Orthotics and Prosthetics, Vol. 32, No. 3, pp. 37-43, September 1978

Tissue Pressure Tolerance As a Guide to Wrist-Hand Orthosis Design

DUANE TODERAN, C.O.[1]
TOM LUNSFORD, M.S.E.[1]

An individual with paralyzed wrist extensor musculature presents a challenge to orthotists. When the wrist is inadvertently maintained in a flexed position, wrist, hand, and finger flexion contracture deformities may result. The weight of the hand itself, and the mechanical and orthotic limitations present formidable problems.

The orthotic recommendation for a patient with paralyzed wrist extensors is often a static wrist-hand orthosis which supports the patient's wrist against flexion while maintaining an extension angle at the wrist, opposition of the thumb, and curvature of palm.

A successful wrist-hand orthosis is not only one with a good appearance, but more importantly, fits well. A wrist-hand orthosis which fits improperly can create excessive pressure.

The forearm, wrist, and hand can be treated as a simple first-class lever system with a force and lever on each side of a fulcrum. This lever system allows an analysis of the demand torque (hand) and support torque (orthosis). Then it follows that force can be deduced from the torque and pressure estimated by the ratio of force to associated area over which the force is applied. Lastly, the estimated values for pressure can be compared to tissue tolerance values and excesses identified.

In a normally extended wrist (30 deg.), the flexion demand torque must be equal to the extension support torque as shown in Figure 1.

$$F_E \cdot d_E = W_H \cdot d_H \qquad (1)$$

Support = Demand

Where, F_E = extensor musculature force required to keep wrist extended lbs.

d_E = extensor lever arm from extensor tendon midline to wrist joint axis n inches.

W_H = weight of hand producing

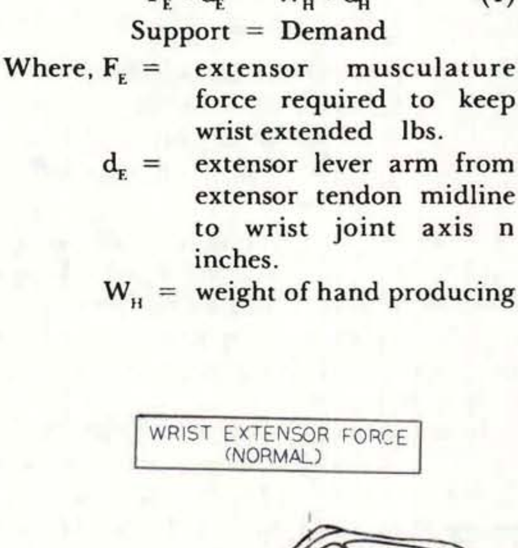

Fig. 1. Graphical presentation of equation (1).

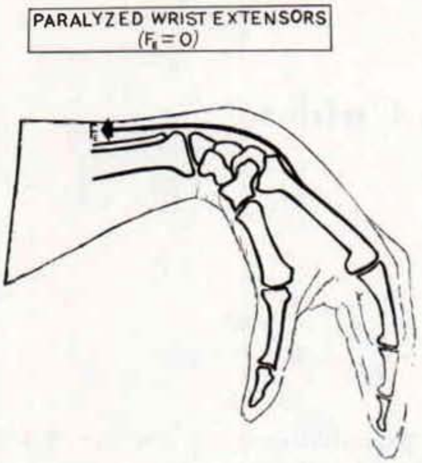

Fig. 2. Schematic of hand with completely paralyzed wrist extensors.

wrist flexion lbs.

d_H = hand lever arm from center of gravity of hand to wrist joint axis n inches.

If the extensor tendons were cut or denervated, the pronated hand would inevitably fall into flexion as shown in Figure 2. Without support extensor torque, an alternative (orthotic) form of support is required.

In most cases the paralyzed wrist can be supported with a static wrist-hand orthosis. As shown in Figure 3, the hand is supported with palmar and forearm components.

Experience with static wrist-hand orthoses suggests that there are three areas where pressure may become excessive. As shown in Figure 4, these areas include the volar forearm, P_1, palmar, P_2, and dorsal wrist, P_3 areas.

Volar Forearm Pressure (P_1)

To determine the volar forearm pressure, P_1, it is necessary to consider the force, F_1, between the proximal strap and

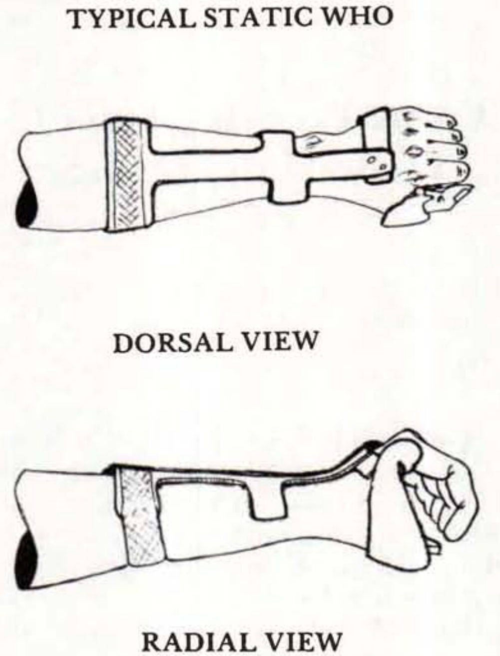

Fig. 3. Typical static wrist-hand orthosis.

volar forearm surface as shown in Figure 5.

The hand in Figure 5 tends toward flexion producing a demand torque (T_D) given by

$$T_D = W_H \cdot d_H \qquad (2)$$

The corresponding support torque (T_S) afforded by the orthosis is given by

$$T_S = F_1 \cdot d_F \qquad (3)$$

Where, F_1 = proximal volar forearm strap force n lbs.

d_F = length of forearm piece from proximal strap to wrist joint axis n inches.

When the wrist is adequately supported the demand torque is balanced by the support torque or

$$T_D = T_S \text{ or} \qquad (4)$$

$$W_H \cdot d_H = F_1 \cdot d_F$$

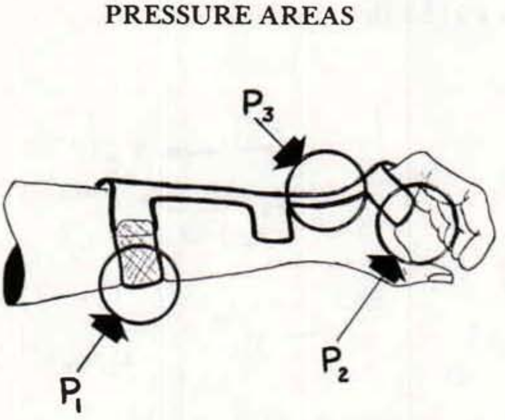

Fig. 4. Areas where excessive pressures are most apt to be found in a static wrist-hand orthosis. P_1 —volar forearm; P_2 —palmer surface; P_3 —dorsal surface of the wrist.

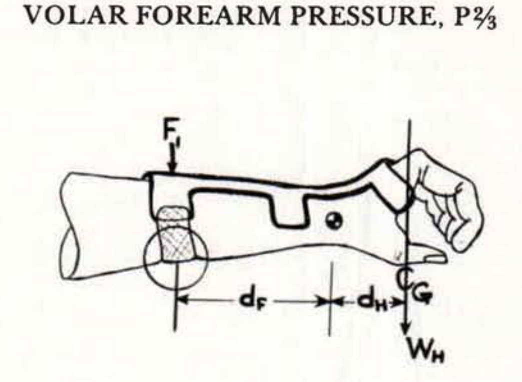

Fig. 5. Elements needed to determine volar arm force in a static wrist-hand orthosis; equation (5).

Rearranging equation (4) yields the following for the volar forearm force,

$$F_1 = \frac{W_H \cdot d_H}{d_F} \qquad (5)$$

The volar forearm strap area is

$$A_{strap} = W_S \cdot L_S \qquad (6)$$

Where, W_S = strap width n inches
L_S = strap length contacting volar surface n inches

Since mechanical pressure is defined as the ratio of force to area, the volar forearm surface pressure, P_1, is obtained from equations (5) and (6).

$$P_1 = \frac{F_1}{A_{strap}} = \frac{W_H \cdot d_H \text{ (num.)}}{d_F \cdot W_S \cdot L_S \text{ (den.)}} \qquad (7)$$

The numerator of equation (7) contains hand weight (W_H) and its lever, (d_H) neither of which can be changed by the orthotist. However, the factors in the denominator forearm lever (d_F), strap width (W_S) and strap length (L_S) can be changed to reduce the volar forearm pressure, P_1.

The value of equation (7) to the orthotist can be realized by a practical example. Consider patients with hands that weigh 1 to 2 pounds (W_H) and each has a 3-inch lever arm (d_H) from the center of gravity of the hand to wrist joint axis. Assume the area of the volar forearm strap is 1/2 wide (W_S) by 3 inches long (L_S). The resulting volar forearm pressure produced as a function of the forearm lever is shown in Figure 6.

Before a value for forearm lever, d_F, can be selected from this graph, it is necessary to know the maximum allowable value for volar forearm pressure, P_1. The maximum volar forearm pressure can be obtained from the tissue tolerance curve shown in Figure 7.

Tissue tolerance can be expressed as a specific pressure applied for a maximum period of time. Any combination of applied pressure and length of time above the curve is unacceptable; values below the curve acceptable. According to this relationship for "pressure tolerance," it is necessary that less than 30 mmHG pressure exists before the orthosis can be worn continuously (8 hours or longer). Referring to the curve of P_1 versus d_F,

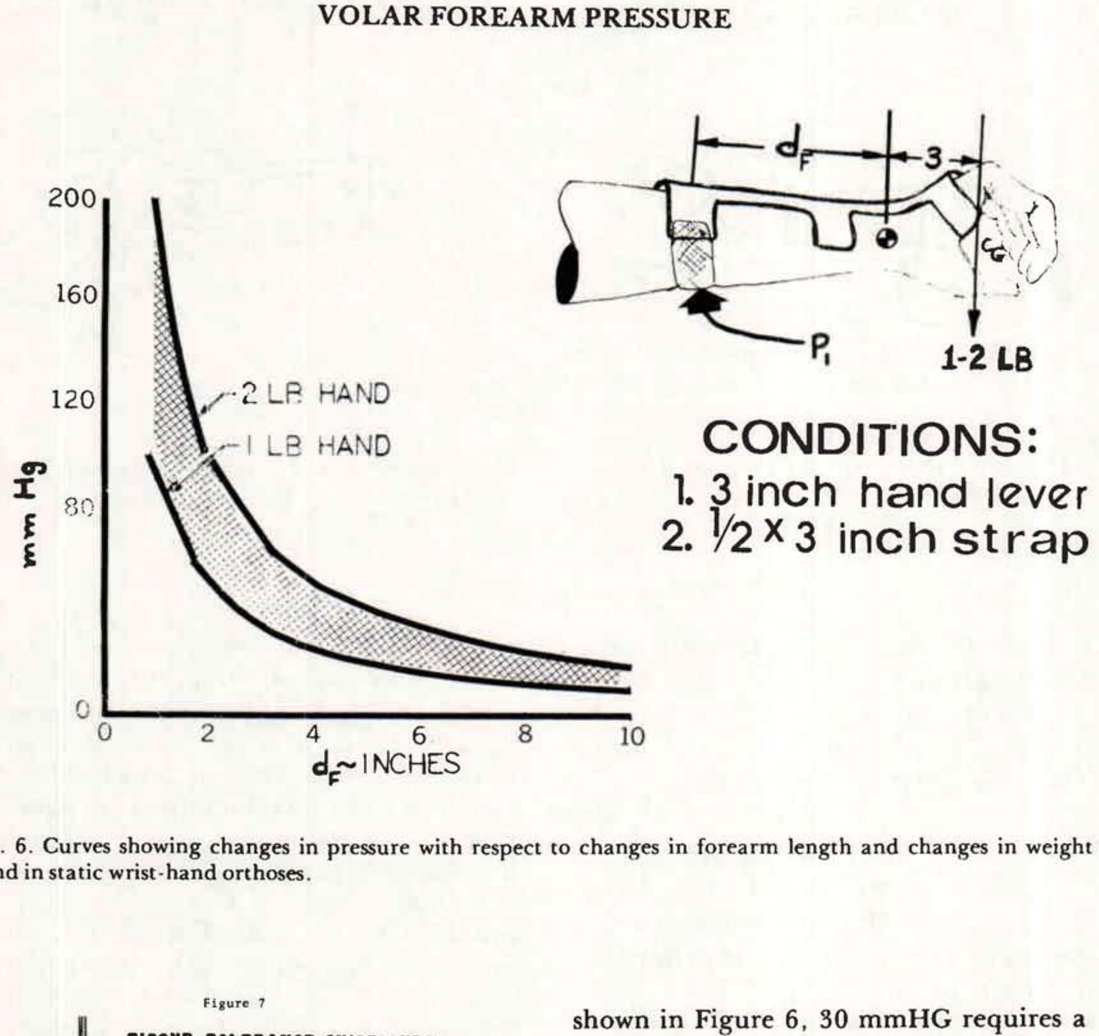

Fig. 6. Curves showing changes in pressure with respect to changes in forearm length and changes in weight of hand in static wrist-hand orthoses.

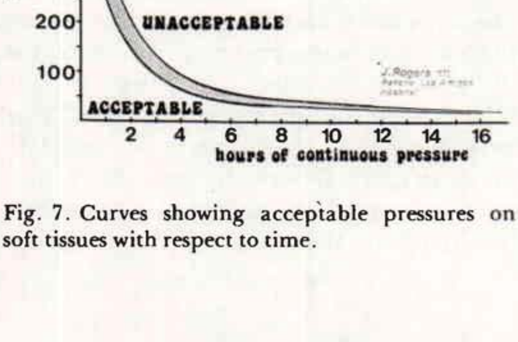

Fig. 7. Curves showing acceptable pressures on soft tissues with respect to time.

shown in Figure 6, 30 mmHG requires a minimum 6-inch proximal forearm lever. Therefore, the distance from the proximal extension of the forearm piece to the wrist joint axis should not be less than 6 inches to ensure that excessive pressure does not exist.

Palmar Pressure (P_2)

The palmar pressure, P_2, is due entirely to the ratio of the weight of the hand (W_H) and to the area of the orthosis in the region of the palm.

$$P_2 = \frac{W_H}{A_P} = \frac{\text{Weight of Hand}}{\text{Area of Orthosis in Palm}} \quad (8)$$

The area of the orthosis at the palm is given by (see Figure 8).

$$A_P = W_{PE} \cdot L_{PE} \quad (9)$$

Where, W_{PE} = width of palmar extension inches

L_{PE} = length of palmar extension inches

Substituting equation (9) into (8) yields

$$P_2 = \frac{W_H}{W_{PE} \cdot L_{PE}} \quad (10)$$

This relationship for palmar pressure is shown graphically in Figure 9. In this case the palmar pressure, P_2, is compared with the width of the palmar extension, W_{PE}. The length of palmar extension, L_{PE}, in contact with the hand is assumed to be 3 inches. With the restraint that the

PALMAR PRESSURE

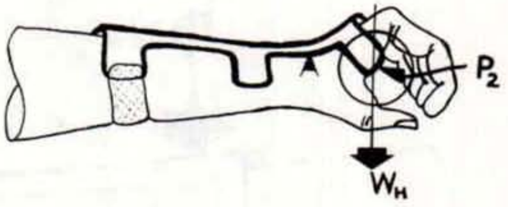

Fig. 8. Graphical presentation of palmar pressure, P_2.

PALMAR PRESSURE, P_2

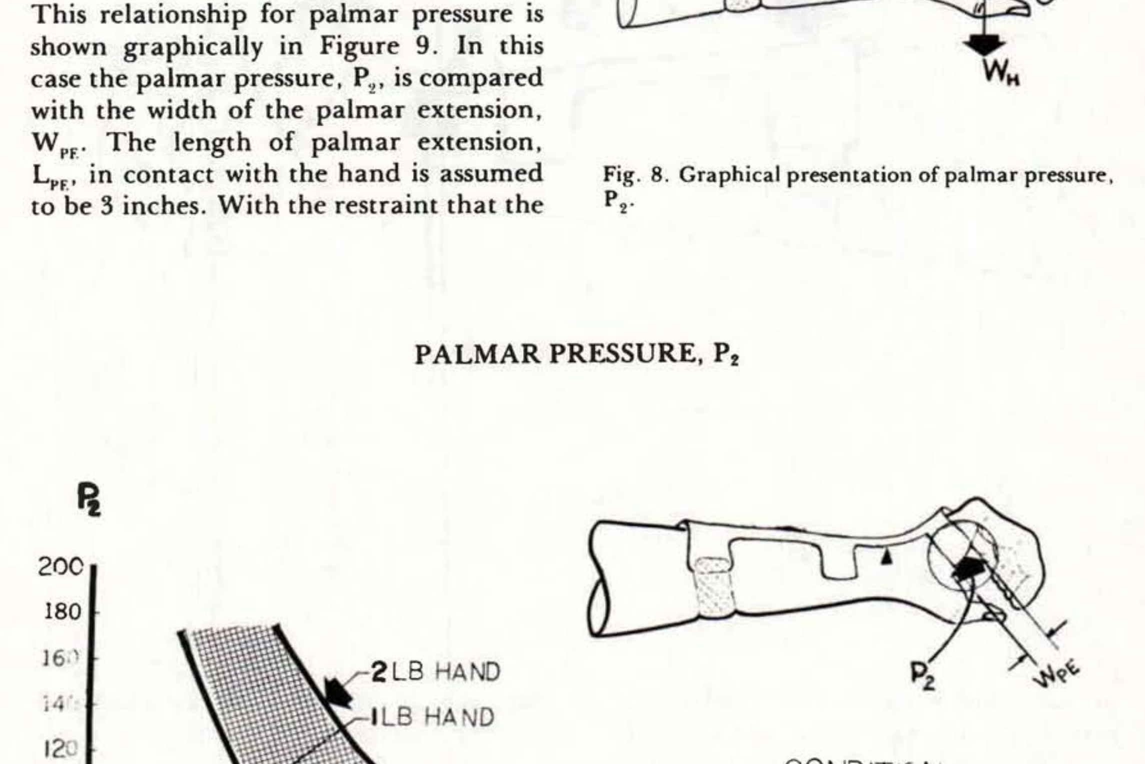

Fig. 9. Schematic of the determination of palmar pressure, P_2, and the effects of variations in hand weight and support width.

P_3-DORSUM PRESSURE

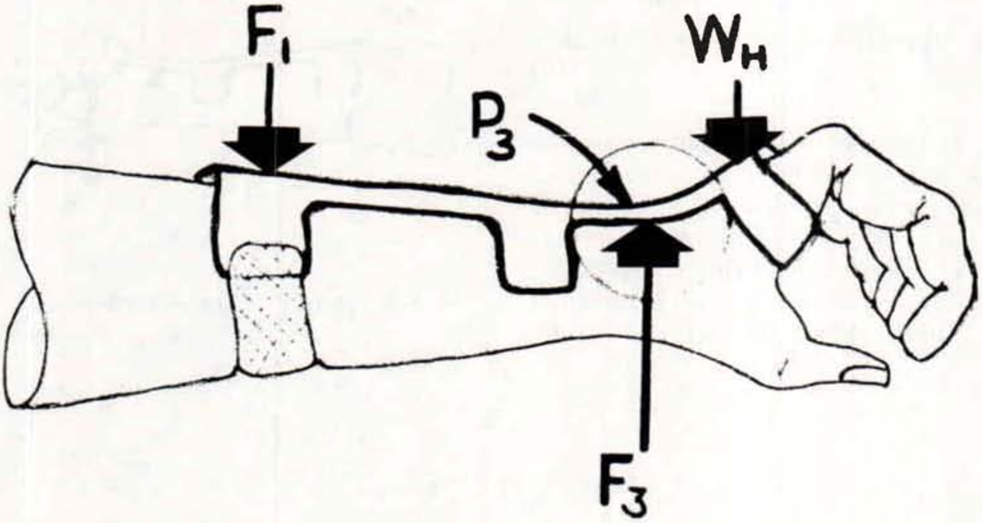

Fig. 10. Dorsum pressure, P_3.

pressure shall not exceed 30 mmHG continuously, the minimum width of the palmar extension is 0.7 inch as shown in Figure 9.

The size of palmar extension (3 x 0.7 inches) will ensure safe pressure but may interfere with rotation of the metacarpal-phalangeal joint. The distal edge of the palmar extension must be positioned proximal to the imaginary line formed by the second and fifth palmar creases.

Dorsal Pressure (P_3)

The dorsal pressure, P_3, is represented in Figure 10. This pressure is given by the ratio of the force, F_3, to the area of the dorsal piece of the wrist-hand orthosis making contact with the wrist.

$$P_3 = \frac{F_3}{\text{area of dorsal piece}} \quad (11)$$

The force F_3 is an equal and opposite reaction to the sum of the forces of the hand, W_H, and forearm piece, F_1.

$$F_3 = W_H + F_1 \quad (12)$$

The area of the dorsal piece is given by its length (L_{DP}) times width or W_{DP}.

$$A_{\text{dorsal piece}} = W_{DP} \cdot L_{DP} \quad (13)$$

Substituting equation (12) and (13) into (11) yields the following expression for dorsal pressure

$$P_3 = \frac{W_H + F_1}{W_{DP} \cdot D_D} \quad (14)$$

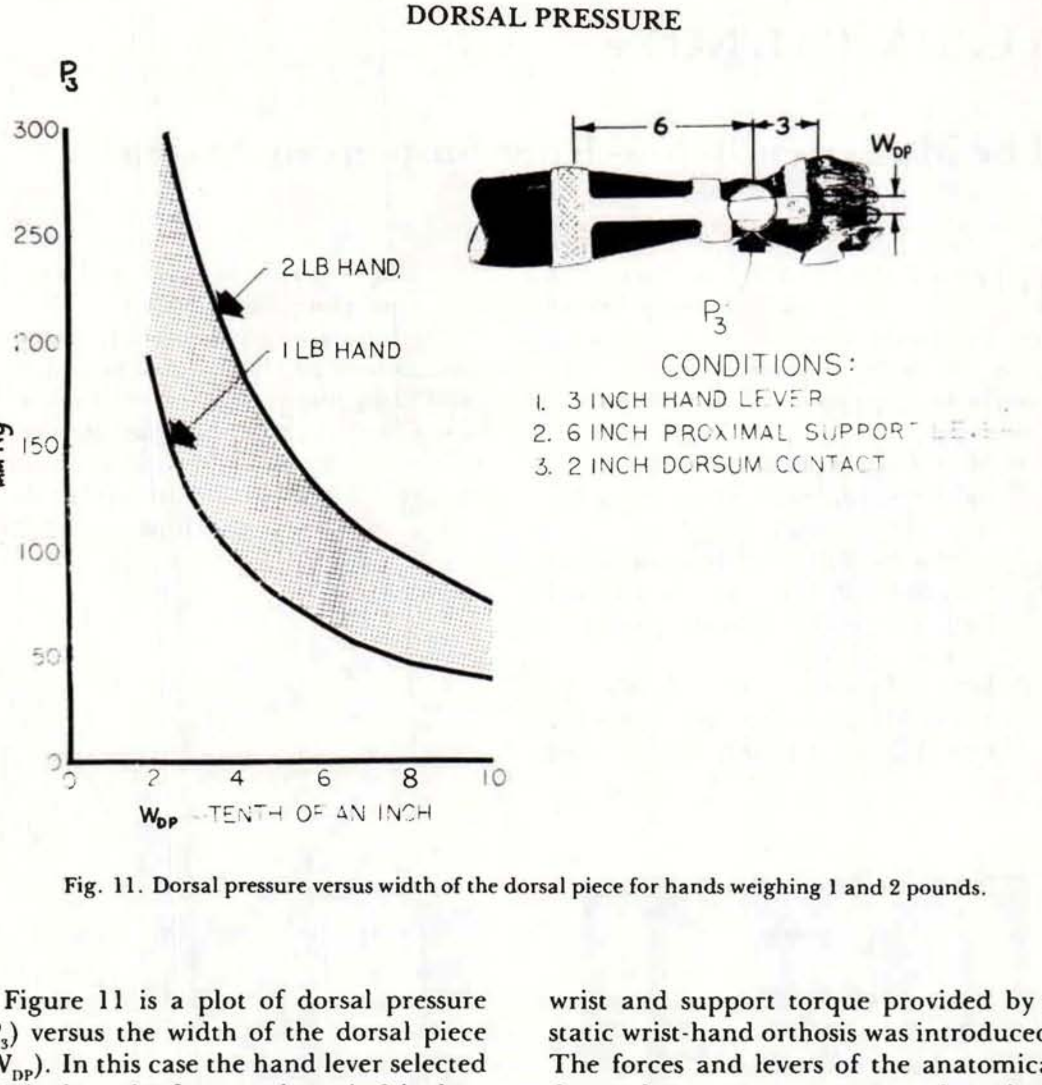

Fig. 11. Dorsal pressure versus width of the dorsal piece for hands weighing 1 and 2 pounds.

Figure 11 is a plot of dorsal pressure (P_3) versus the width of the dorsal piece (W_{DP}). In this case the hand lever selected is 3 inches, the forearm lever is 6 inches, and the length of the dorsal piece making contact with the wrist is assumed to be 2 inches.

For the dorsal pressure not to exceed 30 mmHG, the width of the dorsal piece must be a minimum of one inch.

Summary

Three areas of pressure produced by a static wrist-hand orthosis have been identified. The concept of demand torque produced by a paralyzed and flexible wrist and support torque provided by a static wrist-hand orthosis was introduced. The forces and levers of the anatomical demand system were compared to those of the orthotic supporting system. This information together with an estimate of the area over which the supporting forces occur allowed an estimate to be made of the pressure applied. The applied pressure was evaluated for tissue tolerance.

Footnotes

[1]Rancho Los Amigos Hospital, 7413 Golandrivas Street, Downey, Calif. 90242