THE DESIGN AND PRESCRIPTION OF ABOVE-KNEE ORTHOSES

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Hugh Owen Thomas first described his caliper in 1899. It was designed by him, made by his smith, and finished by his saddler, using the materials of the day. It made no pretense at cosmesis, and being built for strength, was no lightweight structure. In more recent years, light alloy has been used in the fabrication of orthoses, but the basic design, with all its virtues, and vices, has remained unchanged. Just as the design has remained static, so the indications for prescription have remained uncertain and ill-defined. With the advent of plastics and other light-weight materials, with their cosmetic advantages, it has become important to define accurately the indications for the different kinds of above-knee orthoses, and to design each orthosis according to its particular function. Not to do so will result in the under-or over-bracing of patients, or the provision of overweight or understrength orthoses.

It is the purpose of this paper to discuss some of the factors involved in above-knee orthosis prescription and design, research into which has been carried out by the authors at Salford Royal Hospital and the University of Salford.

Technical Considerations

Above-knee orthoses at present available as standard issue items, can be categorized simply:

1. "Total" weight-bearing orthosis—such as patten-ended ischial bearing orthosis. (It must be recognized however, that the weight referred to is that of the body; relief is not obtained from internally generated forces such as are produced by muscles.)

2. "Weight-relieving" ring or corset top orthosis. The proportion of load imparted to the ring or corset top will depend on the accuracy of the fitting, the structure of the ischial bearing area, and the length and stiffness of the orthosis. The axial load that this type of device is required to carry varies from body weight to some unknown partial figure, which is believed will give effective assistance to a weakened limb.

3. "Non-weight-bearing" or "knee-stabilizing" cuff top orthosis, designed primarily to stabilize the knee.

Load-bearing Orthoses

From the engineering viewpoint, the main force systems on a load-bearing orthosis, and a knee-stabilizing orthosis differ fundamentally. The axial loading on a load-bearing orthosis may reach 1.2 times body weight in the course of normal walking on the flat (Fig. 1). This loading is taken primar-

ANDERSON AND HENSHAW

TYPICAL VERTICAL FORCE OF LOWER LIMB
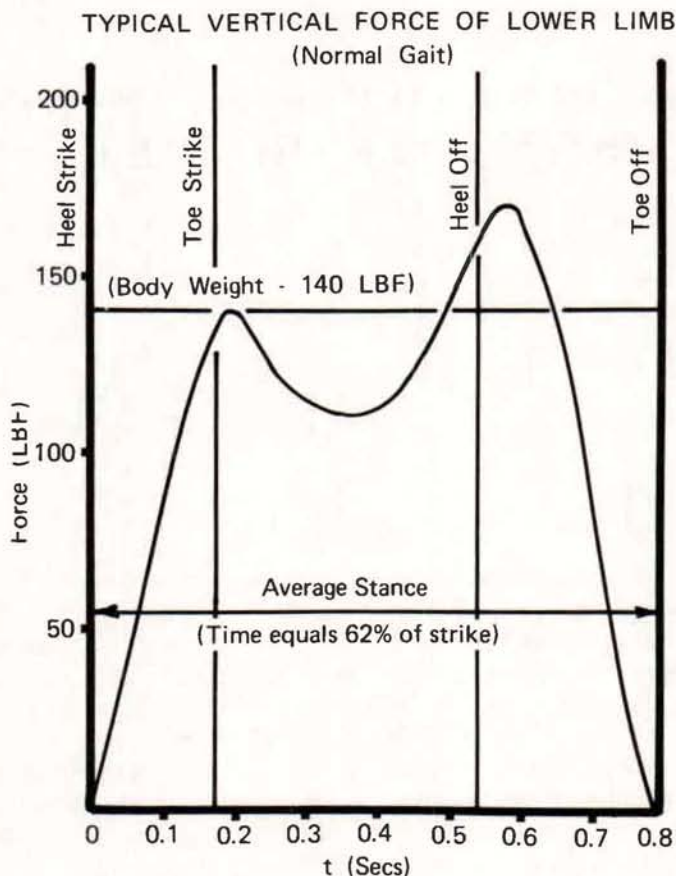### (Normal Gait)

Fig. 1. The vertical load on a caliper.

ily by the pad supporting the ischial tuberosity, and passes from thence via the ring or corset, down the two sidemembers, to the ground (Fig. 2). Some loading may also result from the wedge fit of the thigh in a corset top.

Sidemembers are therefore required to act as struts; that is, members under compressive load. Because free length is critical in strut design, the free length should be as short as possible in order to achieve the required stiffness and thus prevent deformation under load. Stiffness can also be achieved by fitting a calf band to the orthosis structure (Fig. 3), although reliance is often placed (or rather, misplaced) entirely on the knee restraint in non-articulated designs.

A structure designed to be weight-bearing or weight relieving, should be able to carry the maximum expected load, increased by a suitable safety factor, to ensure that no failure under load occurs. The maximum expected load in normal level walking is known; what it becomes when the user hurries, corners sharply, or descends stairs, is not, but it will certainly be increased appreciably. Furthermore, the orthosis should be designed to be "fail-safe" to prevent injury to the user, in case of fatigue failure, for example by the provision of independent knee locks in each sidemember (5,6).

Rotational forces may be applied to the orthosis by the limb, depending on the gait pattern, and the activity of the patient at the
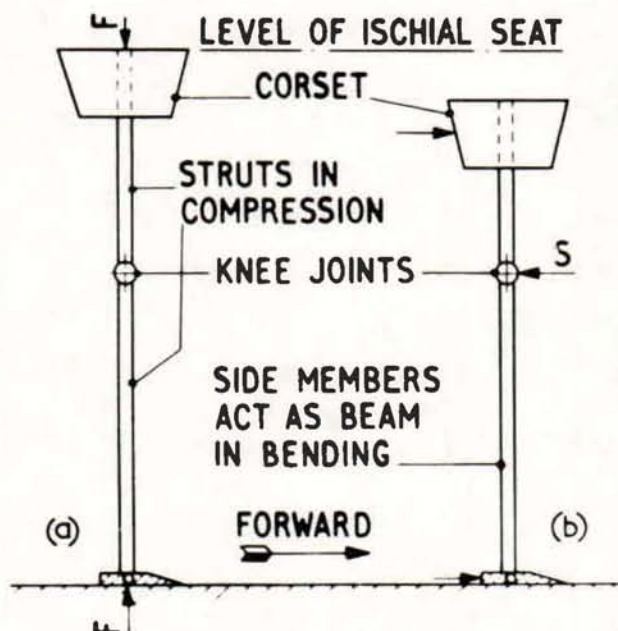
Fig. 2. Above-knee orthoses as engineering structures.

time. But such forces may also be imposed upon the limb by the orthosis; a sloping ischial seat will result in the ischial tuberosity sliding distally, which effectively causes the limb to be rotated internally on each heel strike. This is not an uncommon finding with load-bearing orthoses, and is easily overcome by providing a horizontal ischial seating, at least 10 cms. long, which allows the ischial tuberosity to find its own position (Fig. 4).

Knee-Stabilizing Orthoses

The structure of the knee-stabilizing orthosis has to withstand a force pattern different from the load-bearing types (Fig. 2b). The limb is prevented from deflecting at the knee joint, when under load, by simple three-point fixation (Fig. 5), which allows body weight to be supported by the skeleton. No force is required to maintain the knee in its fully extended "locked" position when static, but on movement, and with knees with fixed angular deformities, consid-

erable force may be required, increasing with increased flexion (Fig. 6). It then becomes important to consider the whole length of the orthosis; the longer the orthosis, the less the horizontal force applied by the cuff to the thigh, and presumably, the more comfortable the orthosis (Fig. 7).

In engineering terms, a structure which is required to stabilize only, should not be nearly so heavily loaded as a structure which is itself required to carry load. Axial loading can be imparted to a stabilizing orthosis by the vertical component of the knee restraint; more significantly, the longer the orthosis is, (i.e. the nearer the cuff top approaches the ischial tuberosity(the greater the axial bearing on the orthosis (2). This relationship is not linear, and must of course be a function of the fit of the orthosis, and the patient's activity.

A stabilizing orthosis can therefore be lighter and simpler in its construction than its load-bearing counterpart, but only if its length is such that it does not carry any sig-
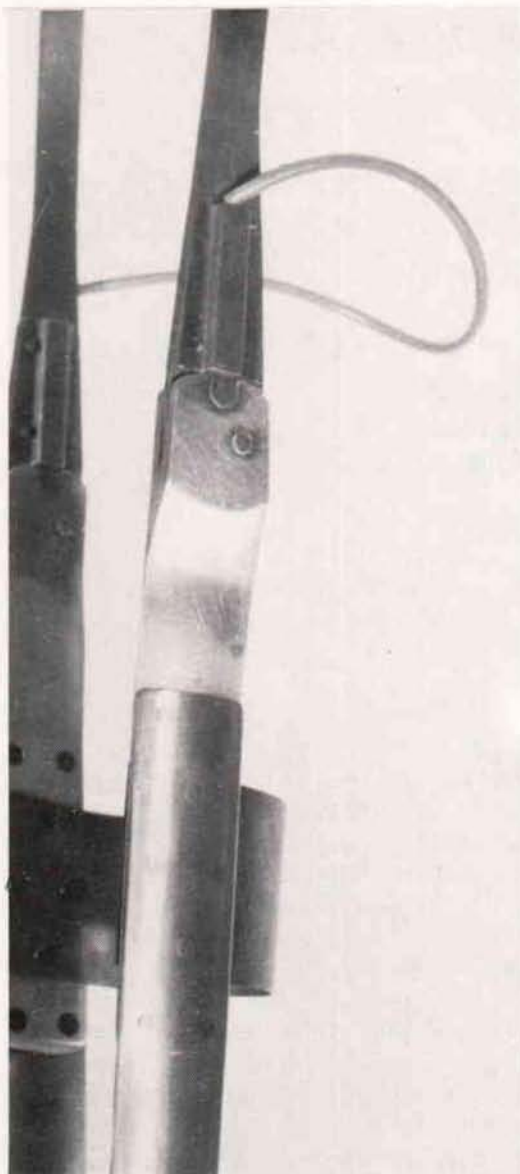
Fig. 3. A calf band.

Fig. 4. The effect of weight-bearing
on an oblique ischial seat.

nificant vertical load. By the same reason-
ing, a stabilizing orthosis cannot be expected
to support the patient in the same way as a
load-bearing orthosis would do, and to ex-
pect it to do so is put the patient at risk.

It will be apparent from the foregoing,
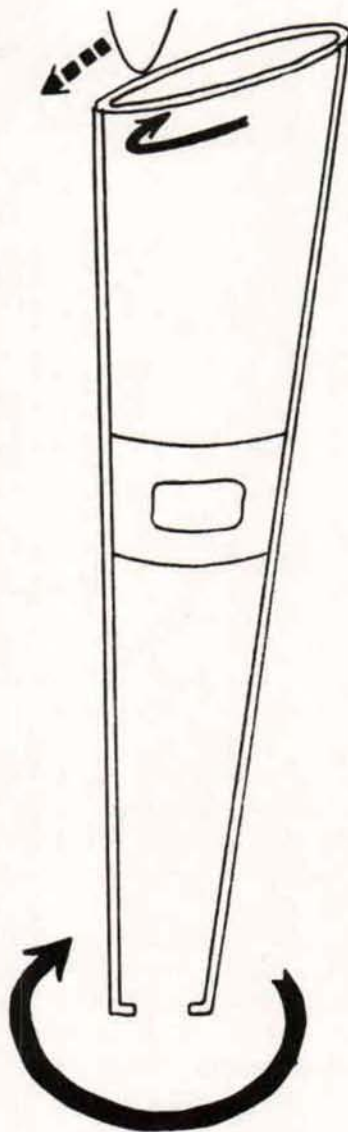that the two types of orthosis are very differ-
ent in function and design. It must also be
emphasized that whilst the latter will usually
do the work of the former, the converse is
not true.

With the introduction of knee-stabilizing
orthoses with lighter structures of either met-
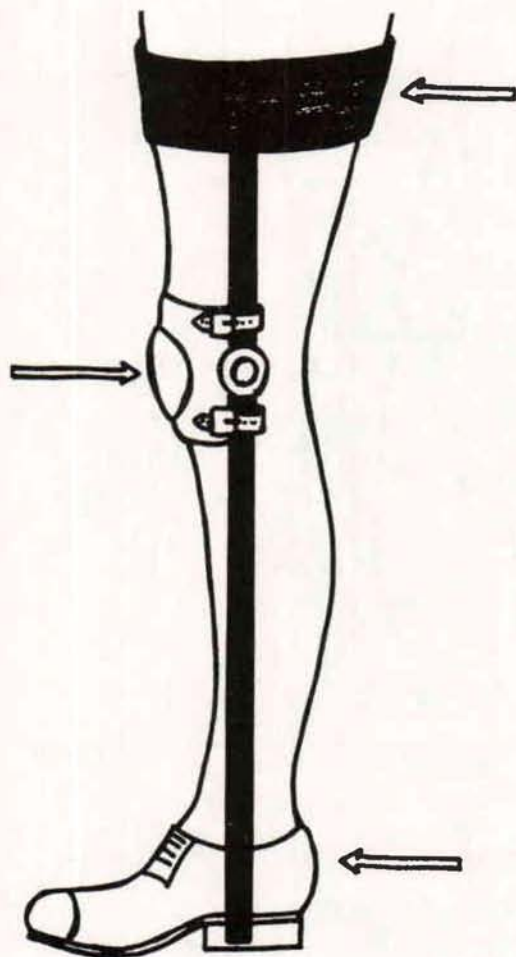al or plastic, a design complication may arise

Fig. 5. Three-point fixation.

thosis structure set to accommodate a genu valgum will deflect medially allowing the knee to deflect with it (Fig. 8). The extent of this deflection in the coronal plane can be in excess of 3 cms. at the knee on an orthosis 80 cms. long when the effective length of the orthosis is reduced by only a few millimeters. 2) As the orthosis deforms, more weight will be imposed upon the limb, which is no longer effectively supported, and any angular deformity of the knee will only increase.

The technical options are, therefore, two. First, the provision of an orthosis designed to accept axial loading; second, the provision of a knee-stabilizing orthosis, which, being shorter, allows full weight-bearing on the limb, and which therefore can sacrifice some strength and stiffness for light weight and cosmesis.

Medical Considerations

There are many indications for above-knee bracing, but they can be conveniently classified according to the particular function(s) required of the orthosis.

1. The Whole Limb
   a) Relief of stress
   b) Correction/prevention of deformity
   c) Protection
2. The Joints
   a) Stabilization
   b) Rest
   c) Control of movement (direction, range, and rotation)

which could have undesirable effects on the patient. Under load, all structures will deflect in proportion to their stiffness. It follows that if a patient loads an orthosis which is not stiff enough for the purpose, the structure may deflect excessively. This can have two effects: 1) Because of the structural instability, the frame is likely to deflect either medially or laterally, depending on which way the orthosis is originally "set" (i.e. the angulation of the sidemembers required to accomodate the shape of the limb). This in turn will reduce the support which the structure would give to the knee joint, e.g. an or-

Put another way, an orthosis is asked to provide two basic functions: regulate angular movement; relieve axial loading. The former is more or less readily achieved by three-point fixation (Fig. 5), and the use of stops to limit the movement at articulations; the latter, conventionally, by the provision of an ischial bearing orthosis. What seems undetermined are the indications for, and the amount of weight to be relieved. There are accepted, clear indications for "total" weight-bearing as provided by a patten-ended orthosis, e.g. in Perthes' disease (although, even in this instance, opinion is di-
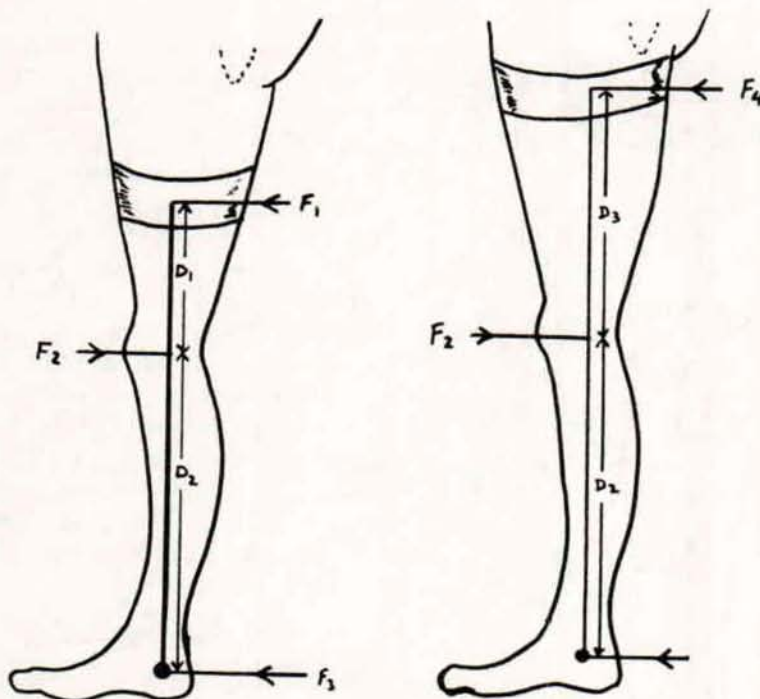
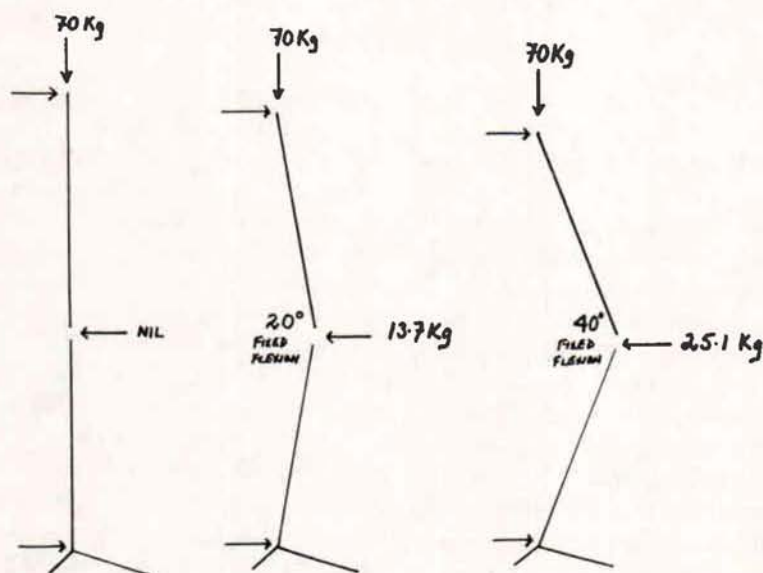Fig. 6. Moments of a short and long knee-stabilizing orthosis.

vided over its value). There do not seem to be the clear indications for the provision of a weight-relieving orthosis, but the following is suggested as a reasonable classification:

1. Discontinuity of, or inherent weakness in the bony structure of the lower limb; e.g.

Fig. 7. Effect of knee flexion on the force required for restraint.

Vertical Deflection
(due to body weight
loading inadequately
stiffened structure)

Resulting medial
deflection of medial
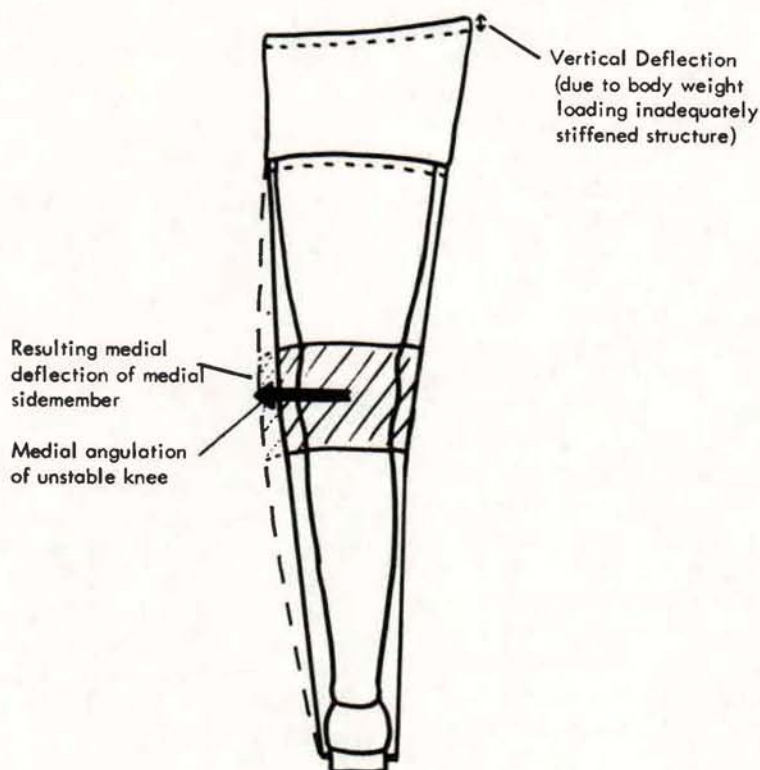sidemember

Medial angulation
of unstable knee

Fig. 8. Effects of loading an inadequately stiffened orthosis.

ununited fracture, unstable pseudarthrosis.

2. Gross knee instability, as for example, a "Charcot" knee.

3. Paralytic disease, e.g. poliomyelitis.

There can be little argument over the first group, the only question for discussion could be the degree of weight relief afforded, and how it can be achieved. Likewise with the second group; unless such a joint is relieved of axial load, the deformity will tend to increase, requiring much greater, even unacceptable forces to restrain it (Fig. 6). It is however in the paralytic situations that opinion is so uncertain. Sharrard (8) suggests that patients with unstable hips due to muscle paralysis can learn to stabilize their hips by trick movements, even with very weak hip muscles, and that in such cases, a weight-relieving orthosis is of considerable benefit.

We reviewed 36 patients who had had poliomyelitis, and whose residual deficits were apparent in only one lower limb, and an attempt was made to find some relationship between their physical deficits and the type of orthosis worn.

There was no relationship between the ability to walk unaided without orthosis, and the type of orthosis normally worn (Table 1).

TABLE 1

Patients Who :	Used A Weight-Relieving Orthosis	Used A Non-Weight-Relieving Orthosis
Can Walk Unaided Without An Orthosis	16	8
Cannot Walk Unaided Without An Orthosis	11	1

It was assumed that all weight-relieving or-
thoses prescribed were necessary, which
was, a priori, an unacceptable assumption.
More reasonable would appear the premise
that those who could not walk unaided with-
out an orthosis, were more likely to require a
weight-relieving orthosis, and this appeared
so. The solitary exception did not differ from
the others in any significant clinical finding.
Of those who could not walk unaided, all
scored less than Grade 2 (M.R.C. Scale) for
muscle power of the extensors of the hip,
knee, and ankle; that is, they had no useful
active extension in the affected limb. The
converse was not valid. An undoubted con-
tributory factor to the inability of those pa-
tients to walk unaided, but one which should
have had no bearing on the question of
weight-relieving, was that 8 of the 12 had
fixed equinus deformities, and six had signi-
ficant (1 cm) shortening of the affected
limb. No other physical finding was constant
in any particular group of patients. We con-
cluded that there was no apparent relation-
ship between the physical deficits of these
patients and the types of orthoses that had
been prescribed for them, and it is this fact
which demanded that further investigation
be made into the function of weight-relieving
orthoses and the indications for their pre-
scription.

Prescription Considerations

In the prescription of lower-limb orthoses,
it is suggested that the following factors
should be considered when deciding the type
to be supplied, having first recognized which
function will be required of it.

Body Weight of the Patient

It would appear self-evident that a 140 Kg.
patient requires a stronger load-bearing or-
thosis than one of 70 Kg. weight assuming
all other factors equal. Other factors are not
usually equal however, and because of this,
the weight of the patient may be a very unre-
liable guide to the type and strength of or-
thosis required.

Joint Stability

The relationship of unstable joints to the
orthosis is complex, and inextricably related
to the need to get the center of gravity of the
body over the area of support during the
stance phase of gait. Nevertheless, some gen-
eral observations may be made. Firstly, a
mobile angular deformity of the knee can be
well controlled by appropriate restraining
straps. They can impose very significant
forces on the orthoses, which are greatly in-
creased when the deformity is fixed. Second-
ly, the hip an extend almost 30 deg. before it
is restrained by the ilio-femoral ligament, in
the absence of active muscles; an ischial-
bearing platform restricts this range by limit-
ing the downward movement of the ischial
tuberosity on extension, and therefore helps
stabilize the hip.

Physical Exertion

One might reasonably assume that a
person who indulges in considerable exer-
tions, e.g. hill-walking, will subject his or-
thosis to more fatigue stresses than the
young girl who sits in an office all day. Not
so frequently considered (or encountered) is
the man who carries bags of cement around
on his back, and is surprised when his ortho-
sis fails. It is not possible, of course, to take
account of all such unusual or excessive
forces, but the point must be made and con-
sidered. Even in everyday living, an orthosis
is subjected to many "abnormal" forces—de-
scending stairs, (particularly if taken two at
a time), jumping off a moving bus, swerving
on the pavement, not to mention the physio-
logical effects of pregnancy.

Patient Fatigue

The effect of physical fatigue is rarely

given adequate consideration. One would expect a weak limb to tire more readily than the normal one of a pair, but the "normal" one, being subjected to more than a fair share of the work, may tire first, thus creating a vicious circle of increasing fatigue. Similarly, a fatigued limb could be expected to be more dependent on its orthosis, and if this is not of an adequate length, strength, or stiffness, it will not provide the necessary support, and it is in such circumstances that one must consider whether a knee stabilizing orthosis would be adequate for the job, or whether a weight-relieving orthosis might not be more opposite.

Age

It is known that paretic muscles lose more power more quickly than normal, with increasing age (1). Some patients who have never had to have a limb braced may find it inevitable as they grow older, and others find they require an increasing degree of support.

The Opposite Limb

The contralateral limb is often affected in the disease process, too. This inevitably has a bearing on the bracing requirements of the limb in question, generally resulting in a greater degree of support being required. Not unreasonably, one might expect the onset of fatigue, and the effects of aging to be enhanced, and this appears so.

Psychological Aspects

Account must be taken of the personality of the patient. In some cases, orthoses are an encumbrance to be tolerated, and in others, their link with normal activity. This is a very individual feature, which needs to be understood and considered in the initial prescription of an orthosis.

Conclusion

It is apparent that in order to prescribe a suitable orthosis for any given patient, much more information about the patient needs to be considered than is often the case. Furthermore, the effects of the patient on his orthosis have not been clearly understood either, although they are equally important, both for the welfare of the patient, and the satisfactory function of the orthosis. This particularly so when deciding between weight-relieving and knee-stabilizing orthoses. The latter are frequently made longer than necessary to make the orthosis more comfortable for the patient, but this subjects it to increasing axial load, which it was not designed to take, in most instances. We would suggest that when prescribing for these patients, if only a knee-stabilizing orthosis is required, the cuff top is situated no higher than mid-thigh; if there is any fixed angular deformity of the knee, or complete loss of extensor power in the limb, or if any of the factors considered above appear dominant, then a weight-relieving orthosis, designed to carry the axial load with a safety margin, is prescribed. Furthermore, an accurate fitting must be ensured, particularly in regard to the ischial seating, and to the orthosis length, which should be no less than the distance from the ischial tuberosity to the ground, as measured in the erect posture.

Summary

The force systems on above-knee orthoses are considered in relation to their functional requirements. The medical indications for different types of above-knee orthoses are discussed together with other relevant medical factors, and suggestions are made for suitable orthotics prescription.

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Footnotes

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