilising the shoulder girdle, to a position between 90 and 180 degrees. Amongst these 3, who were able to flex the elbow above right angle. All 3 had initial function of the biceps. The others had no active flexion of the elbow.

Degree of Elbow Flexion.

The evaluation of the degree of elbow flexion is hardly a relevant expression of functional value and shall only serve for the analysis of the varying results.

A normal degree of elbow flexion was achieved in but ¼ of the patients. All those 6 patients had some type of shoulder stabilisation (arthrodesis (4) and tenodesis (2)). This indicates that stabilisation was of direct value for reaching a maximal degree of flexion.

Another characteristic of this group is that it comprises 5 patients

with fully capable forearm muscles and 3 with severe limitation of extension. Both factors undoubtedly contribute directly or indirectly to the good flexion result. However, the other 3 patients in this group did show normal extension to 180 degrees (only one of these with function in biceps). This shows clearly that a fully capable, transposed forearm flexor group is able to act sufficiently as elbow flexor through a full range of joint excursion.

Elbow Extension.

An assessment of elbow extension does not provide such a pessimistic impression as previous authors have assumed.

In more than ½ (13) of the patients the extension limitation was less than 10 degrees. In 4 between 10 and 25 degrees and in 7 more than 25 degrees. In the last group 2 patients stand out with a flexion contracture of 75 and 70 degrees.

A direct relationship between the strength of the triceps and the degree of extension can not be demonstrated, although a certain connection is indicated.

A comparison with the preoperative extension status shows that an increased limitation in consequence of the operation is present in ⅔ of the patients.

Supination.

According with previous studies the patients are characterised by a limitation of active supination, which in a few cases resulted in a pronation contracture.

10 out of 24 patients have an active supination equal to or more than 135 degrees, including 7 with normal supination. 7 an active supination at between 135 and 90 degrees and 5 a supination of below 90 degrees.

In 2 patients the forearm had a contracture in supination. These 2 patients are characterised by paresis of both pronating and supinating action with reduced strength in the radial part of the flexor group of the forearm (pronator teres and flexor carpi radialis).

A constant finding in all patients was a varying reduction in supination power. The pronation power was normal, except in 5 patients in whom pareses encroached onto the pronating muscles.

Amongst the 7 patients with active supination to 180 degrees 3 had function of biceps and 2 of these showed improved supination in spite of the operation. This was owing to the function of biceps.

In 20 patients the supination remained unchanged after operation. Only in 4 was found increasing pronation contracture.

Refunction of Biceps.

A small number of patients with function in their normal elbow flexors demand special attention, since we are confronted here with simultaneous function of 2 flexion mechanisms.

The group consists of 5 patients (Table 4), including 3 with previous traumatic plexus lesion and 2 with polio paresis.

TABLE 4

The results in 5 patients operated according to Steindler and with simultaneous function in biceps.

5 patients with refunction of biceps						
Pt.	Paresis Etiology	Shoulder arthrodesis	Elbow flex. strength	Triceps strength	Elbow flexion	Active supination
I	Plexus	+	4	5	180/70	20 gr. (contr.)
II	Polio	+	4–5	3	180/25	180 gr.
III	Plexus	—	3	0–1	170/90	90 gr.
IV	Polio	+	4	4	105/25 (contr.)	180 gr.
V	Plexus	—	4	4–5	175/80	180 gr.

Elbow extension was found to be almost normal with the exception of a single patient, in whom an excessive extension limitation is probably to be explained by a too severe tightening of the transplant by operation, combined with insufficient postoperative extension excersise. The degree of flexion ranges from 90 to 25 degrees, probably dependent on the strength achieved by the biceps. In 3 patients there is free supination, in one patient with extensive pareses and numerous tendon transpositions in the hand and the forearm it reaches 90 degrees, while in the last of the group a pronation contracture arose preoperatively.

Pectoralis Plastics a.m. Clarc.

As an alternative to the activation of elbow flexion aided by Steindler's operation, pectoralis plastics reported by *Clarc* in 1946 was em-

ployed in 3 cases. For this operation full strength is required in the lower part of the pectoralis muscle.

All 3 patients were previous polio children and achieved a normal flexion with only a slight limitation of extension. The strength of flexion were 3–4. The result with regard to the 3 factors stated were considerably better than those amongst the patients operated according to Steindler. The degree of supination in a single case remained unchanged postoperatively and must be attributed to the complete lack of biceps function. Formation of contracture prevented a possible improvement of the supination after operation. No anatomical explanation can be given of the obvious and necessary pronation tendency of the forearm in all 3 patients, but it may possibly be due to a simultaneous function of the muscles of the forearm, where the pronating strength is dominant.

DISCUSSION

The growing interest of the last decade in tendon transpositions—their future development and their limitations—could not avoid bringing in those problems which concern the restoration of lost elbow flexion.

An adequate discussion of the subject using the present series as a basis requires a comparison with previously published studies, of which we have especially chosen *Steindler's* from 1939, *Mayer & Green's* from 1954 and *Segal, Seddon & Brooks'* from 1959, since these represent patient series of approximately the same size.

To a large extent there has been concordance about the indications and premises for operation. Concerning the absolute requirement of a strong flexor group, however, our opinion diverges from that of most authors whose rigorous conditions are determined by the desire of an elbow, which can serve as weightbearer or lifter. This should undoubtedly be the ideal aim, but should not exclude aid to those patients whose muscle status puts such a result out of reach. Amongst our patients there is a relatively large number, whose forearm muscles are primarily paretic. All of these have achieved an elbow flexion of at least 90 degrees, which argues quite convincingly in favour of a more liberal attitude when selecting those suitable for operation.

There is no divergent opinion about the value of a stable shoulder. In our series the importance of an arthrodesis in the shoulder is pointed out both for the total functional result and for the degree of flexion which can itself be obtained. The results in cases combined with artho-

desis demonstrate the value of shoulder stabilisation before the Steindler operation.

In accordance with earlier surveys we consider a reduced extension as linked with and as a consequence of the Steindler operation. The average deficiency in extension is in Carroll's series 40 degrees, Seddon & Brook's 60 degrees and Mayer & Green find corresponding values of 30 degrees. In our own material it is found to be between 15 and 20 degrees.

While most authors point out the importance of this lack of extension, which makes the flexion effective by virtue of a flexed initial position, Mayer & Green do not find the results satisfactory and accept at the most 15 degrees of limitation of extension.

An explanation of the deficient stretching ability has been sought in the relationship between the strength of the antagonistic muscles around the elbow joint. In agreement with our own investigations Seddon & Brooks have demonstrated a certain relationship between the strength in the triceps and the degree of extension and at the same time have been able to attribute the most severe limitation to those cases where flexor plastics were supplemented by proximal transposition of the extensor group.

In contrast to this we have found 6 cases with accompanying extensor transfer or with refunction of biceps, who have achieved almost normal elbow extension. These patients all had relatively good triceps strength, so that they do not form any decisive argument against the theory about the significance of the antagonistic strength relationship.

The slight limitation in extension amongst our patients is rather surprising in view of the poor triceps status and varying function of the biceps. The explanation may perhaps be found in the limitation of the transplant strength and the consequently limited effect on the antagonistic strength relationship.

It should be noted here that Seddon & Brooks using Carroll's triceps transplantation observed a severe limitation of extension, while the use of pectoralis plastics, in agreement with our results, rarely were followed by a limitation of more than 15 degrees. This last point argues that other factors, linked with the operative procedure itself, determine the degree of extension limitation. Here one should point out the fundamental difference between Steindler's and Clare's operation. The former operates directly on the anterior aspect of the joint, while the latter operation does not touch this important region.

The degree of flexion is not the decisive factor in the functional re-

sult. Steindler demands at least 60 degrees. Mayer & Green require free flexion to at least 50 degrees, while our patients have all been able to flex to 90 degrees.

The most important problem seems to be a flexion to the horizontal position, from which further movement will be accompanied by decreasing weight. Nevertheless there are numerous of our patients, who have obtained a degree of flexion of just below 90 degrees, though further active flexion is impossible. When considering the slight limitation of extension in these patients and the results from other series with larger extension deficiency and at the same time a greater degree of flexion, the problem seems rather to comprise the active span of the new elbow flexor. Can this muscle, with correct fixation and sufficient training, adjust itself to its new task and carry out a maximal elbow flexion (to 30 degrees) from the normal extension position (180 degrees)? In our series this was achieved in only 3 patients.

Like Seddon & Brooks, who find no change in passive supination after Steindler's operation, we were able to demonstrate a direct relationship between the active supination limitation and the loss of the main supinator, the biceps; a further limitation of supination and increasing formation of contracture in consequence of the operation only occurred in a few cases.

A small group of patients in our series was given special attention owing to simultaneous function of the biceps. These 5 patients provide a warning against too early operation, while the result of the flexor plastics demonstrates the importance of the biceps muscle in maintaining free supination, if passive supination is preserved until the biceps function again.

Clare's pectoralis plastics was in 3 cases the alternative to Steindler's operation. Like Seddon & Brooks we find the extension-limiting effect of this operation to be minimal. Flexion to a normal extent with good strength was obtained.

SUMMARY

27 elbow plastics were followed up and the results were analysed and discussed with special reference to the flexion and extension results of the elbow, the stability of the shoulder and the pronation-supination movement of the forearm. The main emphasis was laid on the 24 Steindler plastics and 5 of these patients with partial recovering of the biceps. 3 pectoralis plastics a.m. Clare were given speciel attention with reference to the influence on functional result.

RESUME

27 cas de coudes en matière plastique ont été suives et les résultats ont été analysés en vue d'établir en particulier le degré de flexion et d'extension du coude, la stabilité de l'épaule et les mouvements de pronation et de supination de l'avant-bras. L'intérêt principal s'est porté sur 24 coudes plastiques Steindler, alors que l'on a examiné avec une attention spéciale, par rapport à la différence des résultats fonctionnels, 5 de ces malades où le biceps a été remis en fonction et 3 avec pectoraux plastiques selon la méthode de Clarc.

ZUSAMMENFASSUNG

27 Ellbogenplastiken wurden nachuntersucht und die Ergebnisse wurden unter besonderer Beachtung der Beuge- und Streckfähigkeit des Ellbogens, der Stabilitet der Schulter, und der Pro- und Supination des Unterarmes analysiert. Das Hauptgewicht wurde auf 24 Steindler Plastiken gelegt, während fünf dieser Patienten mit Wiederherstellung des Biceps und 3 Pectoralis-plastiken nach Clarc eine besondere Aufmerksamkeit hinsichtlich des Unterschiedes des funktionellen Ergebnisse gewidmet wurde.

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