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DYNAMIC ULNAR-DEVIATION SPLINT

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INTRODUCTION

Splinting for the rheumatoid hand has traditionally consisted of static devices designed to minimize pain, correct deformity, and protect against deforming forces. A basic problem has been that these splints immobilize the hand and thus prevent it from carrying out useful activity. There have been few devices that provide necessary correction or protection without unduly restricting function.

Also, it is increasingly apparent that the need for protection is greatest during activity. Studies of the causative factors in rheumatoid deformities of the metacarpophalangeal (MCP) joint indicate that much of the damage to these key joints occurs during pinch or grasp.[1] In addition, pain tends to be worse during movement. Finally, manipulative ability is often more impaired when deformed joints are unsupported.

It has been found that MCP joint deformity is largely the result of the forces generated by the flexor tendons at the mouth of the flexor tunnel.[1] Loss of support for this structure appears to be a primary cause of ulnar subluxation and deviation, at least in digits 2,3, and 4. Therefore an ideal dynamic splint would protect or replace the function of this tunnel mouth. Unfortunately, however, efforts to design such a splint in a practical form have so far been unsuccessful.[2]

A more limited but still worth-while objective would be to prevent the ulnar deviation of the fingers that occurs during active flexion and when external loads are applied. A splint accomplishing this would not necessarily eliminate damage to MCP joint restraints but might reduce it, particularly in the fifth digit where the radial collateral ligament is most vulnerable.[1] Such a splint might also limit that portion of the joint destruction and pain resulting from the fingers tracking along an abnormal path, and from external gravity loads acting in an ulnar direction. Finally, it should permit more effective use of the forces generated by muscles acting on the fingers, and thus should encourage more normal function of the hand.

To this end, a simple splint has been developed which fastens to the ulnar aspect of the hand and incorporates a dynamic or fixed ulnar post for the fifth digit. (Figs. 1,2,3, and 4). The post prevents the fingers from tracking ulnarly when they flex in unison. To prevent the strap from causing the hand to buckle, dorsal and volar extensions over metacarpals 2,3,4 and 5 are incorporated. (Figs. 1,3, and 4). The ulnar post can consist either of a hinged clip (Figs. 1 and 2), a spring-loaded clip, or a rigid Teflon-lined post (Figs. 3 and 4).

Force Analysis

Because the device acts through application of forces, an analysis has been made of the relative magnitude and direction of forces required, as well as the most effective way of applying them. The analysis deals first with the hand position in which the fingers are extended so that all forces are applied in the same plane.

The basic function of the device is to provide a radial deviating torque about the fifth MCP joint strong enough to prevent the finger from deviating ulnarly. In accomplishing this, the splint applies a corrective force, F_1, at the end of the ulnar post against the little finger (Fig. 6). The strap force, F_2, acting on the second metacarpal, reacts to the corrective force, F_1. The strap force, however, cannot be colinear with corrective force F_1 if the strap is to anchor against the second metacarpal. Consequently, there is a torque, $F_1 \cdot d$ (Fig. 6), which acts to cock the end of the splint ulnarly, and a counteracting torque $F_3 \cdot b$ equal to $F_1 \cdot d$, which is applied by the proximal extension of the splint along the ulnar aspect of the hand. The magnitude of the strap force F_2, is equal to F_1 plus F_3.

The shear and moment diagrams appearing in Fig. 6 illustrate the distribution of shear forces and moments within the brace. It might be noted that the maximum moment occurs at the ulnar-post bearing point. For this reason the design of the post becomes important since it must provide the necessary reaction and permit the rotation necessary for flexion and extension of the digit.

It is desirable, of course, to keep all three forces as small as is consistent with the objectives of the splint and with anatomic considerations. As shown in equation 1 of the appendix, F_1 can be minimized by making distance a from the axis of deviation to the point of application of F_1 as long as possible. There are practical limits to this distance, however. If the ulnar post is extended past the PIP joint, additional alignment problems are introduced, and extra forces are transmitted through this joint which may be diseased. A satisfactory compromise has been to carry the post just to the PIP joint where a good pressure-bearing surface exists.

In like manner, force F_3 at the proximal end of the splint can be made smaller by maximizing distance b. One way to increase distance b is to position force F_3 as proximally as possible without interfering with wrist flexion. At the same time, the splint must bulge outward over the mid-hypothenar eminence to avoid pressure there which would shorten b if contact existed.

Also, distance b can be increased by attaching the strap (which applies force F_2 as distally as possible). Factors limiting this are that the strap must remain proximal to the head of the second metacarpal, and that it must not restrict

MCP joint flexion. Thus, on the volar side the strap has been located just behind the distal palmar crease (Fig. 3). The dorsal portion of the strap has been kept more or less in line with the volar portion (Fig. 1) to minimize any unwanted twisting action on the splint.

As F_1 and F_3 are reduced, strap force F_2 is lessened correspondingly, since $F_2 = F_1 + F_3$.

The importance of attaching the strap distally should be emphasized. With the strap correctly located at about two-thirds of the distance from the proximal to the distal contacts, (b/c = 0.67), F_3 is equal to 0.5 the corrective force F_1, and F_2, acting to squeeze the hand equals only 1.5 F_1. In contrast, if the strap is moved proximally to 1/3 the distance between contacts (b/c = 0.33), F_3 increases to twice the size of F_1, and the strap force F_2 to three times F_1.

The preceding analysis has considered all forces to be acting in a single plane through the hand. During finger flexion, however, this is not the case. As is shown in Fig. 7, forces F_2* and F_3 do remain in the plane, but F_1 is separated by the distance e which equals $a \sin \theta$ (Fig. 9, Appendix) and varies with the degree of flexion. This creates a moment $F_1 e$ acting to cock the splint dorsally off the little finger. Force F_5 (Fig. 7) of the volar portion of the splint making contact with the hypothenar eminence in the palm, and equal-but-opposite force F_4 of the dorsal bar pressing on the second metacarpal form a couple, $F_4 f$ which balances moment $F_1 \cdot e$.

F_4 (and F_5) can be minimized by making distance f maximal, i.e. by keeping F_4 and F_5 as far apart as possible. This is done by extending the dorsal bar radially to the second metacarpal. With intermediate degrees of MCP flexion, the cocking moment is transmitted through the more proximal portions of the dorsal

*Where numerical values for a force or dimension may differ between the flexed and extended position, prime marks are used in Fig. 7.

bar. Hence it is important that this bar extend as close to the wrist as possible over metacarpals 3,4, and 5. It is equally important that the splint fit as tightly as it comfortably can around the volar and dorsal surfaces of the 5th metacarpal, so that the splint cannot displace dorsally as the cocking force F_5 is reacted by the volar surface of the 5th metacarpal.

Comparison of Ulnar Posts

Because of the differing advantages and disadvantages among the hinged, fixed, and spring-loaded ulnar posts, there are indications and contraindications for each.

The hinged post when properly fitted offers nearly complete freedom throughout the range of flexion-extension, and only minimal dorsovolar protrusion (an advantage when wearing gloves, putting the hand in pockets, etc.). Its main disadvantage is the alignment problem of placing the hinge in relation to the anatomic joint, although with a little practice this placement can be made with relative ease. The hinged post is indicated whenever active MCP range is greater than nominal and when full correction is needed.

The fixed post (Fig. 3 and 4) is more easily fitted and has no bearing that can wear out or bind, or a critical alignment to maintain; therefore, it is the cheapest. It does not have a phalangeal ring to serve as a potential source of discomfort, and its anteroposterior slope is more easily controlled in case a "cam action" is desired. However, it must protrude dorsally and volarly enough to provide support throughout the patient's range of MCP flexion-extension. To minimize this disadvantage it is used primarily for patients whose extensor tendons have dislocated ulnarly and who lack active extension.

The spring-loaded post permits limited finger abduction and thus greater freedom of movement.[3] In so doing, however, it sacrifices some of its corrective and protective function. When the little finger is abducted in flexion, the radial collateral ligament is stressed, and this is the ligament most damaged in the ulnar deviation deformity. Also, if some abduction is permitted, the splint can counteract only the weaker ulnar deviating forces. The spring-loaded post is useful, however, when some degree of abduction is desired, and the corrective or protective function is less important. This post, of course, has much the same alignment problems as the hinged post.

Construction Details

The splint can be made of either plastic or stainless steel. The plastic has the advantage of being more easily, quickly and accurately contoured to the patient's hand, and thus more likely to be properly fitted. Its transparency permits quick detection of pressure points, and the material is more satisfactory cosmetically. The plastic unit is also cheaper to make, and although the steel model (Fig. 8) is less bulky and more durable, the advantages of the plastic version have seemed to outweigh those of the metal.

The most suitable plastic material found thus far is 0.125-inch rigid high impact polyvinylchloride produced by the Bakelite Company. It is transparent, nontoxic, has adequate strength, is easily cut with a saw without splintering, and becomes moldable at a temperature of 170-180° F. For the metal splint, 0.030-inch stainless steel is used.

The pattern is obtained by tracing the proposed outline for the splint on transparent vinyl film wrapped about the hand. If a hinged or spring-loaded post is employed, the joint is located at the medial tubercle of the 5th metacarpal head. The hinged joint is secured by a separate piece riveted to the 5th metacarpal portion of the splint (Fig. 2), and the friction is reduced by insertion of Teflon washers. If the fixed post is selected, the inner surface can be lined with 0.010-inch sheet of Teflon to reduce friction between the post and the finger.

There are several important details to observe during the fitting process. In the volar hypothenar area the fit should be close to prevent cocking, and in the proximal hypothenar area the splint should be contoured to bring pressure against the 5th metacarpal base, thus keeping distance *c* as long as possible (Fig. 6). On the dorsum the proximal border should be fitted carefully to prevent edge pressure during finger flexion, and in the palm the volar piece should clear the MP joints and the abducted thumb to avoid interference with function. The hinge of the dynamic post should be placed in the desired plane of flexion-extension and the end of the post should not protrude more than a few millimeters beyond the PIP joint (Fig. 1 and 2). The half-rings of the post should be located well proximal to the PIP joint (Figs. 2 and 8). If the rings bind during finger movement, it is indicative of improper alignment of the hinge axis with the joint axis.

The strap has been made of several different materials. Requirements are that the material be durable, relatively inelastic, easily tightened and secured, and comfortable. Leather, plastisol, and Velcro have all been used. A 0.075-inch thick plastisol strap (Fig. 1) has been the most popular because of its ease of construction, comfort to the skin, and ease of cleaning. Leather is the most durable, and Velcro the most inelastic. The strap can easily be fastened by the patient to a stud on the dorsal bar (Fig. 1), when plastisol or leather is used. To avoid possibly uncomfortable edge effects, the plastisol strap can be encased in a length of 1/2-inch Tygon harness tubing.

Results

Dynamic splints along the general lines of the present model have been in use at this center for several years on patients with advanced, painful, but correctable deformity. When the splint has been fitted properly, most patients have reported definite improvement in manipulative function as well as marked reduction in pain during movement. Of the patients followed for more than a year, a majority have continued voluntarily to wear the splint daily. A meaningful determination of the percentage of successful users is not yet available, however, because the number of long-term follow-ups is still small.

The reason for reduction of joint pain during movement is not clear. The most likely explanation appears to be that with malalignment of the joint, the resultant abnormal stresses on the joint can produce pain. The improvement in manipulative ability can be attributed both to the lessening of pain and to the restoration of more normal relationships of tendons to the MCP joint axes.

For patients with early rheumatoid changes the splint has had only limited use. Although it helps protect the fingers from external loads, and the radial collateral ligament of the fifth digit from the action of the hypothenar muscles, it does not protect the collateral ligaments in digits two to four from the deforming action of the flexor tendons. Also, if ulnar deviation has not developed, there is relatively little reason for the splint to reduce pain or improve manipulative function, except as it protects against external forces.

Summary

A simple dynamic splint has been developed for use by rheumatoid patients with ulnar deviation of the fingers. The splint is worn during normal daily activity, and it serves to limit deviation without seriously affecting hand function. The purpose of the splint is to improve manipulative ability of the hand, and to reduce MCP joint pain during activity. The ability of the splint to prevent deformity is probably limited.

APPENDIX

FORCES IMPOSED ON THE HAND BY THE DYNAMIC ULNAR DEVIATION SPLINT

A perspective layout of the forces imposed on the hand by the dynamic ulnar deviation splint is shown in Fig. 9. F_1 (designated $F_1{}'$ when the MCP joint is flexed) is the force of the ulnar post on the fifth digit; F_2 is the force of the strap applied to the radial side of the hand just proximal to the head ot the second metacarpal. F_3 is the force applied by the most proximal end of the splint to the hypothenar eminence. F_4 is the force of the dorsal bar on the dorsum of the hand. F_5 is the force of the splint normal to the palmar surface of the hand on the ulnar side.

As the fifth digit flexes or extends, the point of application of the force F_1 varies along an arc with center at the joint axis of the splint* and a radius of a inches.

Assuming that the torque, T, required to overcome the ulnar deviation tendency remains constant over the working range of joint flexion-extension, and that the splint holds the fifth digit in the neutral position, with respect to ulnar deviation, then,

$$T = F_1 a \qquad (1)$$

This follows from the fact that the sum of the internal and external moments about the joint axis is equal to zero. The sum of the forces in the radioulnar direction is also zero. If each force is regarded as being positive when in the direction shown, then

$$F_2 - F_1 - F = 0 \qquad (2)$$

The sum of the forces in the dorsovolar direction is equal to zero. With the

*(Assumed substantially coincident with anatomical axis)

forces taken as positive in the direction illustrated,

$$F_5 - F_4 = 0 \qquad (3)$$

The sum of the moments about the dorsovolar axis being equal to zero means that

$$F_1 a \cos \theta - F_2 \ (a+b-c) - F_3 \ (c-a) = 0 \qquad (4)$$

Moments about the proximal-distal axis give the equation

$$F_4 f - F_1 a \sin \theta = 0 \qquad (5)$$

If the force F_1 is expressed as a function of the joint corrective torque, and if all other forces are expressed as functions of F_1, the equation for the general solution will be as follows:

$$F_1 = T/a \qquad (6)$$

$$F_2 = F_1 \left[\frac{a}{b} (\cos \theta - 1) + \frac{c}{b}\right] \qquad (7)$$

$$F_3 = F_1 \left[\frac{a}{b} (\cos \theta - 1) = \frac{c}{b} - 1\right] \qquad (8)$$

$$F_4 = F_1 \quad \frac{a \sin \theta}{f} \qquad (9)$$

$$F_5 = F_1 \quad \frac{a \sin \theta}{f} \qquad (10)$$

When $\theta = 0$, i.e. fingers in extended position, the forces will be

$$F_1 = T/a \qquad (11)$$

$$F_2 = F_1 \frac{c}{b} = F_1 \left(\frac{1}{b/c}\right) \qquad (12)$$

$$F_3 = F_1\left(\frac{c}{b} - 1\right) = F \left(\frac{1}{b/c} - 1\right) \qquad (13)$$

$$F_4 = 0 \qquad (14)$$

$$F_5 = 0 \qquad (15)$$

This is the development of the equations used in the text for the condition of fingers extended.

For the case of "full" flexion of the fingers, $\theta = 90°$, the $\sin \theta = 1$ and the $\cos \theta = 0$. Then,

$$F_1 \text{ (or } F_1{}') - T/a \qquad (16)$$

$$F_2 = F_1 \left(\frac{c-a}{b}\right) \qquad (17)$$

$$F_3 = F_1 \left(\frac{c-a}{b} - 1\right) \qquad (18)$$

$$F_4 = F_1 \left(\frac{a}{f}\right) \qquad (19)$$

$$F_5 = F_1 \left(\frac{a}{f}\right) \qquad (20)$$

It might be noted that $(c - a)$ is close in magnitude to b. The quantity $\frac{c-a}{b}$ is close to 1, and, in the care of $\theta = 90°$, F_3 is very small. If the line of action of F_2 were colinear with the joint axis, F_3 would go to zero and F_2 would equal F_1.

For MCP flexion between 0 and 90 degrees all forces will have finite values lying between the extremes indicated above.

An examination of equations 6-10 will indicate how each of these forces can be minimized, when providing a given correction torque, T (with fingers extended).

The force of the ulnar post against the fifth digit, F_1, can be minimized by making the ulnar post as long as possible; i.e., by making the dimension a as large as possible. This is limited, of course, to the length of the proximal phalanx, as the point of application of F_1 usually should not go beyond the interphalangeal joint.

Both F_2 and F_3 can be minimized by maximizing a and c, and minimizing $c-b$. This can be done by placing the strap as distally as possible and placing the proximal radial supporting end of the splint as close to the wrist as possible. Both of these forces are reduced with increase of angle θ as well.

F_4 and F_5 are minimal for low values of θ and high values of f. Practically, they may be minimized by placing their points of contact as far apart as possible in an ulnar-radial direction.

It might be noticed that F_4 and F_5 go to zero when the fingers are fully extended, and F_3 decreases as the fingers are flexed.

The design criteria for the splint should be then to:

(a) Set the ulnar post contact point as far out on the proximal phalanx as possible, i.e. over the PIP joint.

(b) Make the proximal ulnar contact point as close to the wrist as possible to maximize dimension c.

(c) Set the strap on the radial side as distally as possible to minimize $c-b$.

(d) Make dimension f as large as possible by setting F_4 as ulnar and F_5 as radial as possible, i.e., extend the dorsal bar to the second metacarpal, and provide a tight contact between the volar bar and the hypothenar eminence in the palm.

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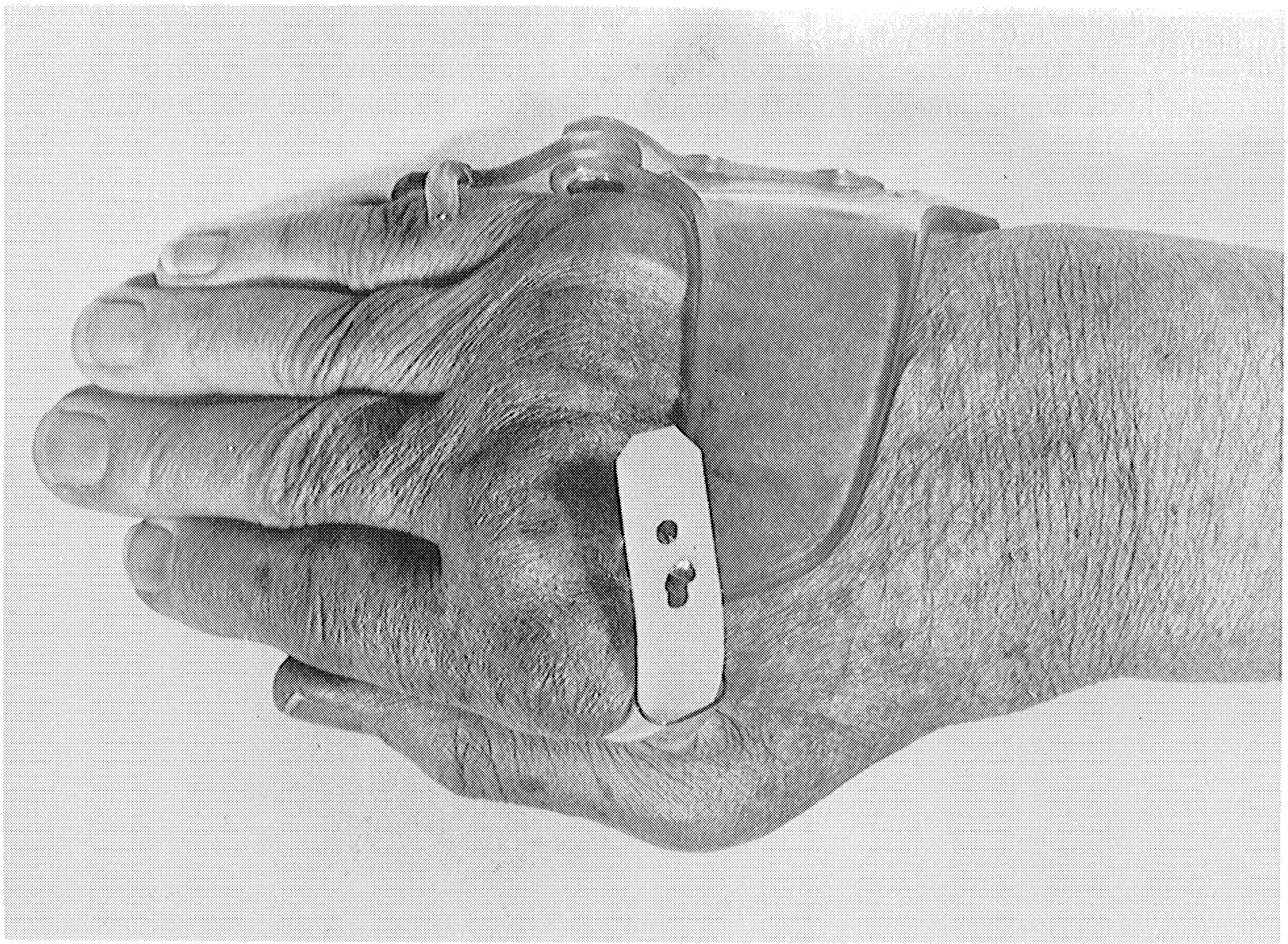

Fig. 1. Dynamic ulnar deviation splint with hinged post, dorsal view.

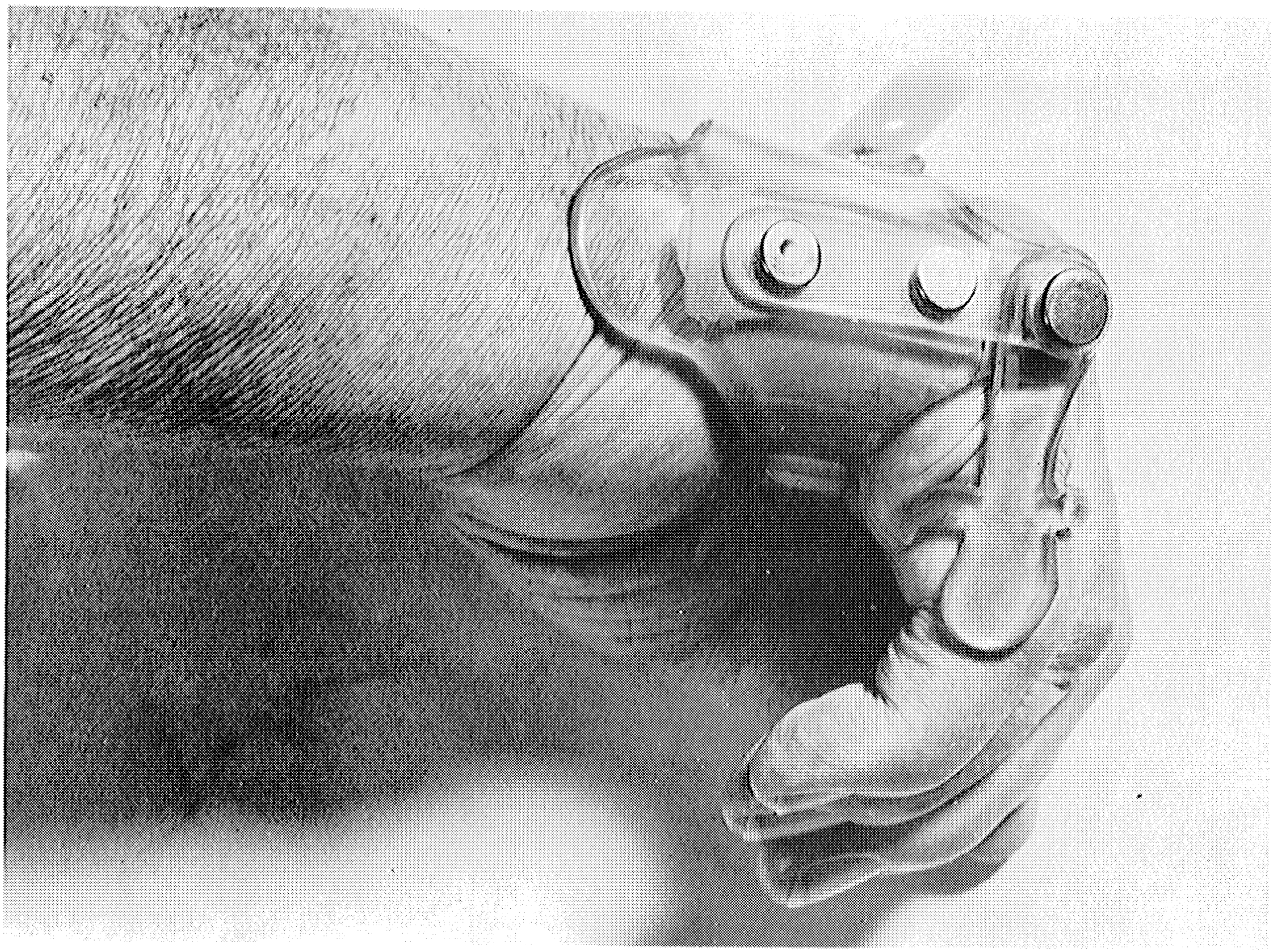

Fig. 2. Dynamic ulnar deviation splint with hinged post, side view.

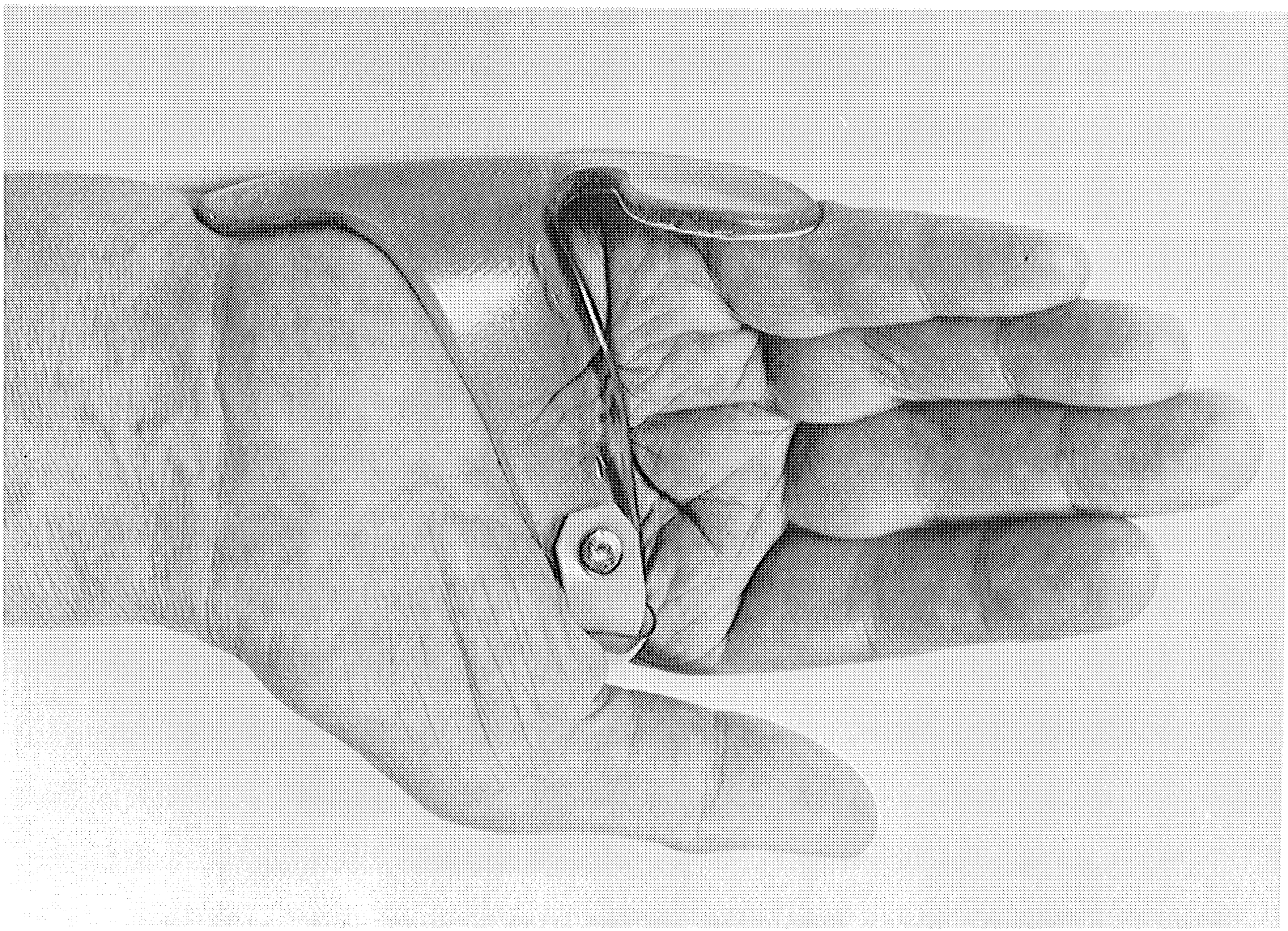

Fig. 3. Dynamic ulnar deviation splint with fixed post, volar view.

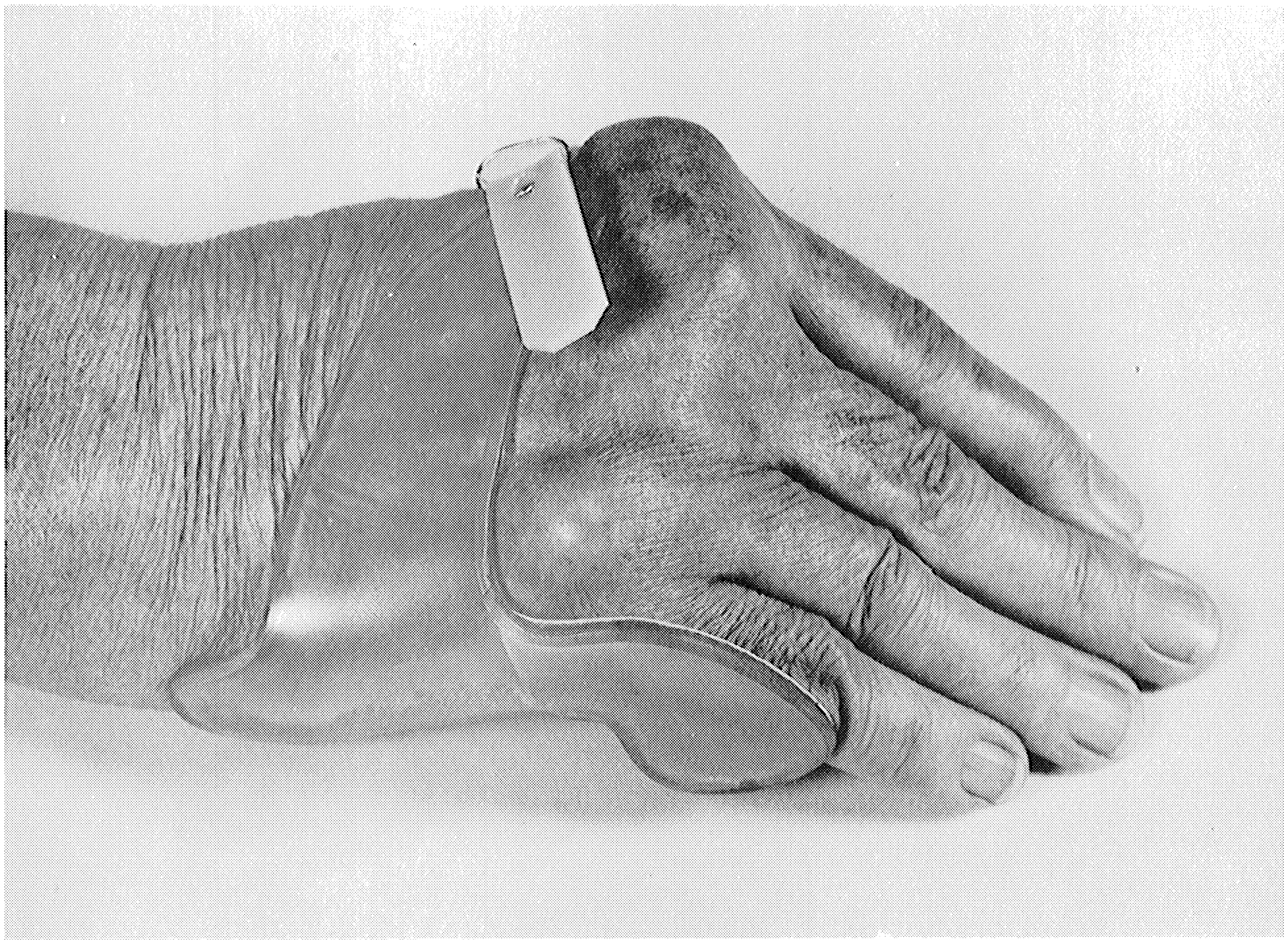

Fig. 4. Dynamic ulnar deviation splint with fixed post, dorsal view.

Fig. 5. Hand illustrated in Figs. 1-4, splints removed.

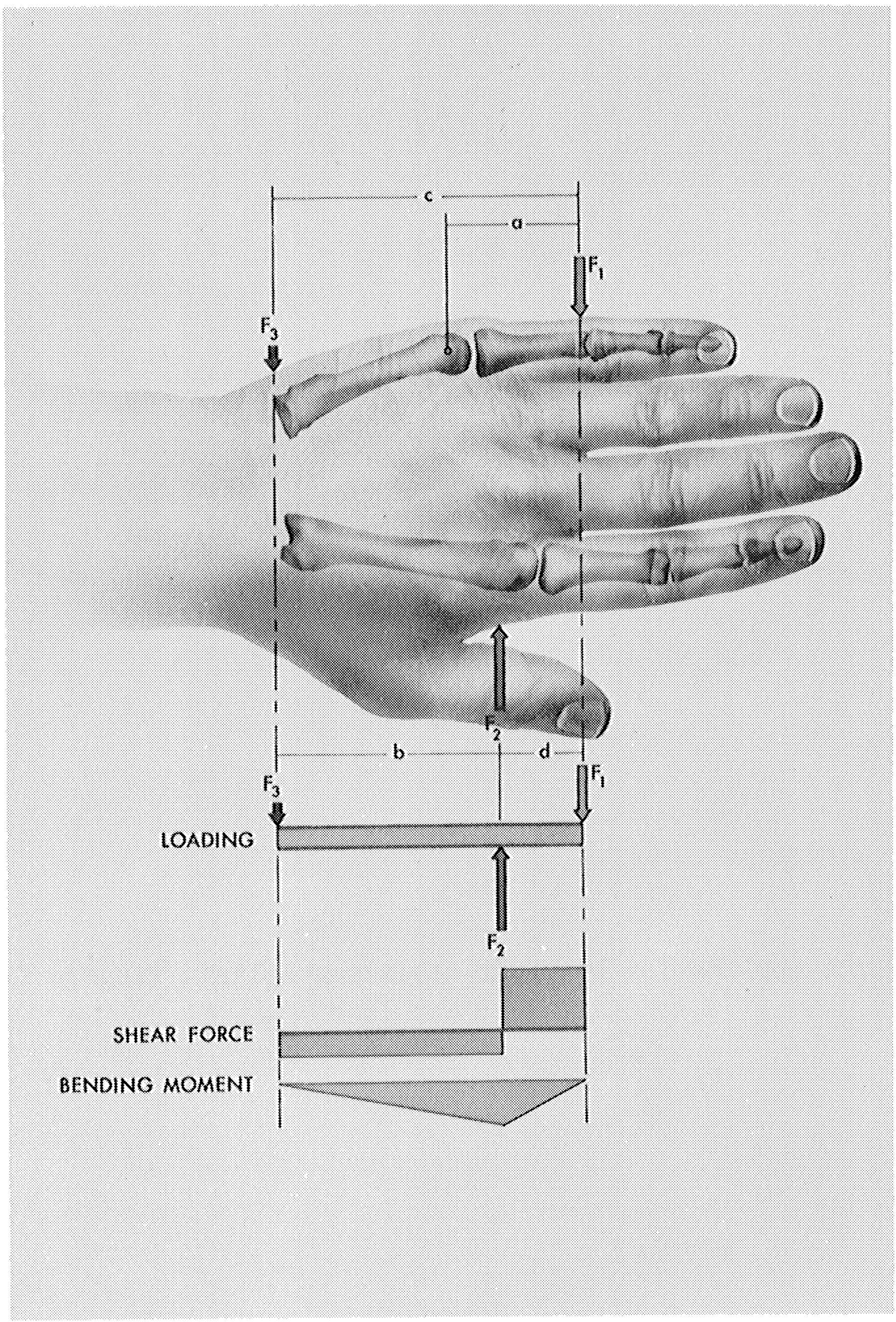

Fig. 6. Force application by ulnar deviation splint, fingers extended.

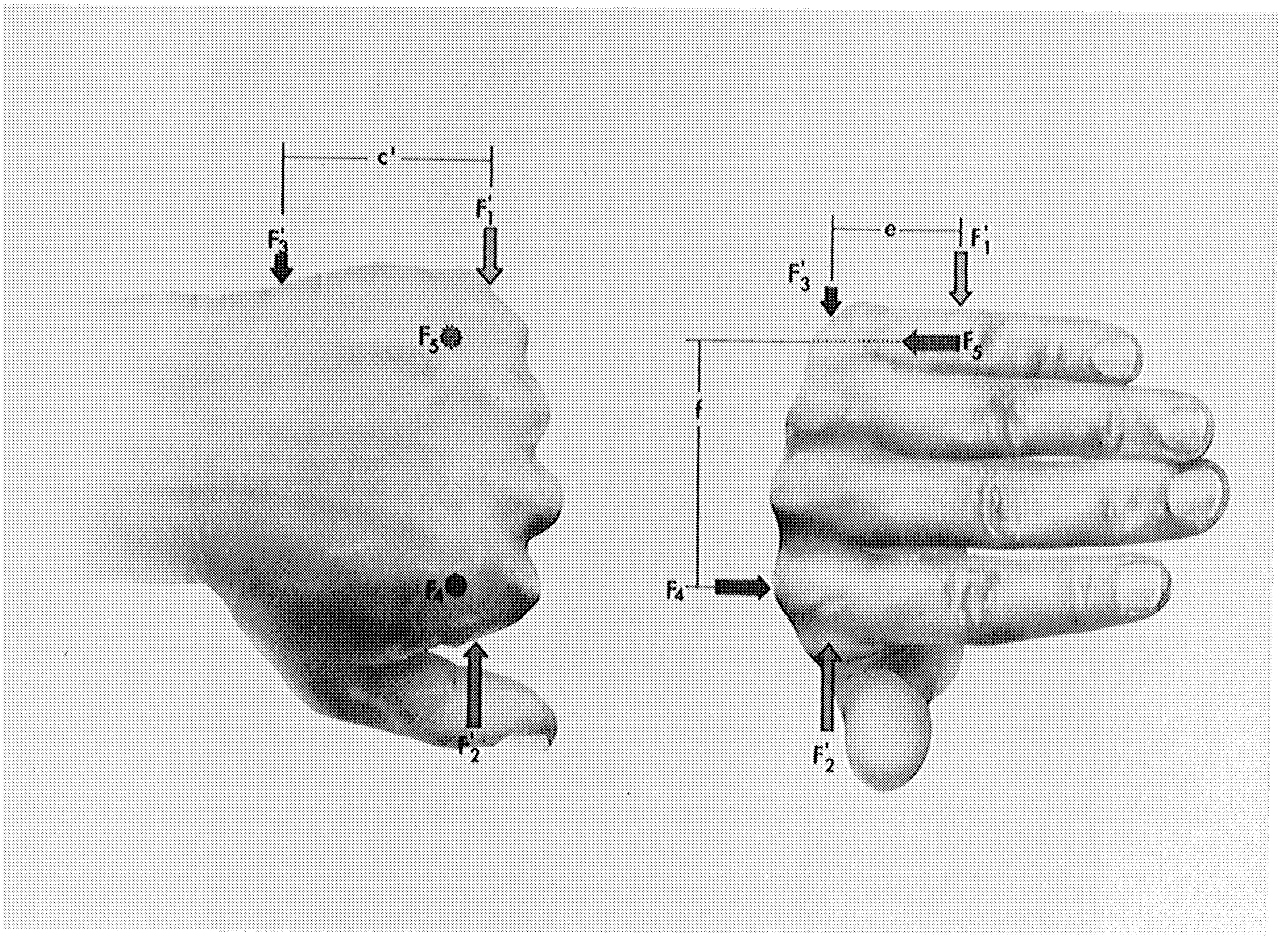

Fig. 7. Force application by ulnar deviation splint, fingers flexed.

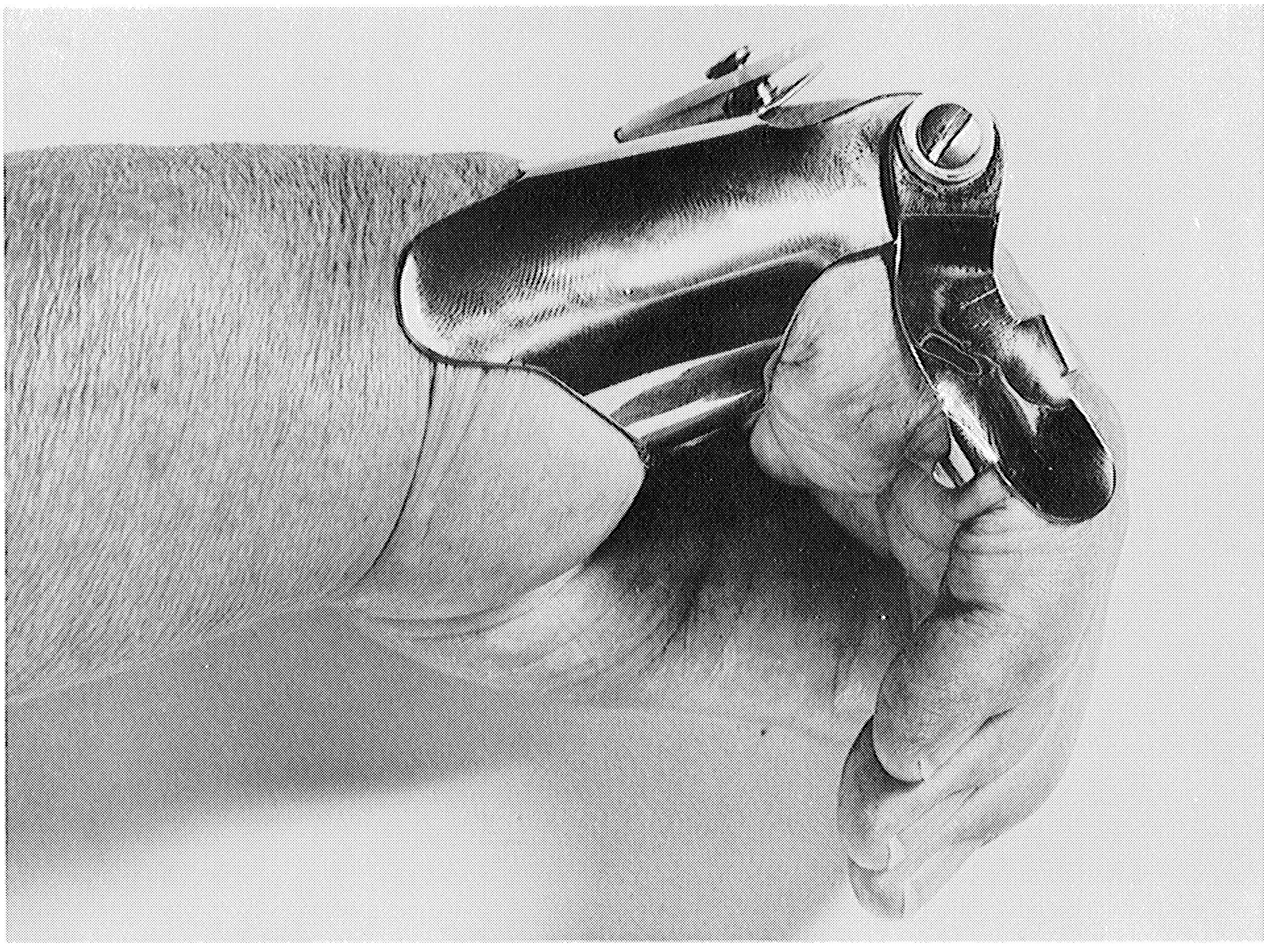

Fig. 8. Dynamic ulnar deviation splint, metal construction.

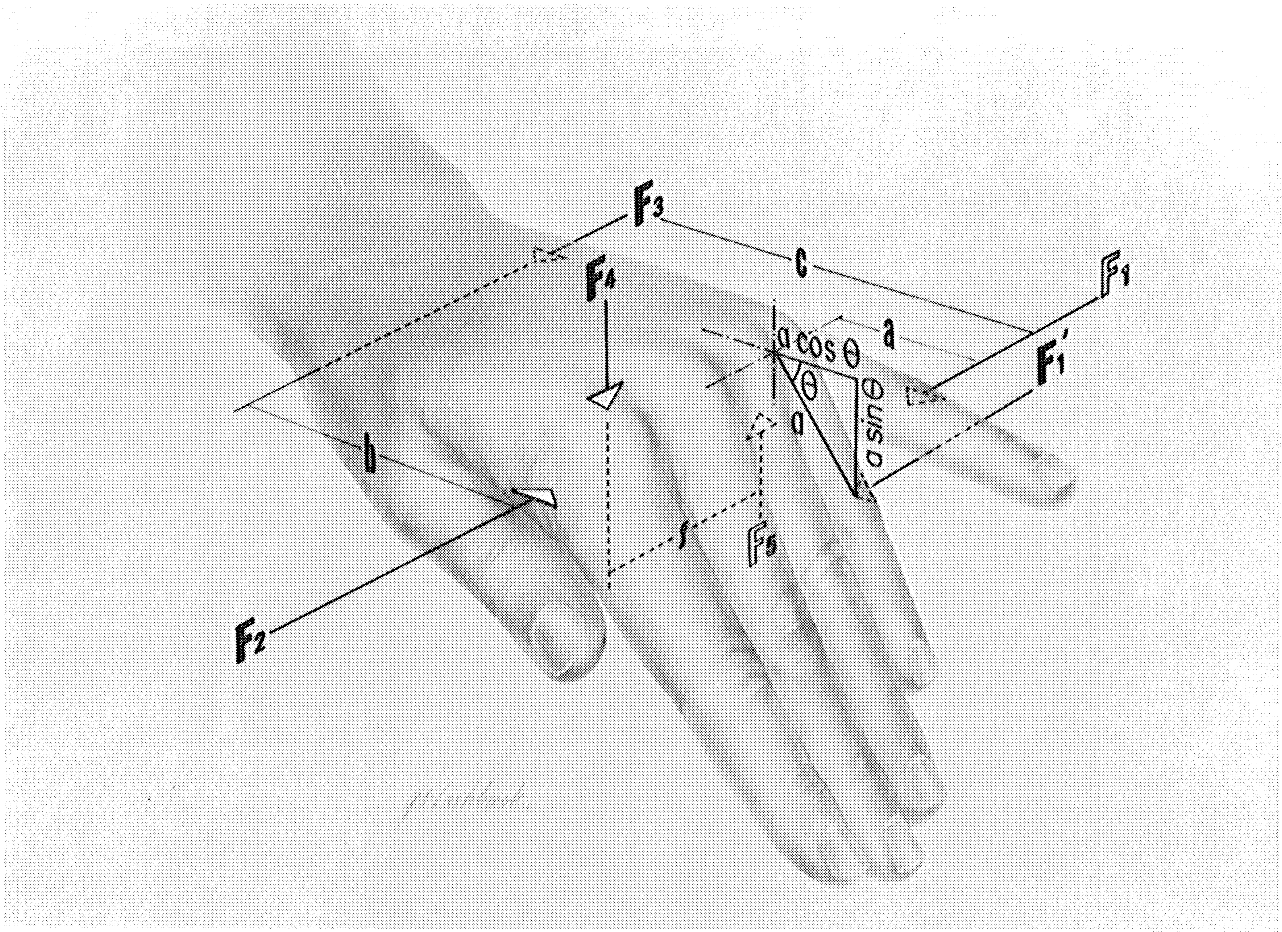

Fig. 9. Force application by ulnar deviation splint, fingers extended and flexed.