*Prosthetics and Orthotics International, 1993, 17, 130–135*

# Technical note

# Continuous passive motion in hand rehabilitation

J. A. DENT

*Dept. of Orthopaedic and Trauma Surgery, University of Dundee, UK*

## Abstract

This paper reviews the literature comparing the results obtained in applying regimes involving motion with those involving rest following injury or surgery. The deleterious effects of immobilisation are compared to those obtained under conditions of passive motion and intermittent passive motion. It is concluded that continuous passive motion (CPM) represents an improvement on intermittent motion. Models of CPM machines are described and some results presented.

It is proposed that "intelligent" CPM would represent a further improvement in technique and a prototype machine for this purpose and some preliminary results are described.

## Motion is better than no motion

In 1982 Bob Salter from Toronto delivered his presidential address to the Canadian Orthopaedic Association entitled, "Motion versus rest—why immobilise joints?". He observed that from the very beginnings of Western medicine there have been two schools of thought about the best way of treating injured limbs, namely the "resters" and the "movers". In the fourth century BC Hippocrates taught that in illness "it is especially needful for the body to be at rest and to lie up" while Aristotle, in the same century wrote, "the principle is that movement is life". From this time, throughout the subsequent development of orthopaedic surgery in the western world, the "resters" have maintained their popularity.

It was Hugh Owen Thomas, whose dictum that rest should be "complete, prolonged, uninterrupted and enforced", who influenced generations of orthopaedic surgeons all over the world. This opinion remained unchallenged until the beginning of the twentieth century when Championniere wrote "every movement, which is not injurious by reason of its amplitude, favours repair". He believed that "massage and motion help to *relieve* pain rather than *aggravate* it".

Such teaching remained controversial, however, and Thomas's principles continued to be practised by Sir Robert Jones and Sir Reginald Watson-Jones until again challenged by Professor George Perkins from St. Thomas's Hospital who wrote that "in making a choice between rest and motion we are largely biased by tradition" adding that the "training of a doctor is such that it is not easy for him to break the tradition". In the face of that tradition he boldly proclaimed "movement is often better that rest" a sentiment succinctly summarised by Alan Graham Apley as "plaster is a disaster!".

The original work of Salter (1989) had shown the deleterious efffects of immobilisation. He demonstrated pressure necrosis of cartilage in immobilised joints and obliterative degeneration of articular cartilage in non-contact areas secondary to adherence of synovial membrane to the joint surface. The microscopic changes described include matrix fibrillation, cleft formation and ulceration. Palmoski *et al.* (1979) demonstrated interference with normal proteoglycan

---

All correspondence to be addressed to Mr. John A. Dent, Department of Orthopaedic & Trauma Surgery, University of Dundee, Caird Block, Royal Infirmary, Dundee, UK.

This paper was based on a presentation made at Dundee '91—International Conference and Instructional Course on Orthotics, 16–20 September, 1991, Dundee, Scotland.

synthesis and the aggregation of large molecular complexes following immobilisation. The immobilisation of joints as we know leads to stiffness, swelling, pain, muscle atrophy and disuse osteoporosis. Such observations plus his laboratory work led Salter to believe that there should be beneficial local effects to be gained from the early active mobilisation of joints. He argued that other disciplines such as open heart surgery demonstrate that tissues do not have to be put to rest in order to heal. Such principles are followed in general surgery by the advocates of early ambulation after abdominal operations and Dr. Earl Shouldice's clinic for day case hernia repair under local anaesthesia. Similar thinking is also found in the modern treatment of fractures whether by functional bracing as put forward by Augusto Sarmiento or by open reduction and internal fixation followed by early active mobilisation as proposed by Muller and Allgower and the AO group.

So much for the benefits of motion as opposed to immobilisation on the rehabilitation of joints. A similar conclusion had also been reached in the upper limb in the field of rehabilitation of flexor tendon repairs. Within the flexor fibro-osseous tunnel, or zone 2 of the hand two tendons run together. Their normal excursion is in the order of 20 mm. In other zones more proximal or distal an excursion of only 5 mm is necessary for normal finger function. Adhesion of the tendon in the fibrous flexor tunnel after injury in zone 2 will occur between 5 and 21 days post-operatively and cause limitation of movement. Early motion after tendon repair was, therefore, advocated by a number of surgeons in the early 1900's when Harmer (1917) developed a special suture technique allowing early active motion.

The most well known method of mobilisation is probably the rubber band traction introduced by Kleinert *et al.* (1967). The back shell allows controlled active extension of the finger with passive flexion being achieved by means of the rubber band (Lister *et al.*, 1977). An alternative method of mobilisation was described by Duran and Houser (1975). They reported a system of controlled passive exercises which mobilised the individual joints of the injured digit separately.

This idea of intermittent passive motion was further studied by Strickland and Glogovac (1980). They looked at 50 digits with zone 2 injuries. Twenty-five were treated by three and a half weeks of immobilisation and the second group of 25 by intermittent passive motion. The results were graded according to the percentage of return of motion at the PIP and DIP joints. In the group treated by immobilisation there were no excellent results and only 12% good results compared to 36% excellent and 20% good results in the early passive motion group. Furthermore increased tendon strength was demonstrated as an effect of early passive motion in that there was only one tendon rupture in this group compared to four ruptures in the group which had been treated by immobilisation. They concluded that "early passive motion appeared to be an effective technique to improve the results of flexor tendon repairs in this area".

Gelbermann *et al.* (1980) studying the effect of mobilisation on tendon repairs in dogs found that the mobilised group showed less vessel density and a quicker return to the normal longitudinal orientation of vessels than the group treated by immobilisation. These changes occurred within three weeks of surgery. They also noticed a significant increase in tendon strength and excursion with mobilisation. Hitchcock *et al.* (1987) showed that by five days after surgery there was a significant difference in tendon strength between an immobilised group and a group allowed immediate active motion. They concluded that immediate active motion allows progressive tendon healing without an intervening phase of tendon softening.

The concept of controlled motion instead of immobilisation for the post-operative treatment of tendon repairs continues to be popular (Creekmore *et al.*, 1985; Cullen *et al.*, 1989; Matthews, 1989; Morris, 1987; Small *et al.*, 1989). Various modifications of Kleinert's original elastic band traction have more recently been described (Edinburg *et al.*, 1987). A recent modification from Kleinert's own group incorporates a coiled lever on the forearm to regulate the traction force and has a spring-loaded roller bar in the palm to improve DIP joint flexion (Werntz *et al.*, 1989). Sometimes a combination of dynamic splint and intermittent passive motion are being used as described by Chow *et al.* (1988).

### Continuous passive motion is better than intermittent passive motion

Salter's original work (1989) led him to ask the question "If intermittent motion is good for articular cartilage, would continuous passive motion be even better?". Continuous active motion of course would not be possible because of muscle fatigue. The benefit of continuous passive motion to joints was originally proposed by Salter in 1970. He described the beneficial effects of this on the healing of articular cartilage after a variety of intra-articular defects (Salter, 1989). He stated that continuous passive motion (CPM) stimulated the pluripotential mesenchymal cells to differentiate into articular cartilage instead of fibrous tissue. It also enhanced the nutrition of articular cartilage and accelerated the healing of extra-articular tissues. Treatment was continued for four weeks at the rate of one complete cycle every 45 seconds. Cartilage regeneration with both cartilage cell proliferation and matrix production was found to be superior in the CPM group compared to the group treated with intermittent active motion. Neochondrogenesis from periosteal autograft was seen in 80% of the group with CPM and only 10% of the group with intermittent active motion. Of a group of intra-articular fractures treated by intermittent passive motion, 50% had not healed, 20% had healed with fibrous tissue and only 30% had healed with cartilage. In a group of intra-articular fractures treated by CPM 80% healed with cartilage within the first week. This superior repair tissue was found to be maintained in the experimental animals a year later.

Beneficial effects of CPM on rabbit tendons was reported by Loitz *et al.* (1989). Cyclical tensile loading led to increased tendon strength, the results being better in this group than in those treated by immobilisation. In other experimental animal work Salter (1989) showed that CPM led to thicker tendon callus and better alignment of tendon fibres than immobilisation or intermittent active motion in rabbits with partial lacerations of the patellar tendon. The breaking strength of the tendon was also higher.

On the basis of this laboratory evidence Salter, in collaboration with Saringer, introduced a continuous passive motion machine in 1979 for use with their patients. This has subsequently been developed in Toronto for use in treating a variety of joints and conditions which will be illustrated later.

In 1972, however, Ketchum, Clark, Robinson and Masters had introduced an electronically controlled, driven hand splint. The machine consisted of nylon lines attached to adjustable thimbles on the fingertips. Gentle, rhythmic, passive motions of 2.3 kg force at varying frequencies could be applied in both extension and flexion of the fingers. This machine was subsequently modified to a safer and simpler model in which the range of motion applied to each finger could be adjusted independently. Ketchum *et al.* (1979) reported a gain in total active and passive motion in stiff fingers using this technique compared to manual passive exercises performed by a therapist. They found a statistically significant improvement after one month in both total active motion and total passive motion in the group treated by CPM compared to the group treated by the hand therapist. The time taken to use the electronically controlled, driven hand splint was half that of the time needed by a hand therapist to treat a patient by passive mobilisation.

Two models of CPM machines are currently available, the Toronto Mobilimb and the Stryker Hand Exerciser. The Toronto Mobilimb is a relatively rigid device capable of five different stoke lengths and giving both passive flexion and extension. The Stryker Hand Exerciser has three stroke lengths and speeds and is attached to the fingers by cables. Both devices are battery operated and lightweight. The applications for CPM suggested by Salter (1989) include its use after MCP joint arthroplasty, intra-articular fractures, synovectomy and arthrolysis. It can also be used after tendon repair, ligament reconstructions and other intra-articular procedures. Other authors have suggested additional uses. Giudice (1990) found it more effective than elevation alone in reducing hand oedema. Shaw and Kasser (1990) used it in the management of septic arthritis. Blauth *et al.* (1990), Soffer and Yahiro (1990) and Letsch *et al.* (1989) have reported it in the management of fractures and arthroplasties in the elbow.

However, not much has been written about the use of CPM in the hand (Bentham *et al.*, 1987). A series of twenty cases of mixed hand conditions treated by CPM were reported by Hamilton (1982). The benefits described were minimal post-operative swelling, little pain and good toleration of the devices. He found that adhesions and contractions were prevented and rehabilitation achieved in the shortest possible time. An important paper by Bunker *et al.* (1989) reported a trial of continuous passive motion following flexor tendon repairs. A prospective study was performed on 17 consecutive patients with flexor tendon injuries in zone 2. The Toronto Mobilimb was used for four and a half weeks after tendon repair. The results were 85% excellent or good and 15% fair or poor using the Buck-Gramcko criteria. There were no poor results.

How do these figures compare with results achieved by other post-operative regimes? With Kleinert traction or Strickland's intermittent passive mobilisation technique between 27 and 61% excellent or good results have been reported. Using a combination of both regimes Chow *et al.* (1988) reported 98% excellent or good results. CPM, therefore, falls between these reports with its 85% excellent or good results. The authors conclude that CPM shows early promise but is not a panacea and certainly not a substitute for meticulous surgical technique and diligent follow-up.

**Intelligent continuous passive motion is better still?**

The results of CPM to date are unequivocal but the machinery, although safe, is still relatively rudimentary. Models currently available are constructed so that the actuating rods will go into reverse if the force generated in any direction exceeds 22 N. This avoids too much force being brought to bear on the finger. However, at present not much is known about how the force, speed and range of movement of the actuating rods should be selected for best effect. It may be that oscillations at the extreme of flexion and extension would be helpful in producing more relaxation in the scar tissue. This is a technique sometimes used by therapists.

So, how much force should be used, what range of movement should be aimed for and what is the most appropriate frequency for the cycle for any particular digit? These are some of the questions being asked in the Dundee Institute of Technology and the Free University of Berlin where a micro-processor controlled CPM machine is being developed. A prototype machine is illustrated in Figure 1. The actuator rods in the current model have a range of motion of 100 mm, a maximum force of 4.5 N and a minimum cycle time of 8.5 s. The excursion and speed of the rods can be varied. Electromechanical goniometers and potentiometers are used to provide information for the afferent arm of the feedback control for the actuator. A potentiometer determines the position of the actuating rod and a strain gauge transducer the magnitude of the force exerted. The device is connected by an umbilical cord to a desk top micro-processor. This control unit contains the motor control circuit boards, amplifiers for the strain gauges and potentiometers and the microprocessors. There is an output port for data collection.

A clinical project has been started in the Free University of Berlin to determine how range of movement in a finger can be improved by CPM and to quantify in biomechanical terms the changes in joint stiffness during treatment. To date data has been collected from two patients after 11.5 and 9.5 hours of treatment showing not only significant increase in range of finger movement with treament but also the continuing effects of stress relaxation while the finger is resting. In this study the machine mobilised the joint for five minutes and then stopped for two minutes while continuing to record data from the contracted finger during this stress relaxation phase.

The tracings produced (Fig. 2) record the motion of the actuator rod and the metacarpo-phalangeal joint. The strain gauge recording of

Fig. 1. The prototype continuous passive motion machine showing the actuator rod exercising one finger.

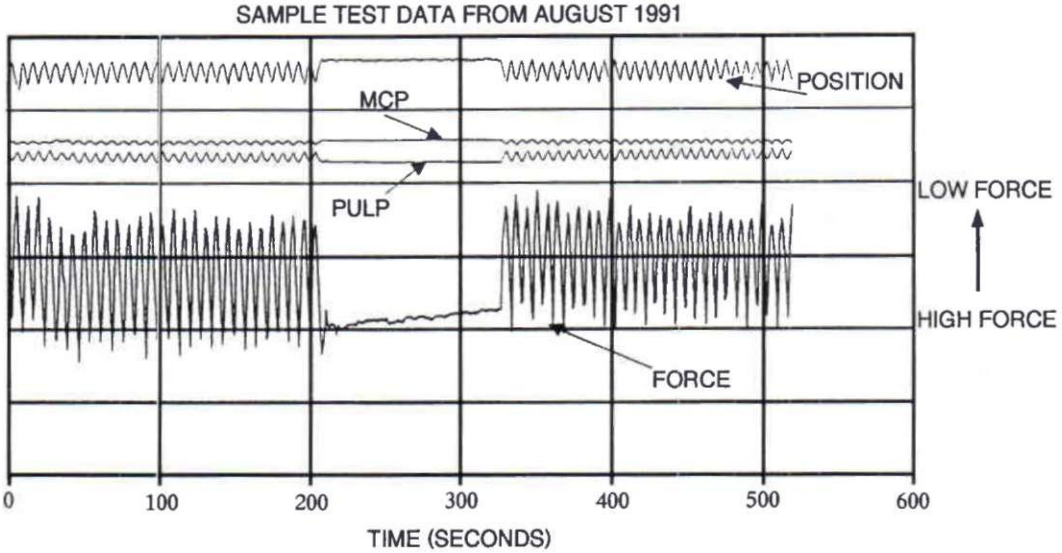

Fig. 2. The tracing produced during a 520 second exercise period. The top trace shows the movement of the actuator rod and the middle tracing the movement achieved in the MCP joint and finger tip. The lower tracing shows the stress relaxation effect.

force is shown in a third tracing. It can be seen that during the rest period (from 200–300 s) the force required to hold the finger in the same position becomes less. It is suggested that the contracture is relaxing under the applied force during this period.

Eventually the development of an intelligent CPM is envisaged which will be able to calculate the appropriate type of mobilisation for each finger. It is intended that eventually such a machine will have the ability initially to interrogate the finger and then calculate the appropriate force, range of movement and frequency of the cycle appropriate for the rehabilitation of that particular digit.

## REFERENCES

Bentham JS, Brereton WDS, Cochrane IW, Lyttle D (1987). Continuous passive motion device for hand rehabilitation. *Arch Phys Med Rehabil* **68**, 248–250.

Blauth M, Hass NP, Sudkamp NP, Happe T (1990). Die ellbogenarthrolyse bei post traumatischer gelenksteije. (Arthrolysis of the elbow in post-traumatic contracture). Orthopade **19**, 332–342.

Bunker TD, Potter B, Barton NJ (1989). Continuous passive motion following flexor tendon repair. *J Hand Surg* **14B**, 406–411.

Chow JA, Thomes LJ, Dovelle S, Monsivais J, Milnor WH, Jackson JP (1988). Controlled motion rehabilitation after flexor repair and grafting: a multicentre study. *J Bone Joint Surg* **70B**, 591–595.

Creekmore H, Bellinghausen H, Young VL, Wray CR, Weeks PM, Grasse PS (1985). Comparison of early passive motion and immobilisation after flexor tendon repairs. *Plast Reconstr Surg* **75**, 55–59.

Cullen KW, Tolhurst P, Lang D, Page RE (1989). Flexor tendon repair in zone 2 followed by controlled active mobilisation. *J Hand Surg* **14B**, 392–395.

Duran RJ, House RG (1975). Controlled passive motion following flexor tendon repair in zones 2 and 3. Symposium on tendon surgery in the hand.—American Academy of Orthopaedic Surgeons—St. Louis: DC Mosby.

Edinburg M, Widgerow AD, Biddulph SL (1987). Early postoperative mobilisation of flexor tendon injuries using a modification of the Kleinert technique. *J Hand Surg* **12A**, 34–38.

Gelberman RH, Menon J, Gonsalves M, Akeson WH (1980). The effects of mobilization on the vascularisation of healing flexor tendons in dogs. *Clin Orthop* **153**, 283–289.

Giudice ML (1990). Effects of continuous passive motion and elevation on hand oedema. *Am J Occup Ther* **44**, 914–921.

Hamilton HW (1982). Five years' experience with continuous passive motion (CPM). *J Bone Joint Surg* **64B**, 259.

Harmer TW (1917). Tendon suture. *Boston Med Surg J* **167,** 808.

Hitchcock TF, Light TR, Bunch WH, Knight GW, Sartori MJ, Patwardhan AG, Hollyfield RL (1987). The effect of immediate constrained digital motion on the strength of flexor tendon repairs in chickens. *J Hand Surg* **12A,** 590–595.

Ketchum LD, Clark LC, Robinson DW, Masters FW (1972). A new electric hand splint. *J Bone Joint Surg* **54A,** 902.

Ketchum LD, Hibbard A, Hassanein KM (1979). Follow-up report on the electrically driven hand splint. *J Hand Surg* **4,** 474–481.

Kleinert HE, Kutz JE, Ashbell TS, Martine E (1967). Primary repair of flexor tendons in "no man's land". *J Bone Joint Surg* **49A,** 577.

Letsch R, Schmit-Neuerburg KP, Sturmer KM, Walz M (1989). Intra-articular fractures of the distal humerus: surgical treatment and results. *Clin Orthop* **241,** 238–244.

Lister GD, Kleinert HE, Kutz JE, Atasoy E (1977). .Primary flexor tendon repair followed by immediate controlled mobilization. *J Hand Surg* **2.** 441–451.

Loitz BJ, Zernicke RF, Vailas AC, Kody MH, Meals RA (1989). Effects of short-term immobilisation versus continuous passive motion on the biomechanical and biochemical properties of the rabbit tendon. *Clin Orthop* **244,** 265–271.

Matthews JP (1989). Early mobilization after flexor tendon repair. *J Hand Surg* **14B,** 363–367.

Morris JS (1987). Continuous passive motion in post-operative rehabilitation of the hand: a prospective study (abstract). *J Bone Joint Surg* **69B,** 501.

Palmoski MJ, Brandt KD (1979). Effect of salicylate on proteoglycan metabolism in normal canine articular cartilage in vitro. Arthritis Rheum **22,** 746–754.

Salter RB (1982). Motion vs. rest: why immobilise joints? Presidential address to the Canadian Orthopaedic Associations. *J Bone Joint Surg* **64B,** 251–254.

Salter RB (1989). The biologic concept of continuous passive motion of synovial joints. *Clin Orthop* **242,** 12–25.

Small JO, Brennan MD, Colville J (1989). Early active mobilization following flexor tendon repair in zone 2. *J Hand Surg* **14B,** 383–391.

Soffer SR, Yahiro MA (1990). Continuous passive motion after internal fixation of distal humerus. *Orthop Rev* **19,** 88–93.

Stickland JW, Glogovac SV (1980). Digital function following flexor tendon repair in zone II: a comparison of immobilization and controlled passive motion techniques. *J Hand Surg* **5,** 537–543.

Shaw BA, Kasser JR (1990). Acute septic arthritis in infancy and childhood. *Clin Orthop* **257,** 212–215.

Werntz JR, Chesher SP, Breidenbach WC, Kleinert HE, Bissonnette MA (1989). A new dynamic splint for post-operative treatment of flexor tendon injury. *J Hand Surg* **14A,** 558–566.