AN EVALUATION DEVICE FOR QUANTIFYING JOINT STIFFNESS IN THE BURNED HAND

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Reprinted from
THE JOURNAL OF BURN CARE & REHABILITATION,
St. Louis

Vol. 11, No. 4, pp. 312-317, July-August, 1990

An Evaluation Device for Quantifying Joint Stiffness in the Burned Hand

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An electronic device capable of measuring finger joint stiffness has been developed and used to evaluate the effects of dynamic flexion splinting on the recovery of joint motion in patients with burned hands. The device locates an angle of primary (greatest) resistance and the reactive torque at that angle for a selected joint. Using the device, four subjects with stiff hands were measured before and after dynamic splinting treatments. During the 3-day treatment period, there were statistically significant differences in the angle of primary resistance ($p < 0.0001$) and reactive torque ($p < 0.001$). This initial trial suggests that: (1) finger stiffness can be quantified in terms of reactive torque as well as joint excursion, (2) dynamic rubber-band flexion splinting does alter joint condition and allow increased motion, (3) the amount of initial joint stiffness may be an indicator of treatment outcome, and (4) increasing treatment time may not enhance outcome. (J Burn Care Rehabil 1990;11:312-17)

Stiffness of hand joints associated with functional impairment is a frequent complication after burn injury. In addition to tissue damage from the original injury, prolonged edema and subsequent immobilization after skin grafting contribute to loss of motion. Although protection of the extensor hood mechanism of the proximal interphalangeal joints is of major importance in the management of the severely burned hand,[1] metacarpophalangeal joint mobility must also be maintained. Loss of motion at these joints can severely limit hand function, as they serve to position the distal phalanges to perform full opening or closing of the hand as well as other manipulative motions. After burn injury, the metacarpophalangeal joints are subject to the development of stiffness from scarring over the dorsum of the hand, shortening of the collateral ligaments, and adhesions of the dorsal synovial pouch, extensor tendon, and volar plate.[2] Maintaining, and if necessary regaining, metacarpophalangeal joint motion is one of the primary goals of rehabilitation of the burned hand.

Dynamic splinting is commonly used as a treatment modality in rehabilitation of the burned hand.[3-6] This type of splinting uses an outrigger, rubber bands, and finger slings to apply moderate force to a joint for an extended period of time. Because human tissues are viscoelastic, they respond to the forces applied by a dynamic splint in specific ways.[7] If force is applied for a short period of time, the tissue will display an elastic response in which it will be elongated but recover its initial shape when the force is removed. If the force is of low magnitude and prolonged, the tissue will display a plastic response and remain elongated after removal of the force. This elongation is thought to be a result of cell proliferation and reorientation in the stressed tissue.[8]

Elongation of the tissue that surrounds an impaired joint allows increased joint motion that can be measured with a goniometer. This angular measurement alone, however, does not completely de-

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Presented at the Twenty-first Annual Meeting of the American Burn Association, March 29 to April 1, 1989, New Orleans, Louisiana.
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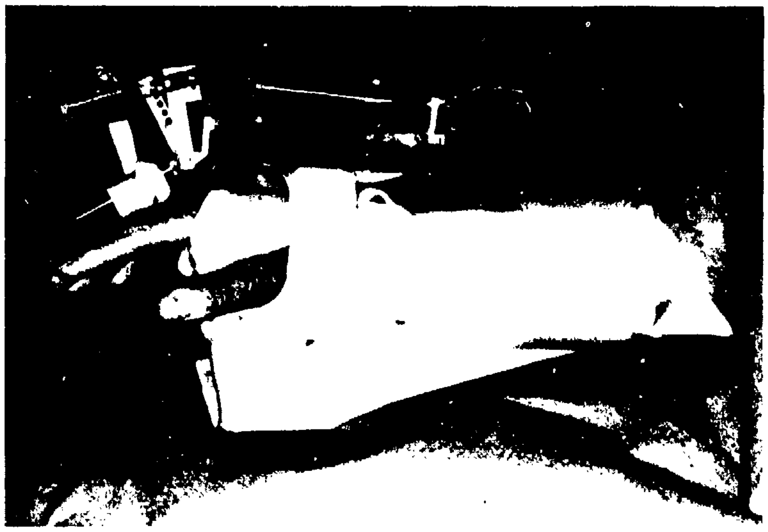

Figure 1. Electronic finger joint stiffness measurement device.

scribe the stiffness of the joint. Joint stiffness is a measure of the joint's resistance as it is moved through a given range of motion. Currently, there is no reliable objective method to measure joint stiffness in the hand. The treatment outcome of splinting and other rehabilitation procedures is therefore generally measured in terms of joint excursion without reference to the force required to achieve that excursion. An additional problem is concerned with the selection of the force levels applied with dynamic splints. Splinting force levels are based primarily on the subjective judgment of the therapist as modified by the need to avoid local tissue ischemia that results from finger sling pressure. Splinting procedures continue to be more of an art than a science. The ability to quantify the stiffness of a joint and the surrounding tissue could lead to a better understanding of the effects of dynamic splinting and to the development of objectively based treatment protocols.

The objective of this study was to develop an instrument to quantify joint stiffness in burned hands and to measure the effects of different treatments on recovery of range of motion in impaired metacarpophalangeal joints.

MATERIALS AND METHODS

A device capable of concurrently producing and measuring forces similar to those applied to a phalanx by a dynamic splint was designed and constructed. The complete system consisted of: (1) a dorsal thermoplastic wrist-control splint that supported an electromagnetically controlled hydraulic piston linked to a finger "cradle" (Figure 1), (2) a single board microcomputer that was configured to control the position and rate of movement of the piston, and (3) a laptop computer that served as a master controller and provided data logging and analysis functions. The system (Figure 2) was configured to apply a torque at a constant 90-degree angle to the proximal phalanx, which would match the reactive torque that was being generated by the involved joint structure. Because the joint tissue components are viscoelastic, the loading rate was kept constant (0.5 degrees per second) for all applications. As the phalanx was moved through its range of motion, the resulting curve of reactive torques, measured in inch-pounds, and their associated angular locations were recorded. The first measurement logged was the angle at which initial resistance was encountered. The computer then calculated the rate of change (torque per degree) for the curve and located the point at which the largest change occurred. This point was called the point of primary resistance and along with its corresponding reactive torque was selected to characterize joint stiffness. Figure 3 shows the shape of the torque and angle curve and location of the angles of initial and primary resistance for an uninjured metacarpophalangeal joint.

Four male subjects with a total of 20 stiff metacarpophalangeal joints following burn injury participated in the initial trial of the device. After informed

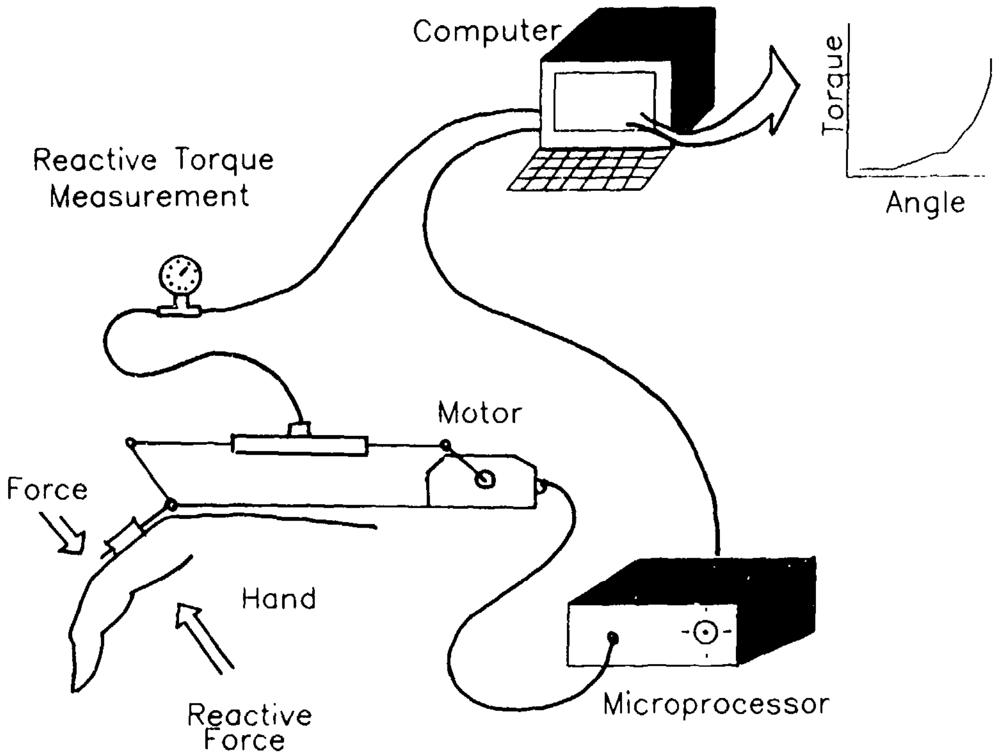

Figure 2. Mechanical and electronic components of the finger joint stiffness measurement device. A microprocessor controls an electric motor that applies force to a finger through a hydraulic piston system, which concurrently measures the resistance of the joint. A computer calculates the angle of the joint from the motor actuator arm, logs the data, and generates a torque and angle curve for the measured joint.

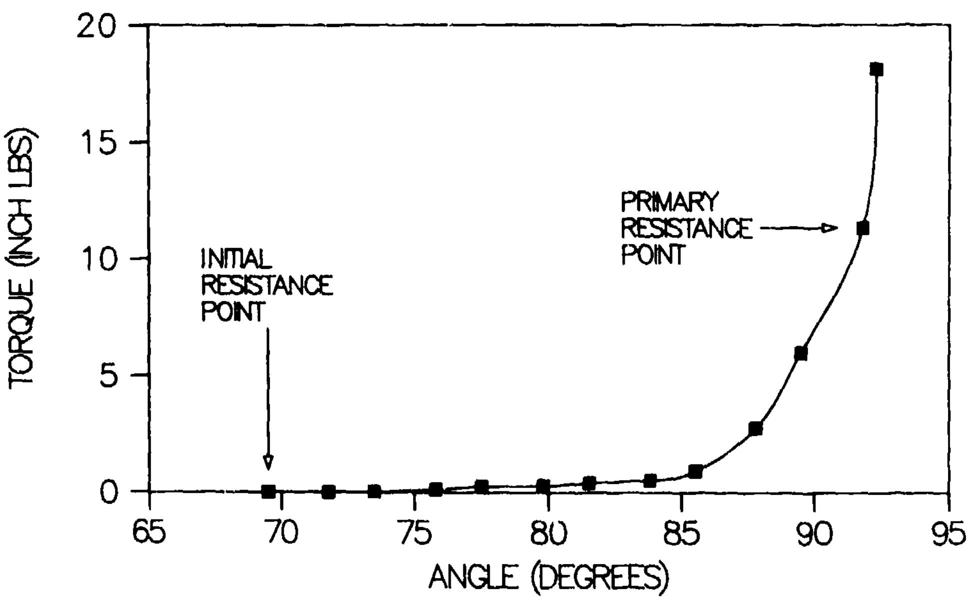

Figure 3. Uninjured finger torque and angle curve showing points of initial and primary resistance.

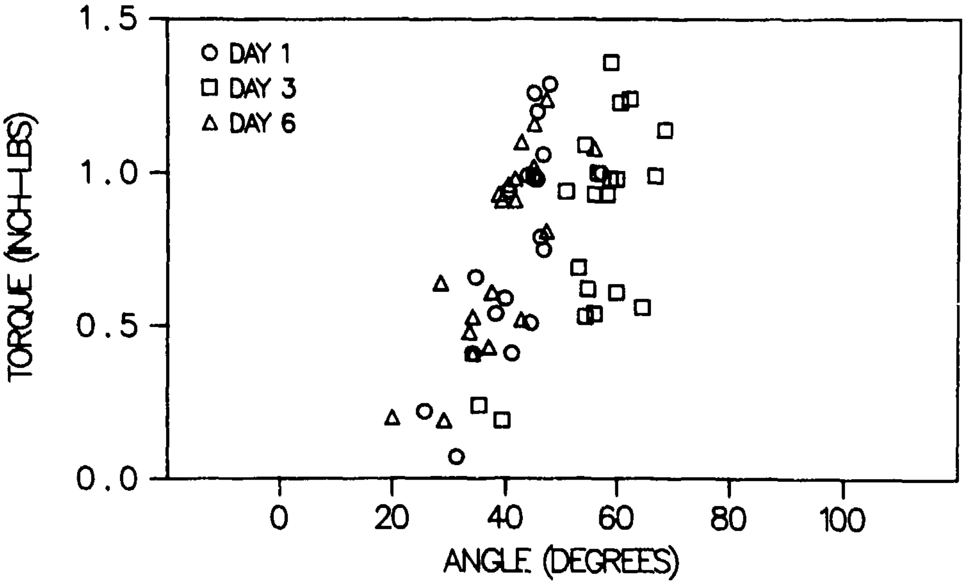

Figure 4. Plots of primary resistance points for 20 injured fingers for days 1 to 6.

consent was obtained, each subject's joints were measured with the device, and on the basis of initial values of primary resistance, each joint was assigned to either a high- or a low-stiffness group. The division of the stiffness groups was arbitrarily defined by the midpoint of the range of initial resistance values. The joints were evenly assigned to the groups so that the half with the highest angles, that is greater motion before reaching their points of primary resistance, were placed in the low-stiffness group and the remainder in the high-stiffness group. The patients in each of the stiffness groups were then randomly assigned to one of two treatment groups. Each group received dynamic flexion splinting of the metacarpophalangeal joints with a ventral rubber-band-powered dynamic splint that exerted 400 gm of force on each joint. Group 1 received 1 hour of treatment once daily, and group 2 received 1 hour twice daily. Each participant received 3 days of treatment; measurements of primary resistance were taken before and after each session. On day 6, after 2 days of no splinting, a fourth measurement was taken to assess the effects of discontinuing treatment. Two-way ANOVA of treatment days and the variables, angle of initial resistance, angle of primary resistance, and reactive torque was performed.

RESULTS

Figure 4 shows the plots of the primary resistance points for the 20 fingers for treatment days 1 through 3 compared with day 6. The shifting of the points to the right over the 3 treatment days suggests a decrease in joint stiffness. On day 6, however, the points of primary resistance shifted back to the left, which indicates a return to pretreatment levels of stiffness. The ANOVA between treatment days and angles of initial and primary resistance and reactive torque showed significant differences. There was a mean increase of 6.8 degrees in the initial angle of resistance between treatment days 1 and 3, followed by a decrease of 2.3 degrees after 2 days of no splinting ($p < 0.0001$). The mean angle of primary resistance increased by 15 degrees and then decreased by 3 degrees ($p < 0.0001$). Mean reactive torque increased by 2.3 inch-pounds between days 1 and 3 then increased an additional 1.7 inch pounds between days 3 and 6 ($p < 0.001$). Figure 5 compares the change of the mean values of the three variables over the treatment period. There was an increase in all three variables over the treatment days. There was also a change in the relationship between the angle of primary resistance and reactive torque. On day 1 the angle of primary resistance was less than reactive torque; on day 2 they were equal, and by day 3, the angle of primary resistance was greater. A Duncan's multiple range test that compared the high- and low-stiffness groups for differences in treatment days, angular position of initial resistance, reactive torque, stiffness, and length of treatment time was performed. There were statistically significant differences between the low- and high-stiffness groups in

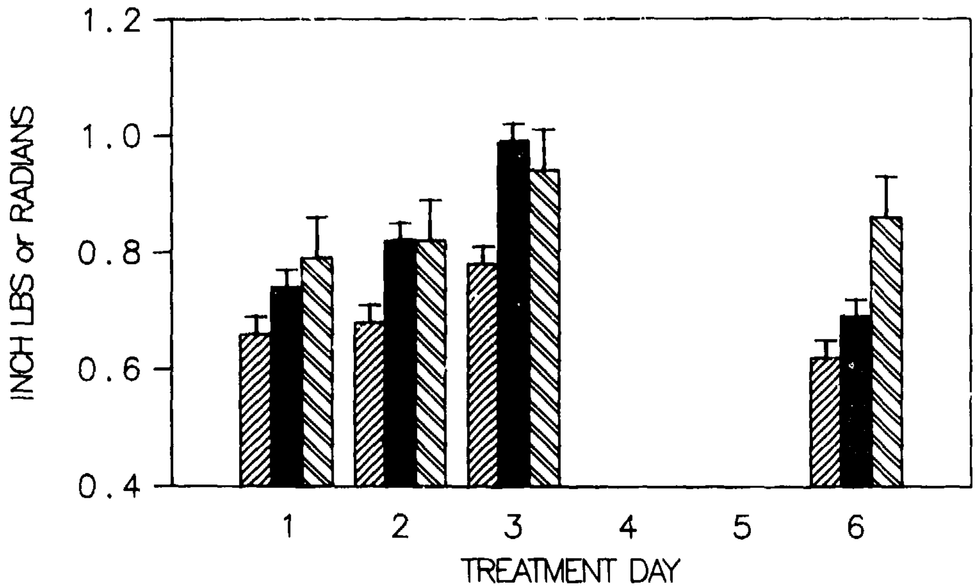

Figure 5. Change in mean values of initial and primary resistance points and reactive torque for days 1 to 6. Angles are reported in radians, which equal 57 degrees. ▨ angle of initial resistance (radians) ± SEM; ■ angle of primary resistance (radians) ± SEM; ⧅ reactive torque (inch-pounds) ± SEM.

angular position of primary resistance ($p < 0.05$) and reactive torque ($p < 0.0001$). There were no significant differences between the 1- and 2-hour treatment groups.

DISCUSSION

The results of this initial trial of a finger joint stiffness measurement device show that splinting effects can be measured in terms of joint stiffness (reactive torque) as well as range of joint motion. Normal joints demonstrate minimal reactive torque through the majority of their excursion but show a rapid increase in torque at the end of the range. Impaired joints show an increase in torque much earlier in the range of motion. In the treatment of impaired joints, the desired effect would therefore be to decrease reactive torque during submaximal range of motion. The data from the 3 treatment days suggest that although dynamic flexion splinting of the metacarpophalangeal joints does increase joint range of motion, reactive torque also increases. It is, however, interesting to compare the rates of change. The angle of primary resistance increased at a faster rate than reactive torque did. It is possible that this was an early indication of the viscous tissue response in which the elongation of joint structures allowed increased excursion without matching reactive torques. The loss of joint motion after the termination of treatment on day 3 supports previous clinical observations that short-term treatment effects are generally temporary. The significant differences in posttreatment joint stiffness between the low- and high-stiffness groups further suggest that the initial stiffness of a joint may be an indicator of treatment outcome. Although an optimum duration of treatment was not defined, the lack of significant change in joint stiffness as the result of treatment frequency does suggest that increased treatment time may not enhance outcome.

Although this trial of the splint monitoring device was limited in subject number and study duration, the results suggest that the study of hand-joint function and recovery after injury may be enhanced by analysis of reactive torque as well as range of joint motion. The device will be used to document joint motion characteristics of uninjured and injured joints, outcome comparisons of a variety of hand treatment modalities and, ultimately, the dynamic splint force levels and treatment durations required for optimum rehabilitation of the hand.

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