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CONTINUOUS PASSIVE MOTION FOLLOWING FLEXOR TENDON REPAIR

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A prospective study was performed of 20 consecutive patients with 35 flexor tendon lacerations, in whom post-operative mobilisation was carried out using the Toronto Mobilimb Continuous Passive Motion machine for the first 4½ weeks. Overall the results assessed by Buck Gramcko criteria were 17 (85%) excellent or good, 3 (15%) fair and no poor results. Taking the 17 fingers with zone II lacerations, 14 (82%) were excellent or good, 3 (18%) fair and no poor results.

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Pulvertaft in 1948 stated that "It is not difficult to suture tendons and prepare the ground for sound union. The real problem is to obtain a freely sliding tendon capable of good function." Since that time, there has been a gradual progression towards early mobilisation of the sutured tendons to prevent adhesion formation. However the concept of early passive mobilisation depends on both an intelligent and a motivated patient. Passive mobilisation can be performed for the patient by a therapist, but this is expensive in terms of manpower. Early active extension, popularised by Kleinert, is also totally dependent upon the active co-operative of the patient. This study expanded upon the concept of early passive mobilisation by using a Continuous Passive Motion machine to flex and extend the patient's finger, from the time of operation, for 24 hours a day, until 4½ weeks after repair.

Method

All clean flexor tendon injuries of the hand in Verdan's zone 2 attending the Accident Department of the University Hospital, Nottingham between July 1987 and February 1989 were referred to the Senior House Officer on call for the Hand Service. The patient was examined thoroughly, the wound cleaned and sutured under local anaesthetic and the patient was admitted to the ward and prepared for surgery. Patients were excluded from the study if the wound was dirty, if the patient was psychiatrically disturbed, or if the thumb was involved. All surgery was performed by one designated Senior Registrar (T.D.B.), to exclude operator variables. Repair was undertaken within 12 hours, usually during the night following admission.

The wound was extended to expose the tendon ends. If the tendons had retracted into the palm, as was found in six of the 20 cases, then they were retrieved by the method of Sourmelis and McGrouther (1987), through a separate incision in the palm. A routine method of repair was used in all cases. Tension was relieved from the repair by transfixion of the distal tendons to the skin using a 16 gauge needle. 4/0 Ethibond modified Mason-Allen core sutures were used and a circumferential 6/0 Ethilon continuous tidying suture was then placed around the tendon. In women with lacerations to the little finger the slips of F.D.S. were sometimes very small and 6/0 Ethilon mattress sutures were used in such cases. Sheath repair was performed if possible, but not if it compromised tendon excursion. Meticulous haemostasis was performed, and in 17 cases nerve repair carried out with interrupted 8/0 Ethilon sutures. The skin was then closed with interrupted 5/0 Ethilon sutures.

A pre-formed Baycast backslab was applied over the padded arm and hand with the wrist in 30° of flexion and the M.P. joints flexed to 70°. The plastic attachment piece of the Toronto Mobilimb Continuous Passive Motion unit was stuck to the patient's skin over the distal phalanx using an elastoplast butterfly dressing. The machine itself was then attached and switched on until it came out to the end of its stroke. The unit was stopped in this position and, with the finger fully extended against the backslab, the C.P.M. unit was fastened to the forearm by velcro straps (Fig. 1). The machine was then switched on and observed, to check that undue tension was not applied at any time throughout the motion cycle. When the adjustment was satisfactory the patient was awakened from anaesthesia. The patient was then returned to the

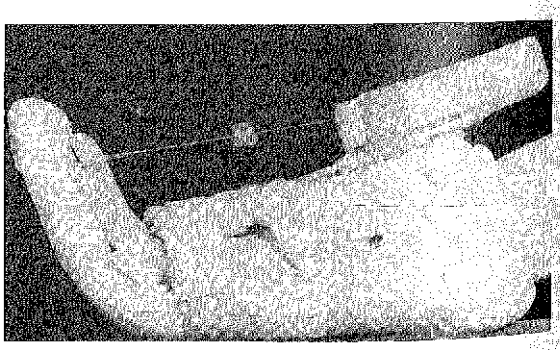

Fig. 1 The hand has been placed on a protective backsplint. The Toronto Continuous Passive Motion Unit has been fastened to the splint and the end of its reciprocating rod attached to the top of the little finger with sticky-plaster. Here the machine is producing its maximum extension.

ward with the C.P.M. unit functioning and the hand elevated for 24 hours.

Next day, the hand therapist visited the patient to check the splint. To exclude variables, one therapist (B.P.) saw all the patients, followed them up in the physiotherapy department and checked the batteries. Although a battery charger and rechargeable batteries were provided, the patients seemed happy to buy new Duracell batteries themselves when the power ran out.

All patients were followed up weekly in the Hand Clinic, by one surgeon (N.J.B.). The C.P.M. units were kept on for 4½ weeks (between four and five weeks, depending which weekly clinic was closest to the 4½ week mark). The patient was then encouraged to move the finger passively against the retained backslab until six weeks after repair. At six weeks the backslab was removed and patients were encouraged in both active and passive finger motion.

Results

20 consecutive patients were prospectively studied over the period July 1987 to February 1989. Fourteen of the patients were men. The average age of the patients was 25.7 years and the average follow up was 10.6 months (range 3–19 months). Seven of the lacerations were caused by glass and four by knives; five were crush injuries, three from sharp metal and there was one closed avulsion.

In 15 patients, the dominant hand was involved. 35 tendons were divided in the 20 fingers, and these were accompanied by 17 nerve injuries. In five patients the laceration was deep, dividing both tendons and the volar plate over the P.I.P. joint, two of these patients having cartilage loss in the open joint injury.

Although the study was designed for zone 2 injuries, three patients were included who were just outside zone 2; one was in zone 3 on the edge of the A1 pulley, one was in zone 1 at the A5 pulley and one was a closed avulsion of F.D.P. from its insertion in zone 1. Thus there were 17 true zone 2 injuries (31 tendons).

Every patient entered into the study was followed up. This proved difficult as nine of the patients refused repeated requests to come to the follow-up clinic. Those on the telephone were contacted personally by the surgeon and most attended. Three of the four remaining patients were visited at home, and the final patient, who had moved out of the area, was questioned at length over the telephone.

The patients were assessed by the methods of Buck Gramcko and of Kleinert (see Table 1). The average Total Active Motion for the group was 199°. The ranges at each joint are shown in Table 2.

According to Buck Gramcko criteria, fifteen had an excellent result, two a good result, three a fair result and there were no poor results (Table 3). Of the three fair results, two were due to dehiscence of the repaired profundus tendon, one occurring after two weeks and the other after two months. The third unsatisfactory result was in a patient with severe eczema, who continually removed his C.P.M. unit and splint in order to scratch the underlying skin.

The patients were also assessed by the method of Kleinert, which is a stricter method than that of Buck Gramcko, since relatively small amounts of extension deficit will pull the patients into a poorer group.

Table 1—The methods of assessment of Buck-Gramcko and Kleinert

a) Buck Gramcko criteria (composite scoring system)

1. Tip to crease/Composite flexion	
0–2.5 cm./over 200°	6
2.5–4 cm./over 180°	4
3–6 cm./over 150°	2
over 6 cm./under 150°	0
2. Total Active Motion	
over 160°	6
over 140°	4
over 120°	2
under 120°	0
3. Extension deficit	
0 30°	3
31–50°	2
51–70°	1
over 70°	0
Resultant score:	
Excellent	14–15
Good	11–13
Fair	7–10
Poor	0 6

b) Kleinert criteria

	Tip-crease interval (cm.)	ext deficit
Excellent	0–1	0–15°
Good	1–1.5	16 30°
Fair	1.5–3	31–50°
Poor	over 3	over 50°

Table 2—Results: average range of motion at each joint

	Average extension average flexion
Average M.C.P.J. range	0.7° 89.1°
Average P.I.P.J. joint	7.2°–81.6°
Average D.I.P.J. range	4°–40.7°
Total Active Motion	199°

Table 3—Results assessed by Buck-Gramcko criteria

Excellent	15
Good	2
Fair	3
Poor	0

According to Kleinert criteria there were nine excellent, five good, three fair and three poor results (Table 4). Examining the unsatisfactory results, the two patients with F.D.P. dehiscences are rated fair and the patient with exzema poor. The three extra unsatisfactory patients are one with a combined extension deficit of over 31° and two patients with a combined extension deficit of over 50°.

Table 4—Results assessed by Kleinert criteria

Excellent	9
Good	5
Fair	3
Poor	3

There were 31 tendon repairs in 17 fingers in zone 2. Two of these patients broke the protocol: the one who removed the C.P.M. unit to scratch and another who switched the machine off. A third patient was converted to a different regime following re-repair of the early profundus dehiscence. Since these patients were not treated by C.P.M., they could be classed as protocol deviants and excluded from the study. However, for comparison with other studies which may also have included protocol deviants in their results, our results are presented both including and excluding protocol deviants.

In the fourteen patients in whom the C.P.M. machine was used continuously, the results for zone 2 injuries assessed by Buck Gramcko criteria were eleven excellent (79%), one good (7%) and two fair (14%), with no poor results (Table 5). Assessed on Kleinert criteria six were excellent (43%), four good (29%), two fair (14%), and two poor (14%) (Table 6). Table 7 shows a comparison of the results of this study against those of recent studies of zone 2 injuries. These results are simplifed in Table 8 to show the percentage of satisfactory (that is excellent or good) results.

Table 5—Results in zone 2, assessed by Buck Gramcko criteria

Excellent	11	(12)
Good	1	(2)
Fair	2	(3)
Poor	0	(0)
Total	14	(17)

(Results in brackets include three protocol deviants)

Table 6—Results in zone 2; assessed by Kleinert critera

Excellent	6	(6)
Good	4	(5)
Fair	2	(3)
Poor	2	(3)
Total	14	(17)

(Results in brackets include three protocol deviants)

Problems and complications

Early in the study it became apparent that full extension was not being achieved at the P.I.P. joint. This was corrected by placing a cube of orthopaedic felt on the dorsal side of the proximal phalanx, thus increasing flexion of the M.P. joint and increasing extension at the

Table 7—Comparison of recent results of zone 2 injuries

Author	*Year*	*Excellent*	*Good*	*Fair*	*Poor*	*n*	*Assessment*
Strickland	1980	0	12	25	11	25	Strickland
Creekmore	1985	12	15	23	50	18	Kleinert
Gault	1988	36	8	32	24	25	Kleinert
Singer	1988	49		51		39	Lister
Earley	1982	50	5	15	30	54	Kleinert
Strickland	1980	36	20	16	24	25	Strickland
Werntz	1989	35	21	21	6	50	Strickland
Strickland	1985	25	31	27	13		Strickland
Langlais	1986	58		34		103	Kleinert
Edinburg	1987	31	30	20	19	70	Buck-Gramcko
Nottingham	1989	43	29	14	14	14	Kleinert
		79	7	14	0	14	Buck-Gramcko
Chow	1988	80	18	2	0	66	Strickland
Werntz	1989	76	24	0	0	36	Strickland

Edinburg: results all zones. Werntz: 27 of 63 patients excluded, leaving 36

Table 8—Simplified comparison of recent results of zone 2 injuries.

Author	*Year*	*Satisfactory results*	*Post-operative management*
Strickland	1980	12%	Immobilised
Creekmore	1985	27%	Kleinert
Gault	1988	44%	Kleinert
Singer	1988	49%	Strickland
Farley	1982	55%	Strickland
Strickland	1980	56%	Strickland
Kleinert	1989	56%	Kleinert
Strickland	1985	56%	Strickland
Langlais	1986	58%	Kleinert or Strickland
Edinburg	1987	61%	Kleinert
Nottingham	1989	72%	C.P.M.
Chow	1988	98%	Combined Kleinert & Strickland
Werntz	1989	100%*	New Kleinert tendon traction brace

*27 patients of 63 excluded from results.

P.I.P. joint (Fig. 2). However, those with extension deficits causing unsatisfactory results (fair and poor) were not clustered early in the series.

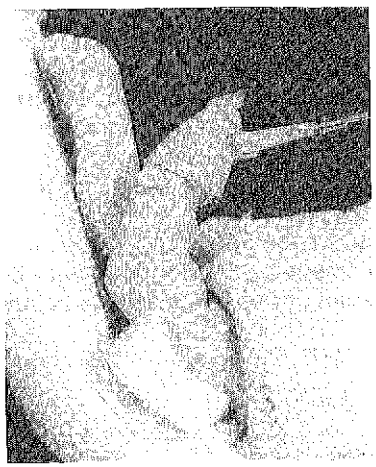

Fig. 2 The machine is now at the other end of its cycle, flexing the finger. Note the felt pad behind the proximal phalanx, to ensure as much extension of the P.I.P. joint as possible.

The second problem was with the attachment of the device to the fingertip, the elastoplast inevitably stretching or unsticking, which meant that it had to be replaced many times.

The third problem was that the unit gave very little movement to the *distal* interphalangeal joint. Wehbé and Hunter (1985) have shown that relative motion between the tendons occurs only with movement of the D.I.P. joint, and this was confirmed by direct observation in our study. Werntz and Kleinert (1989) state that with minimal D.I.P. joint movement relative movement is only 1–2 mm, but with full D.I.P. joint movement 1 cm of differential gliding occurs. Using this principle, Chow et al. (1988) and Werntz and Kleinert (1989) have achieved exceptionally good results (see Tables 7 and 8).

Two of the patients, to our knowledge, tampered with the machine, which is difficult to prevent in such a group of patients. There were two tendon dehiscences, one early (at two weeks) and one late (at two months). One patient required a tenolysis under a wrist block and with tourniquet. This showed that the adhesion formation was limited to the area of repair and not throughout the area of the sheath as has been the senior author's usual observation during tenolysis after more conventional management: a good result was obtained. Six patients exhibited cold intolerance.

Discussion

Mason and Allen (1941), in extensive studies on tendon grafts, showed that the tendon became weakened after grafting and concluded that movement should not be allowed until after three weeks. This dogma was transferred to tendon repair and it was not until the 1960s and 1970s that the poor results following immobilisation were questioned and movement following tendon repair became acceptable. Two schools of thought emerged during this period, which have become known as the Kleinert regime and the Strickland regime.

The Kleinert regime needs good patient selection and motivation. This was shown by Kleinert himself in 1967 for, on his teaching service, only 24% of patients had a satisfactory outcome and he concluded that this was because the patients were "unreliable and indigent". Recently Kleinert has improved on his original splint using a more complex system, with the rubber band travelling under a spring-loaded roller bar to a housed tensioned coiled lever (Werntz et al., 1989). It remains to

be seen whether others can match their outstanding results.

The alternative school of thought is early protected mobilisation. Young and Harmon (1960) reported a large series using passive mobilisation, the only protection being a rubber band holding the finger in flexion. Whereas Kleinert's group developed this to active extension, the other school kept the passive motion and did away with the rubber band, using an extension blocking splint instead. Duran and Houser (1975) and then Strickland (1980) popularised this regime. More recently Langlais (1986) and Chow (1988) have combined the best of both schools, leading to very good results. However passive motion depends again upon a motivated patient, for the finger must be moved by either the patient or a therapist.

Both early passive mobilisation and early active extension regimes thus depend upon a highly motivated, co-operative and intelligent patient, attributes sometimes lacking in patients in need of flexor tendon repair. The advent of Continuous Passive Motion units for the hand meant that poor motivation and low intelligence could be circumvented, although some degree of co-operation was still required.

Clinical experience has shown that mobilisation, whether active extension and passive recoil or passive protected flexion and extension, has greatly improved upon immobilisation. In a prospective controlled study, Strickland found 12% satisfactory results with immobilisation and 56% with mobilisation. Theoretically also, movement seems attractive. Gelberman (1980) showed increased tensile strength and excursion in dog tendons with passive mobilisation following repair. Hitchcock et al. (1987) showed that whereas immobilised chicken tendon repairs showed a marked decrease in strength during the first 20 days, those on immediate constrained mobilisation showed immediate and progressive gains in strength during the same period. These clinical and theoretical benefits were the setting for us to start the study on the use of continuous passive motion following flexor tendon repair in the human.

We were concerned that such a regime might lead to a higher re-rupture rate. Two of 35 tendons dehisced, a rate of 5.7%, which is high compared to series such as Gault at 3.5%. Looked at in terms of patients, two of the 17 patients with zone 2 injuries had a dehiscence: a rate of 12%, which is very similar to the 15% using the Kleinert system (Werntz et al., 1989). This must remain an area for concern.

Neither traditional Kleinert traction nor the C.P.M. unit used in this study move the distal interphalangeal joint through a full arc of motion. Kleinert has recently improved his results by using the pulley system and, following this pilot study, we are working on a new Continuous Passive Motion System with a pulley to encourage movement of the D.I.P. joint.

This study can be criticised for not using controls, but zone 2 injuries are less frequent than is often supposed and the use of controls would have doubled the time of aquisition. The Nottingham University Hospital is a large trauma centre, serving a population of 804,000, and yet only 12 zone 2 injuries could be collected in a year, a figure similar to that of Gault (1987) from the North East Thames Regional Plastic Surgery Unit.

The results with the C.P.M. machine compare well with other studies of zone 2 tendon repairs during the 1980's (Table 8), despite a number of adverse factors. Our series contained five severe lacerations which involved the volar plate, two with osteochondral loss in the P.I.P. joint. Such severe injuries are known to do badly (Gault, 1987) and Langlais showed that satisfactory results dropped from 75% in isolated tendon division to only 23% satisfactory if the floor of the tunnel was involved. There were also five crush injuries in the present series, another factor associated with poor results (Gault, 1987). Other authors have excluded crush injuries from their series; for instance, crush injury was one of the reasons for the 27 excluded patients out of 63 in Kleinert's latest series. We have excluded none. Some of our patients were "unreliable and indigent", as shown by the great efforts required to follow them up: this is another factor cited by Kleinert for the 63% worse outcome in his teaching compared to his private practice.

Continuous Passive Motion is neither a panacea for the aftercare of flexor tendon injury nor does it absolve the surgeon from diligent and frequent follow-up. There are still many features of the system which could be improved and we intend pursuing this line of treatment. Continuous Passive Motion following flexor tendon repair shows early promise and should be studied further.

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