Wun-Schen Chen

Restoration of elbow flexion by modified Steindler flexorplasty

Accepted: 17 November 1999

Abstract A modified Steindler flexorplasty was used to restore elbow flexion in 8 patients with post-traumatic flail elbow. In 5 patients there was associated loss of wrist and finger extension, which was treated by tendon transfer and in 2 patients an associated flail shoulder was treated by arthrodesis. The results were not compromised in patients whose flexor tendons had been transferred for wrist and finger extension. All patients had a stable and mobile elbow with marked improvement of upper limb function. Modified Steindler flexorplasty is a simple, effective and reliable procedure for the restoration of elbow flexion.

Résumé Huit patients avec un coude en fléau posttraumatique ont subi un rétablissement de leur flexion de coude au moyen de la plastie des fléchisseurs "Steindler" modifiée. Cinq patients ont aussi eu une perte de flexion de la main et des doigts, et ont été traitée par transfert de tendon. Deux ont eu une épaule en fléau et ont été traitée par une arthrodèse d'épaule. Pour les patients dont les tendons fléchisseurs avait été transférés pour l'extension de la main et des doigts, les résultats de la plastie de "Steindler" modifiée n'ont pas été compromis. Tous les patients avaient un coude stable et mobile, avec une amélioration importante de la fonction de leur membre supérieure. La plastie "Steindler" modifiée est une procédure simple, effective et fiable pour le rétablissement de la flexion de coude.

Introduction

A mobile and stable elbow with adequate flexion strength is essential for adequate upper limb function in occupational, recreational and daily activities [26]. Total loss of elbow flexion is a very severe disability. In some

patients, a flail elbow is associated with a flail shoulder and loss of wrist and finger extension. In such patients, the shoulder can be stabilised by arthrodesis [18, 19] and wrist and finger extension restored by tendon transfer [9]. The function of the upper extremity will be much improved by restoration of elbow flexion.

Several procedures have been devised to restore elbow flexion: Steindler flexorplasty and its modifications [3, 7, 8, 17, 23, 25, 32], anterior transposition of the triceps tendon [10], transfer of the pectoralis major to biceps [5, 12, 16, 30, 31], shoulder arthrodesis and sternomastoid transfer with the addition of a fascia lata graft to the biceps tendon [11], neurotization [14, 27, 28, 29], free muscle transfer [14, 15], and unipolar or bipolar transfer of the latissimus dorsi [1, 2, 4, 6, 13, 20, 30, 33, 34].

Steindler flexorplasty and its modifications is a reliable procedure to restore elbow flexion if the flexor-pronator muscles are intact and available for transfer [3, 7, 8, 17, 23, 25, 32]. However, the use of this procedure has not been recorded in patients whose flexor-pronator muscles have been used for wrist and finger extension.

Patients and methods

Between 1984 and 1995, 8 male patients, aged 25 to 48 years (average 36 years) with post-traumatic flail elbow were treated by modified Steindler flexorplasty (Table 1), each in their dominant arm. In 5 patients, loss of elbow flexion was a sequel of brachial plexus injury 1 to 5 years previously; 4 had undergone brachial plexus exploration, nerve repair, nerve graft or intercostal nerve implantation. 4 patients had loss of elbow flexion combined with loss of extension of the wrist and fingers and 2 patients had a flail shoulder. Staged reconstruction was performed. At the first stage, tendon transfers were performed in 4 patients to restore wrist and finger extension (palmaris longus to rerouted extensor pollicis longus, pronator teres to extensor carpi radialis brevis, flexor carpi ulnaris to extensor digitorum communis). 6 weeks later the modified Steindler flexorplasty was performed. The 2 patients with a flail shoulder underwent arthrodesis 3 to 6 months later.

3 patients after motorcycle accidents, had associated compound fractures of the humerus, with extensive soft tissue loss including brachialis, biceps and triceps muscle and the radial nerve, with intact median and ulnar nerves. Radial palsy was treated by

W.-S. Chen (✉)

Department of Orthopedic Surgery,
Chang-Gung Memorial Hospital at Kaohsiung, 123 Ta-Pei Road,
Niao-Sung, Kaohsiung, 833 Taiwan, ROC
e-mail: wunschen@ms15.hinet.net;
Tel.: +886-7-7317123, Fax: 886-7-7318762

Table 1 Characteristics of the patients

Case	Age	Sex	Side	Etiology	Associated injuries	Active elbow motions ³ Extension	Flexion	Supination
1	25	M	L	BPI ¹	RP ²	—	—	15
2	28	M	R	BPI	RP	—	—	0
3	54	M	R	BPI	RP; FS ²	—	—	0
4	28	M	R	BPI	FS	—	—	0
5	36	M	R	ML ¹	RP	—	—	0
6	27	M	R	ML	RP	—	—	0
7	48	M	R	ML	RP	—	—	0
8	42	M	R	BPI	RP; FS	—	—	80

¹ Etiology: *BPI* brachial plexus injury; *ML* muscle loss due to crush injury or debridement for post-traumatic infection

² Associated injuries: *RP* radial palsy; *FS* post-traumatic flail shoulder. Active elbow motions are measured by degrees.

Fig. 1 The flexor-pronator muscles along with a bone block are transferred 7.5 cm proximally. A 3.5 mm cortical screw is used for fixation. At 3 months, solid fusion between the humerus and the transferred bone block is noted

tendon transfers (pronator teres to extensor carpi radialis brevis, flexor carpi ulnaris to extensor digitorum communis, and palmaris longus to the rerouted extensor pollicis longus). 6 weeks later a modified Steindler flexorplasty was performed.

Surgical technique

The procedure follows the modification of Mayer and Green [25] and Lindholm and Einola [22], except that a screw was used for fixation of the common pronator-flexor origin to the humerus. The operation consists of four steps:

(i) The median and ulnar nerves, and the common pronator-flexor origin are exposed through a curved anteromedial incision.

The ulnar head of flexor carpi ulnaris is dissected from the ulna; the motor branches of the ulnar and median nerves are preserved.

(ii) The atrophic biceps and the brachialis muscles are split longitudinally and the anterior periosteum of the humerus is incised at a distance of 7.5 cm above the elbow. The humerus is pre-drilled and tapped with a 3.5 mm drill. The anteroposterior width of humerus is measured.

(iii) The common pronator-flexor origin is mobilised with its bony attachment. A bone block incorporating the common origin from the lateral epicondyle, about 2.5×2.5×1.5 cm in size is elevated, after a 3.5 mm hole has been made in its centre and a cortical screw, 15 mm longer than the premeasured anteroposterior width of the humerus has been inserted for 1.0 cm into the block. The bone block is then removed.

(iv) The common pronator-flexor origin is separated from the anterior surface of the joint, the coronoid process and the interosseous membrane for a distance of 7 cms and is brought proximally to the humerus; and the screw is inserted into the predrilled hole (Fig. 1). The median nerve and the brachial artery are inspected carefully as the pronator-flexor muscles are mobilised, transferred and fixed to the humerus to prevent undue tension, compression or entrapment. If there is tension from the ulnar nerve, with the elbow at 90° of flexion, it is anteriorly transferred under the ulnar head of flexor carpi ulnaris. The elbow is immobilised with a splint in 90° of flexion. Isometric exercises are started post-operatively and at 6 weeks the splint is removed and active movement started; at 8 weeks resisted flexion is started.

The average period of follow-up was 8 (4–15) years. The following functional results were recorded: 1) active range of movement; 2) strength of elbow flexion measured in kilograms of weight lifted and sustained; 3) endurance of elbow flexion as measured by the period of time that a weight of 2 kg (or, if less than 2 kg the maximum weight lifted) was lifted and sustained; 4) flexion contracture; 5) pronation contracture; 6) functional evaluation of occupational, recreational and daily activities; 7) working status.

Results

The operation time was 120 to 180 min, and the estimated blood loss was 50 to 250 ml. The transferred muscles acquired their new function without reeducation. Union between the humerus and the transferred bone block was achieved at 3 months. All patients had voluntary elbow flexion at final follow-up (Table 2). The maximum flexion achieved ranged from 110° to 130° and all patients could reach their mouth. The average flexion contracture was 37° (25° to 45°). The average full range of movement was 83° (70° to 100°). The strength of elbow flexion increased gradually after removal of the splint and achieved an average of 3.3 (2.5–4.0) kg at 6 to 9 months; and thereafter the endurance improved at 12 to 24 months. All patients had a stable and mobile elbow with marked improvement in upper limb function.

Table 2 Results after modified Steindler flexorplasty

Case	Muscle strength	Endurance	Arc of motion ²	Reach mouth	Flexion contracture	Active supination	Pronation deformity	Functional status	Return to work
1	1.51	5 min	35–125	+	35	15	20	Helping	–
2	2.0	3 min	15–115	+	24	0	10	Dominant	+
3	4.0	20 min	40–110	+	40	0	35	Dominant	+
4	3.5	20 min	45–120	+	45	0	35	Dominant	+
5	2.5	5 min	45–125	+	45	0	20	Helping	–
6	4.0	20 min	35–120	+	35	0	0	Dominant	+
7	4.0	20 min	35–125	+	35	0	25	Dominant	+
8	3.0	15 min	35–110	+	35	60	15	Dominant	–

¹ Muscle strength are measured in kilograms

² Arc of motion, flexion contracture, active supination, and pronation deformity all are measured in degrees

Discussion

The order of the reconstructive procedures in these patients remains controversial. We prefer to start distally. Once the movements of the wrist and fingers are improved, restoration of elbow flexion and stabilisation of the shoulder should be undertaken. If shoulder arthrodesis is performed early, the loss of shoulder mobility will compromise the transfer of muscles around the shoulder such as the latissimus dorsi, and will significantly interfere with the ability to perform other procedures in the forearm and hand. We recommend tendon transfer for wrist and finger movement should precede the restoration of elbow flexion and that shoulder arthrodesis, if necessary, should be the last stage of reconstruction.

Many methods of restoring elbow flexion have been described. Steindler flexorplasty is a reliable procedure, which will restore useful elbow flexion in 50 to 90% of patients in whom the power of the flexor-pronator muscles is greater than Grade IV [17, 21–25]. In patients in whom several flexor-pronator tendons (palmaris longus, pronator teres, flexor carpi radialis or flexor carpi ulnaris) have been used in tendon transfer procedures to restore wrist and finger extension, the use of a modified Steindler flexorplasty may be questioned. Our experience has shown that transfer of one or several flexor-pronator tendons for wrist and finger extension did not affect the results after flexorplasty. Careful preoperative assessment of the muscle power is essential as flexorplasty will fail if the transferred muscle is weak [22–25], and where the power of the flexor-pronator muscles is less than Grade IV alternative procedures should be considered. Other causes of failure include inadequate proximal transfer and poor fixation of the transferred muscles to the distal humerus. In the original description, the flexor-pronator muscles were transferred proximally between brachialis and triceps and sutured to the medial epicondylar ridge two inches above the epicondyle. Our earlier experience with this procedure showed that suturing the flexor-pronator muscles to the medial epicondylar ridge did not provide enough fixation; and although active elbow flexion was restored

the strength and endurance was inadequate for most occupational, recreational and daily activities. We therefore believe that more proximal transfer results in better mechanical advantage, increased strength and endurance of elbow flexion. Transfer by more than 7.5 cms requires very extensive dissection and this may jeopardise the innervation of the muscles and increase the postoperative flexor contracture. Our method of fixation, with a bone block, allows early post-operative isometric exercises. Inclusion of a bone block at the anterior surface of the humerus also increases the lever arm of the transferred muscle when initiating elbow flexion. A flexion contracture of the elbow, a pronation contracture of the forearm, and a flexion contracture of the wrist are frequently encountered after this procedure [7, 8, 17, 22, 23, 25, 32]. The degree of flexion contracture of the elbow and of pronation contracture of the forearm that are tolerable depends on the functional demands of the patient. An active flexion excursion from 20° to 135° is required for most daily activities [25]. An active excursion from 30° to 120° may be sufficient in an injured limb; and 115° of flexion is required to reach the mouth. A satisfactory active flexion excursion was restored in all our patients with an acceptable flexion contracture of 45° or less and a pronation contracture of 35° or less. In summary, in patients with a flail elbow, a stable and mobile elbow joint with a satisfactory range of movement, strength and endurance, may be restored by a modified Steindler flexorplasty. It may be recommended for restoration of elbow flexion in patients with satisfactory flexor pronator-muscle strength. Previous tendon transfer procedures to restore wrist and finger extension do not adversely affect the outcome.

References

1. Axen A, Segal D, Elkon A (1973) Partial transplantation of the latissimus dorsi: a new operative technique to restore elbow and finger flexion. *J Bone Joint Surg [Am]* 55:1259–1264
2. Bartlett SP, May JW jr, Yaremchuk MY (1981) The latissimus dorsi muscle: a fresh cadaver study of the primary neurovascular pedicle. *Plast Reconstr Surg* 67:631–636
3. Botte MJ, Wood MB (1989) Flexorplasty of the elbow. *Clin Orthop* 245:110–116

4. Brones MF, Wheeler ES, Lesavoy MA (1982) Restoration of elbow flexion and arm contour with the latissimus dorsi myocutaneous flap. *Plast Reconstr Surg* 69:329–332
5. Brooks DM, Seddon HJ (1959) Pectoral transplantation for paralysis of the flexors of the elbow. *J Bone Joint Surg [Br]* 41:36–50
6. Brumback RJ, McBride MS, Ortolani NC (1992) Functional evaluation of the shoulder after transfer of the vascularized latissimus dorsi muscle. *J Bone Joint Surg [Am]* 74:377–382
7. Brunelli GA, Vigasio A, Brunelli GR (1995) Modified Steindler procedure for elbow flexion restoration. *J Hand Surg [Am]* 20:743–746
8. Bunnell S (1951) Restoring flexion to the paralytic elbow. *J Bone Joint Surg [Am]* 33:566–571
9. Calandruccio JH, Jobe MT (1998) Paralytic hand. In: Canale S.T. (ed) *Campbell's operative orthopedics*, 9th edn, vol. 4. Mosby, St. Louis, pp 3570–3573
10. Carroll RE (1955) Restoration of flexor power to the flail elbow by transplantation of the triceps tendon. *Surg Gynecol Obstet* 95:685–688
11. Carroll RE (1962) Restoration of elbow flexion by transplantation of the sternocleidomastoid muscle. *J Bone Joint Surg [Am]* 44:1039
12. Carroll RE, Kleinman WB (1979) Pectoralis major transplantation to restore elbow flexion to the paralytic limb. *J Hand Surg* 4:501–507
13. Chen WS (1990) Restoration of elbow flexion by latissimus dorsi myocutaneous or muscle flap. *Arch Orthop Trauma Surg* 109:117–120
14. Chuang DC, Epstein MD, Yeh MC, Wei FC (1993) Functional restoration of elbow flexion in brachial plexus injury. *J Hand Surg [Am]* 18:285–291
15. Chuang D (1995) Functional free muscle transplantation for brachial plexus injury. *Clin Orthop* 314:104–111
16. Clark JMP (1946) Reconstruction of the biceps brachii by pectoral muscle transplantation. *Br J Surg* 34:180–181
17. Dutton RO, Dawson EG (1981) Elbow flexorplasty: an analysis of long term results. *J Bone Joint Surg [Am]* 63:1064–1069
18. Emmelot CH, Nielsen HK, Eisma WH (1997) Shoulder fusion for paralyzed upper limb. *Clin Orthop* 340:95–101
19. Gonzalez-Diaz R, Rodriguez-Merchan EC, Gilbert MS (1997) The role of shoulder fusion in the era of arthroplasty. *Int Orthop* 21:204–209
20. Havnanian AP (1956) Latissimus dorsi transplantation for loss of flexion or extension at the elbow: a preliminary report on technic. *Ann Surg* 143:493–499
21. Kettelkamp DB, Larson CB (1963) Evaluation of the Steindler flexorplasty. *J Bone Joint Surg [Am]* 45:513–518
22. Lindholm TS, Einola S (1973) Flexorplasty of paralytic elbows: an analysis of late functional results. *Acta Orthop Scand* 44:1–4
23. Liu TK, Yang RS, Sun JS (1993) Long-term results of Steindler flexorplasty. *Clin Orthop* 296:104–108
24. Marshall RW, William DH, Birch R, Bonney G (1988) Operations to restore elbow flexion after brachial plexus injury. *J Bone Joint Surg [Br]* 70:577–582
25. Mayer L, Green W (1954) Experience with the Steindler flexorplasty at the elbow. *J Bone Joint Surg [Am]* 36:775–789
26. Morrey BF, Askew LJ, Chao EY (1981) A biomechanical study of normal functional elbow motion. *J Bone Joint Surg [Am]* 63:872–877
27. Nagano A, Ochiai N, Okinaga S (1992) Restoration of elbow flexion in root lesions of brachial plexus injury. *J Hand Surg [Am]* 17:815–821
28. Narakas AO, Hentz VR (1988) Neurotization in brachial plexus injuries: Indication and results. *Clin Orthop* 237:43–56
29. Ruch DS, Friedman A, Nunley JA (1995) The restoration of elbow flexion with intercostal nerve transfers. *Clin Orthop* 314:95–103
30. Schottstaedt ER, Larson LJ, Post FC (1955) Complete muscle transposition. *J Bone Joint Surg [Am]* 37:897–919
31. Spira E (1957) Replacement of the biceps brachii by pectoralis minor transplantation. *J Bone Joint Surg [Br]* 39:126–127
32. Steindler A (1919) Operative treatment of paralytic condition of the upper extremity. *J Orthop Surg* 1:608–619
33. Tobin GR, Schusterman M, Peterson GH, Nichols G, Bland KI (1981) The intermuscular neurovascular anatomy of the latissimus dorsi muscle: the basis for splitting the flap. *Plast Reconstr Surg* 67:637–641
34. Zancolli E, Mitre H (1973) Latissimus dorsi transfer to restore elbow flexion: an appraisal of eight cases. *J Bone Joint Surg [Am]* 55:1265–1275