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FRIDAY, NOVEMBER 11, 1977
Convention Center, Holiday Inn—West

8:00 Registration
8:30 Welcome
Siegfried W. Paul, C.P.O.
President A.A.O.P.
J. Leonard Goldner, M.D.
8:45 Seminar Objectives
Bert R. Titus, C.P.O.
9:00 Evolution of Non-operative Treatment of Idiopathic Scoliosis
Sidney L. Wallace, M.D.
9:30 Coffee
10:00 Duke Spinal Cord Injury Team
Donald S. Bright, M.D.
Wesley A. Cook, Jr., M.D.
Patricia Friderichs, R.N.
Morrene L. Kallihan, R.N.
Bert R. Titus, C.P.O.
William E. Harris, C.O.
Percy H. Ray, C.O.
12:00 Lunch
1:00 Operative and Non-Operative Treatment of the Thoracolumbar Spine
Frank H. Bassett, III, M.D.
1:30 Rehabilitation After Acute Care
Frank W. Clippinger, M.D.
2:00 Treatment of Patients with Kyphosis
Ralph W. Coonrad, M.D.
2:30 Coffee
3:00 Greenville Spinal Orthosis
Lawrence W. Brown, M.D.
W. Dewey Friddle, Jr., C.P.O.
4:00 Scoliosis Patients—Management and Treatment
Frank E. Pollock, M.D.

SATURDAY, NOVEMBER 12, 1977
Convention Center, Holiday Inn—West

8:00 Scoliosis Patients—Management and Treatment
Sidney L. Wallace, M.D.
Karl Fillauer, C.P.O.
9:00 Scoliosis Patients—Management and Treatment
Charles F. Heinig, M.D.
Clarence A. Borrows, C.O.
10:00 Coffee
10:30 Development of Prefabricated Components
Carlton Fillauer, C.P.O.
11:00 A New Orthotic Concept in Non-Operative Treatment of Idiopathic Scoliosis
John J. Glancy, C.O.
12:00 Lunch
1:30 Football at Duke Stadium
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Today's highly successful practitioners, as a group, are more expert in patient management than they are in fabrication techniques. They have a thorough clinical knowledge of anatomy, physiology, kinesiology, and biomechanics. They deal competently with engineering concepts.

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Most people learn by trial and error — if they survive long enough. However, the learning process can be shortened through formal education, which will be required of budding practitioners as of 1980.

We have discussed at length the benefits of formal education at the baccalaureate level in prosthetics and orthotics. We have beaten, skinned, and dried that mule. It is time for us to stop talking and start doing.

We must get on with the task of finding something to pull our wagon down the road of continually improved devices and better service for the handicapped citizens of this nation. We should all support the existing educational programs and encourage other medical schools to begin baccalaureate degree programs in prosthetics and orthotics.

Bernard Simons
PNEUMATIC SUPRACONDYLAR SUSPENSION FOR KNEE-DISARTICULATION PROSTHESES

A. Bar, B.Sc.¹
R. Seliktar, Ph.D.²
Z. Susack, M.D.³

There is considerable controversy over through-knee amputations due to the technical complexity of the prosthetic fitting. The biomechanical advantages, however, resulting from knee disarticulation in provision of an end, or load-bearing, stump overrule all other considerations. We therefore believe that knee disarticulation should be preferred over above-knee amputations whenever this is possible (2).

The two major sources of problems in through-knee (T.K.) amputations are the lack of space below the stump for installation of a conventional or controlled knee mechanism and the broad femoral condyles which impose severe socket design limitations. The shape of the stump requires the use of either a leather corset type of socket or a hard socket with a flexible or open area at the supra-condylar region, so as to enable passage of the wide bony end of the stump (femoral condyle). The leather socket is disappearing gradually from prosthetics practice due to its disadvantages of too much flexibility of the socket as a whole, and tightness resulting from use of laces, which causes muscle atrophy. The hard (fibre reinforced plastic) socket is gaining popularity but the procedure for fabrication involves various casting stages including a flexible silicone rubber window with a hard flap for tightening, and therefore is rather complex and requires special skills. Due to the flexibility of this arrangement and inaccuracy in the production process, significant "piston" action may occur during gait.

The use of surgical techniques by which the width of the condyles is reduced is contradictory to the end-bearing concept. Reduction of the load-bearing area increases the interface pressures to a point that it is not comfortable for the patient to support himself on the end of the stump.

This paper describes a technique that uses inflatable pneumatic bags fitted inside the socket at the supracondylar region to provide a practical means of suspension.

Method

In the first prototype, the conventional technique for plastic socket fabrication was employed. A plaster cast of the stump was produced. "Pe-Lite" was used for an inner lining of the hard socket and two shaped rubber bags were designed to engulf the narrow supracondylar neck of the "Pe-Lite" socket. The outer hard socket, therefore, obtained a more cylindrical shape and allowed free passage of the femoral condyles when the bags were deflated. The two bags (Fig. 1)
were fitted between the socket and the liner, one on the medial side and one on the lateral side as illustrated in Figure 2. The bags were connected via a three-way manifold and a rubber tube fitted with a manually operated valve to a pneumatic bulb (hand pump). The bulb, valve, and tubes were taken from a standard blood pressure cuff (5).

The amputee inserts his stump into the socket and after finding the correct position inflates the bags. The Pe-Lite liner is compressed against the stump and the condyles are locked into place. The liner assists in spreading the pressure of the bags over a larger area of the stump (4). The pressure in the bags can be adjusted by the amputee and once the desired pressure has been reached, the valve can be locked and the bulb removed. To remove the prosthesis, the amputee opens the valve to let the bags deflate.

The advantages of the proposed technique are the following:

1. Good grip of the socket over the stump and thus reduced "piston" action.
2. Easy and quick assembly of the prosthesis.
3. A good fit and large range of adjustability to variations in the stump volume due to climatic changes, weight variation, and edema.
4. Even pressure distribution in the vicinity of the bags and, therefore, elimination of stress concentration on the soft tissue and reduction of the risks of developing pressure sores.
5. Ability to reduce pressures on the stump during prolonged sitting by deflating the bags temporarily, without the necessity to undress to remove the leg.
**Evaluation of the Concept**

A preliminary study was conducted to evaluate the concept with special emphasis on the "piston" action phenomenon. At this stage only one patient had been fitted with an "OHC" knee-disarticulation prosthesis (four-bar knee joint with a Dynaplex hydraulic unit) employing the proposed suspension technique. The patient was a 38-year-old war veteran, who had used a prosthesis for 2 1/2 years, and was a current user of the "OHC" prosthesis.

A comparative study between the performance with the conventionally fitted socket and the experimental socket was carried out with respect to three points:

1. Relative displacement between the stump and the socket during gait.
2. Convenience especially in donning and removing the prosthesis.
3. Adequacy of fitting.

The relative movement between the stump and socket was measured by taking X-rays of two simulated gait positions (Figs. 3-6):

1. When the prosthesis was bearing all of the weight of the patient.
2. When the prosthesis was suspended on the stump and the other leg was bearing all of the weight of the patient.

Although this approach disregards the effects of inertia and the dynamics of the walking cycle, it can provide significant information on the "piston" action. The X-rays also provided information in relation to the geometrical match between the socket and the stump. Figures 3 and 4 illustrate the locking action which the bags apply to the femoral condyles. By comparing these results to the ones in Figures 5 and 6 which illustrate the same positions with the conventionally fitted prosthesis, it is evident that the relative

---

**Fig. 3.** X-ray of the new socket with both legs bearing weight.

**Fig. 4.** X-ray of the new socket when the prosthesis is not bearing weight.
The displacement which was measured from the X-rays was 42mm with the conventionally fitted technique and only 23mm with the pneumatic bags. The patient's subjective opinion was that during movement there was far less "piston action" than with his previously fitted prosthesis. This, in his opinion, improved his gait performance.

The patient was also filmed by a television system and video-tape-recorder with slow motion facilities, and the ground forces applied by both his feet during gait were recorded by two "Kistler" force plates. The T.V. and force records will not be discussed here since they require further exploration.

**Conclusions**

From the limited evaluation of the concept, it was evident that the suspension of the prosthesis was improved considerably by use of the pneumatic system. As a consequence the kinematic features of gait were improved. The pressure distribution on the stump was assessed subjectively by the patient and he commented on a more uniform distribution with this arrangement.

It is recognized that the analysis is rather
limited at this stage but a further study with a larger group of patients is now being planned.

Acknowledgement

The study was conducted at the Department of Bio-Medical Engineering in the Technion-Israel Institute of Technology and the Biomechanics Unit of the Loewenstein Rehabilitation Hospital. The prosthetic facilities were provided by "Gapim" Ltd. and the bags were manufactured by "Franz Levi" Ltd.

Literature Cited


Footnotes

1 Biomechanics Unit, Loewenstein Rehabilitation Hospital, Raanana, also Post Graduate student at the Bio-Medical Engineering Department, Technion Israel Institute of Technology.

2 Department of Bio-Medical Engineering, Technion-Israel Institute of Technology and the Biomechanical Unit, Loewenstein Rehabilitation Hospital, Raanana.

3 Loewenstein Rehabilitation Hospital, Raanana.

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VAPC PRESCRIPTION PROCEDURES FOR KNEE ORTHOSES AND KNEE-ANKLE-FOOT ORTHOSES

by Gustav Rubin, M.D., FACS
Malcolm Dixon, B.S., M.A., RPT
Michael Danisi, C.O.

It is the purpose of this paper to present the VAPC Clinic Team's approach to the prescription of knee orthoses (KO's) and knee-ankle-foot orthoses (KAFO's).

To conform to recently accepted procedure the use of eponyms has been avoided wherever possible. Because the total elimination of eponyms from orthotic literature is still in transition, the parenthetical inclusion, such as the term, "Swedish Knee Cage" (Fig. 1), will be noted in the KO-KAFO chart (Fig. 2). This is, as indicated, a metal "rigid three-point pressure KO" (1) and should be distinguished from a plastic contoured "rigid three-point pressure KO" such as the IRM SK KO (2) shown in Fig. 3.

In the accompanying KO-KAFO chart the authors have placed emphasis upon the knee. As Viel has indicated the "key problem remains knee stability" (14). AFO and shoe component charts (Figs. 4 & 5) have been included, which, with the KAFO chart, aid in the representation of a total KAFO orthotic system.

Evaluation Procedure
The development of an orthotic prescription proceeds through several stages:
1. Patient's History
<table>
<thead>
<tr>
<th>ETIOLOGY</th>
<th>PATHOLOGY</th>
<th>MODIFYING FACTORS</th>
<th>DESIRED KNEE CONTROLS</th>
<th>Rx (KNEE)*</th>
<th>ELABORATION**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Lower Motor Neuron Disease</td>
<td>Female trauma (CVA, etc.)</td>
<td>1. With M1 instability, but hyperextension (positive varus and varus past normal limits)</td>
<td>Mild Hyperextension</td>
<td>Stop hyperextension if present or if maximum limit above (slow sufficient for stability)</td>
<td>1. Case if needed</td>
</tr>
<tr>
<td></td>
<td>2. Spinal cord trauma</td>
<td>2. With AP instability</td>
<td>Severe Hyperextension (15° or more)</td>
<td>Prevent excessive hyperextension</td>
<td>2. Varus-valgus knee strap or extension knee cap as indicated, with double bar KAO.</td>
</tr>
<tr>
<td>Specifics:</td>
<td>3. OMS Disease (Tumor, M.S., etc.)</td>
<td>3. With M1 Ligament Laxity</td>
<td>Knee collapse in flexion</td>
<td>Knee stability AFO, Spinal KD, Polypropylene KD or double bar KAO, with knee lock parts</td>
<td></td>
</tr>
<tr>
<td>Diabetic (ischemic, vascular, peripheral neuropathy)</td>
<td>5. Other</td>
<td>Same as Above</td>
<td>Same as Above</td>
<td>Same as Above</td>
<td>Same as Above</td>
</tr>
<tr>
<td>Dislocation to Knee Ligaments</td>
<td>Medial collateral</td>
<td>Mild Laxity</td>
<td>Medial Laxity</td>
<td>Knee lock</td>
<td>1. Case if needed</td>
</tr>
<tr>
<td></td>
<td>Lateral collateral</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
<td>Polypropylene KD, Double Bar KAO, Double anterior knee cap BD (Lancis MD)</td>
<td></td>
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<tr>
<td></td>
<td>Cruciate (antero)</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
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<td></td>
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<tr>
<td></td>
<td>Cruciate (postero)</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>All of above</td>
<td>Instability in all directions</td>
<td>Instability in all directions</td>
<td>Offset knee parts</td>
<td></td>
</tr>
<tr>
<td>Injury to Muscles</td>
<td>Quadriceps</td>
<td>Mild Laxity</td>
<td>Medial Laxity</td>
<td>Knee lock</td>
<td>1. Case if needed</td>
</tr>
<tr>
<td></td>
<td>Quadricep (antero)</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
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<td>Quadricep (postero)</td>
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<tr>
<td></td>
<td>Flexor Carpi Ulnaris</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
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<td></td>
<td>Flexor Carpi Radialis</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
<td>Medial Laxity</td>
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<tr>
<td></td>
<td>All of above</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inadequacy of the Femur</td>
<td>1. Fracture</td>
<td>Knee pain must be located to efficiently transfer stresses from the bone to the orthosis, and to the pelvis, and thereby partially unload the hip.</td>
<td>Knee pain</td>
<td>1. Case if mild pain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inadequacy of the Femur</td>
<td></td>
<td></td>
<td></td>
<td>2. If pain is prolonged, in situ splinting or diaphyseal KAO with locked knee and locked (or limited motion) ankle, if necessary, and cane or crutches.</td>
</tr>
<tr>
<td>Osteitis</td>
<td>2. Ber smelled</td>
<td>Degree of pain experienced</td>
<td>Knee pain</td>
<td>2. Varus-valgus knee strap as indicated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Osteitis</td>
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<td></td>
<td>Other</td>
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<tr>
<td>Paralytic Articular Impairment of Knee Joint</td>
<td>1. Osteoarthrosis</td>
<td>Degree of unweighting necessary will be based on extent of involvement and potential for actual structural weakness of the femur, or pain</td>
<td>As above</td>
<td>Cane</td>
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<td>2. Musculoskeletal Cancer</td>
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<td>3. Paget's Disease</td>
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<td>4. Other</td>
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<tr>
<td>Paralytic Articular Impairment of Knee Joint (or Distal Limb Length is present see C Above)</td>
<td>1. Osteoarthrosis</td>
<td>Mild stress pain</td>
<td>As above</td>
<td>Cane</td>
<td></td>
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</tbody>
</table>
| | 2. Musculoskeletal Congenital abnormalities | Spasticity due to 
| | | contracture | | |
| | 3. Post-oinfections arthritis | | | | |
| | 4. Other | | | | |
| Paraplegic Articular Impairment of Knee Joint | 1. Poorly vascular | | | | |
| | 2. Poorly vascular | | | | |
| | 3. Poorly vascular | | | | |
| | 4. Poorly vascular | | | | |
| Paraplegic Articular Impairment of Knee Joint | 1. Poorly vascular | | | | |
| | 2. Poorly vascular | | | | |
| | 3. Poorly vascular | | | | |
| | Paraplegic Articular Impairment of Knee Joint | | | | |
| | 1. Paraplegic Arthritis | | | | |
| | 2. Poorly vascular | | | | |
| | 3. Poorly vascular | | | | |
| | 4. Poorly vascular | | | | |
| Paraplegic Articular Impairment of Knee Joint | 1. Paraplegic Arthritis | | | | |
| | 2. Poorly vascular | | | | |
| | 3. Poorly vascular | | | | |
| | 4. Poorly vascular | | | | |

*See KAO and Shoe Components Charts for Additional Elements of the Prescription.**

1. AFO and double bar KAO.
2. Polypropylene KD or double bar KAO.
3. Spinal KD.
4. Polypropylene KD or double bar KAO.
5. Polypropylene KD or double bar KAO.
6. Polypropylene KD or double bar KAO.
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96. Polypropylene KD or double bar KAO.
97. Polypropylene KD or double bar KAO.
98. Polypropylene KD or double bar KAO.
99. Polypropylene KD or double bar KAO.
100. Polypropylene KD or double bar KAO.

Fig. 2. Prescription Procedures for Knee Orthoses and Knee-Ankle-Foot Orthoses for Adults
History

Information should be elicited about the character of the terrain where the patient will walk and, when indicated, frequency and duration of clonic episodes, conditions within the home environment (stairs, etc.), age, general health and past experience with orthoses.

Physical Demands of the Patient's Vocational and Recreational Pursuits

These factors will directly influence selection of components. An example of this consideration is given later. Most patients present unique problems which can be evaluated only on an individual basis.

Physical Status

When clinically indicated, a referral to an internist for an examination including cardio-pulmonary evaluation should be made, especially when a great amount of effort will be required, as with bilateral KAFO's. Neuro-musculo-skeletal evaluation including the conditions of joints and their supporting structures should be given particular attention by the Clinic Team. Other consultants should be called upon for opinions where necessary, as, for example, dermatologists.

Gait Characteristics

The patient who can ambulate or stand should be required to do so, even if assistance or parallel bars are needed. The problems that are manifested, in association with the findings of the first three stages, will lead the Clinic Team directly to the next stage, determination of the functional requirements of the orthoses.

Determination of the Functional Requirements of the Components Needed

The format developed by McCollough (1) is very useful. He suggests the use of the following symbols "to indicate desired control of designated function":

2. Physical Demands of Patient's Vocational and Recreational Pursuits
3. Physical Status
4. Gait Characteristics
5. Determination of Functional Requirements of Components
6. Selection of Components
7. Discussion with the Patient to Obtain His Acceptance of the Prescription
8. Prescription of the Orthosis
### Prescription Procedures for AFO's

<table>
<thead>
<tr>
<th>ETIOLOGY</th>
<th>PATHOLOGY</th>
<th>MODIFYING FACTORS</th>
<th>DESIRED CONTROL</th>
<th>PRESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. LOWER MOTOR NEURON DEFECT (PERONEAL N.)</strong></td>
<td>FLACCID PES EQUINUS</td>
<td>STABLE*</td>
<td>Assist dorsiflexion of foot at ankle</td>
<td>SHOE CLASP (VACP) AFO</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UNSTABLE*</td>
<td>MILD MOD.</td>
<td>Assist dorsiflexion and resist varus-valgus</td>
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<td></td>
<td></td>
<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td>FLACCID PES EQUINUS (WITH CALF MUSCLE CONTRACTURE**)</td>
<td>STABLE*</td>
<td>Assist dorsiflexion of foot at ankle</td>
<td>SHOE CLASP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>POLYETHYLENE</td>
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<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UNSTABLE*</td>
<td>MILD MOD.</td>
<td>Assist dorsiflexion and resist varus-valgus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td>FLACCID PES EQUINO-CALCANEOUS (WITHOUT CALF MUSCLE CONTRACTURE)</td>
<td>STABILITY NOT A FACTOR SINCE CHOICE IS LIMITED TO STABLE ORTHOSES</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>SPINAL ORTHOSIS (THO), BUT IF BILATERAL INVOLVEMENT, THEN - POLYETHYLENE OR POLYPROPYLENE FABRICATED TO RESIST DORSIFLEXION AND PLANTAR-FLEXION</td>
</tr>
<tr>
<td><strong>2. LOWER MOTOR NEURON DEFECT (SCIATIC N.)</strong></td>
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<tr>
<td><strong>3. UPPER MOTOR NEURON DEFECT</strong></td>
<td>SPASTIC PES EQUINUS</td>
<td>MILD***</td>
<td>Assist dorsiflexion</td>
<td>SHOE CLASP</td>
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<td></td>
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<td></td>
<td>POLYETHYLENE</td>
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<td></td>
<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MOD.***</td>
<td>Assist dorsiflexion and resist plantar flexion</td>
<td>POLYETHYLENE; IF NOT ADEQUATE, THEN - POLYPROPYLENE</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>POLYPROPYLENE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SEVERE***</td>
<td>Stop dorsiflexion and plantar flexion</td>
<td>POLYPROPYLENE; IF NOT ADEQUATE, THEN - DOUBLE BAR (SHOE ATTACHMENT) AFO</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>DOUBLE BAR AFO IF SUBJECT IS OVERWEIGHT OR VERY ACTIVE</td>
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<tr>
<td><strong>4. ANY OF THE ABOVE</strong></td>
<td>ANY OF THE ABOVE</td>
<td>ANY OF THE ABOVE</td>
<td>Allow limited subtalar motion</td>
<td>SINGLE BAR (ROTATION) ORTHOSIS (VACP) FOR FLACCID OR SINGLE BAR (NO ROTATION) FOR SPASTIC OR DOUBLE BAR AFO IF SUBJECT IS OVERWEIGHT OR VERY ACTIVE</td>
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<tr>
<td><strong>5. PAINFUL DESTRUCTIVE DISEASE OF ANKLE</strong></td>
<td>ARTHRITIS (POST-TRAUMATIC, INFECTIONS, INFLAMMATORY, ETC.)</td>
<td>PAIN ON AF OR ML</td>
<td>Stop plantar-flexion, dorsiflexion, varus and valgus</td>
<td>POLYPROPYLENE ORTHOSIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MODIFIED TO RESTRICT DORSIFLEXION AND PLANTAR FLEXION</td>
</tr>
<tr>
<td>**6. **</td>
<td><strong>A) STRUCTURAL IN-ADEQUATE DUAL TO THE KNEE</strong></td>
<td><strong>NON-UNION OR DELAYED UNION OF TIBIA, CAPSULAR'S DISEASE OF ANKLE/FOOT, ETC.</strong></td>
<td>TISSUE BENEATH THE CUFF AREA MUST BE CAPABLE OF TOLERATING THE PRESSURES OF PARTIAL UNWEIGHTING; FOR EXAMPLE, SENSATION MUST BE INTACT</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PARTIALLY UNWEIGHT THE LEG, ANKLE, OR FOOT</td>
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<tr>
<td></td>
<td><strong>B) PAIN DISTAL TO KNEE, OR WEIGHT BEARING</strong></td>
<td><strong>DESTRUCTIVE DISEASE OF ANKLE, ETC.</strong></td>
<td></td>
<td>PYS WEIGHT-BEARING AFO</td>
</tr>
</tbody>
</table>

* Stability is: a. evaluated during trial of a stock brace (VACP shoe clamp, Teufel, Polypropylene) on the patient by the Clinic Team, or, b. can be assessed by the nature of the terrain the subject may walk upon (fields, golf courses, etc.).

** Many patients with sciatic nerve injuries develop calf contractures sufficient to stabilize the ankle at about 90°, in the weight bearing position. These patients need only a correction for the flaccid pes equinus.

*** During the clinic team evaluation of orthoses, the degree of spasticity is related to the "triggering" of spastic equinus (or equino-varus) by the stock braces tested directly on the patient as part of the evaluation procedure. For example, if the stock shoe clamp triggers the foot into spastic equinus, one must try the stock Teufel, or finally, the stock Polypropylene. If the foot deforms within the Polypropylene, external (shoe) attachment bracing is required. Very severe spasticity cannot be controlled by a brace.

**** Most such patients will tolerate a properly fitted shoe insert brace, or a shoe clamp. Those who develop areas of irritation should be changed to external bracing with individualized shoe modifications, if indicated.
## LOWER LIMB SYSTEM

<table>
<thead>
<tr>
<th>THE ANKLE-LEG COMPONENT</th>
<th>THE FOOT COMPONENT*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td><strong>AFO Designation</strong></td>
</tr>
<tr>
<td>Dorsiflexion Assist AFO</td>
<td>1- Shoe Clasp</td>
</tr>
<tr>
<td></td>
<td>2- Polypropylene Posterior Leaf Spring</td>
</tr>
<tr>
<td></td>
<td>3- Ortholene Posterior Leaf Spring</td>
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<td></td>
<td>4- Conventional</td>
</tr>
<tr>
<td>Dorsiflexion Assist plus spring-loaded varus control</td>
<td>Posterior Leaf Spring Orthosis with spring-loaded varus correction</td>
</tr>
<tr>
<td>AFO with plantarflexion stop***</td>
<td>1- Polypropylene</td>
</tr>
<tr>
<td></td>
<td>2- Conventional Double Bar</td>
</tr>
<tr>
<td></td>
<td>3- Single Bar</td>
</tr>
<tr>
<td>AFO with dorsiflexion stop</td>
<td>Conventional Double Bar</td>
</tr>
<tr>
<td>AFO with limited motion ankle</td>
<td>1- Conventional Double Bar</td>
</tr>
<tr>
<td></td>
<td>2- PTB Orthosis</td>
</tr>
</tbody>
</table>
F = FREE — Free motion.
A = ASSIST — Application of an external force for the purpose of increasing the range, velocity, or force of a motion.
R = RESIST — Application of an external force for the purpose of decreasing the velocity or force of a motion.
S = STOP — Inclusion of a static unit to deter an undesired motion in one direction.
v = Variable — A unit that can be adjusted without making a structural change.
H = HOLD — Elimination of all motion in prescribed plane (verify position).
L = LOCK — Device includes an optional lock.

The authors use in a clinical trial a stock shoe clasp or a stock polypropylene AFO to aid in evaluation of the anticipated response to AFO’s. This is particularly helpful to determine if spring loading will precipitate clonus when mild to moderate spasm exists.

Selection of the Most Desirable Components For the Individual Patients

This decision will take into account not only the function of the components but also the weight, cosmesis, and sturdiness of the materials. A 118-lb. city-dwelling female will usually require a different prescription for the same condition than would a 250-lb. male farm worker. For the farm worker, in contrast to the city dweller, it would usually be advisable to sacrifice cosmesis for strength and durability of components. As indicated above, the AFO components (Fig. 4) and the shoe components (Fig. 5) have been charted separately and those charts should be used in conjunction with the KAFO chart to arrive at a prescription.

Discussion With the Patient

The prescription developed by the Clinic Team should be discussed with the patient to obtain his cooperation. When possible, a device similar to that planned for him should be shown to the patient. He may refuse to accept change and prefer to continue with an orthosis of a type to which he is accustomed rather than a more modern orthosis. Prescription over the patient’s objection will almost invariably lead to rejection.
Prescription

When all of the factors discussed above have been considered thoroughly the prescription will usually "fall into place."

KO's and KAFO's

The following orthoses are discussed briefly in the order in which they are referred to in Figure 2.

Rigid Three-Point Pressure KO (Figs. 1)

There are several variants of this KO. The simplest is of metal and fabric, the metal rigid three-point pressure KO (Fig. 1). Examples of plastic "rigid three-point pressure KO's" have been demonstrated by Lehneis (1) (the IRM SK KO), (Fig. 3) and by Nitschke (the PTS KO) (1). The metal device is available commercially and the latter two require custom fabrication. The area of clinical application of these orthoses is described in the chart. Their principal function is to limit knee hyperextension by virtue of the three-point pressure design. The mediolateral support that is provided by rigid orthoses of this type is only present in the hyperextended position. As soon as knee flexion occurs the effectiveness of the M-L support is lost.

KO With Offset Knee Joints or Knee Locks (Figs. 6 and 7)

These may be used to stop or lock the knee to control hyperextension. If the knee hyperextension is between 5 deg. and 15 deg. the offset knee joints may be satisfactory and a trial with offset joints should be made since knee motion will be retained. If these joints are not adequate, i.e., if the knee is in slight flexion, or in excessive hyperextension, it will be necessary to use knee locks. For the offset knee joints to function properly and prevent knee collapse in flexion several prerequisites must exist, 1) the knee must hyperextend at least 5 deg., 2) there should be no hip flexion contracture, 3) there should be no ankle dorsiflexion deformity, and 4) there

Knee Stabilizing AFO (Fig. 8)

This design is designated an AFO because no component of the orthosis crosses the knee joint; nevertheless, its principal action is on the knee joint (9), and it, therefore, is included here. It may be used if, in addition to the need for knee stabilization, there is a concomitant requirement for an ankle orthosis. The ankle orthosis should incorporate a dorsiflexion stop adjusted in plantarflexion to produce a knee extension force. There must also be an absence of hip flexion contracture as well as retention of fair hip extensor power (7). The authors pre-
Fig. 8. Ankle Foot Orthosis Designed to Provide Stabilization About the Knee

Fig. 9. A Knee Orthosis made of elastic fabric, known as the Spiral KO

fer to use this orthosis when quadriceps power is rated not less than "poor" and with an intact opposite lower limb. When the indications for its use are present, this orthosis allows the patient to retain an important freedom, knee motion. It is useful when mild or moderate knee flexion instability is present.

The Spiral KO (Fig. 9)

The Spiral KO is an elastic fabric KO reinforced with flexible stays. It is useful only for mild instability and functions primarily as a "reminder" type of orthosis, i.e., as the patient ambulates the restraints introduced "remind" him to bring his knee to full extension on weight-bearing, and thereby stabilize the knee. Its presence also "reminds" the patient to favor the knee when it is used for mild medio-lateral instability. The stays add only minimal resistance to knee instability.

Polypropylene KO (Fig. 10)

This orthosis (2) includes the unique fea-
ture of suprapatellar-cuff suspension in the manner of the cuff suspension of the PTB prosthesis. It can be fabricated with drop locks at the knee for moderate or severe flexion instability. When used to resist mediolateral ligament laxity, a knee lock is unnecessary except in extreme cases.

Double-Bar or Single-Bar KAFO (Fig. 11)

Traditionally this is the term used to describe a KAFO fabricated with either aluminum or steel medial and/or lateral bars, with or without (as specifically indicated) an ankle joint, and with either a solid stirrup or a split stirrup. Offset knee joints or knee locks may be used. Variants may employ all

Fig. 10. A polypropylene knee-orthosis developed at the VAPC. This model has a knee lock.
polypropylene (Fig. 12), polypropylene and polyethylene (Fig. 13), pneumatic knee joint locks (Fig. 14), or a KAFO of polypropylene plus a shoe clasp (Fig. 15).

**Hinged Elastic KO (Fig. 16)**

The hinged elastic KO is slightly more effective for resistance to medio-lateral knee ligament laxity than is the spiral KO, and is used if the complaints are mild. The improved resistance to M-L displacement and the addition of limited A-P displacement resistance are achieved with hinged medial and lateral metal struts and knee locks. These provide resistance restraints rather than true locking because of the elasticity of the cuffs.

**Double Anterior Loop KO (Lenox Hill Derotation Orthosis) (Fig. 17)**

The double anterior loop KO is essentially a metal KO fabricated to provide resistance to medio-lateral displacement and limited resistance to anteroposterior placement due to ligament laxity. A stop to A-P displacement is added when knee locks are employed. Suspension is achieved by the use of circular latex-rubber straps, a disadvantage when circulatory or edema problems are present.

**Plastic "Shell" KO (Fig. 18)**

The plastic "shell" KO is a custom made, contoured solid knee orthosis providing...
knee immobilization. The figure shows the minimum length of this device that was adequate in the illustrated instance. To achieve maximum efficiency the orthosis should reach as far as possible proximally and distally and yet allow hip and ankle motion. Suspension is achieved by contouring the orthosis over the suprapatellar area and above the flare of the femoral condyles.

Ischial Ring KAFO (Fig. 19)

This double bar KAFO utilizes a knee lock and limited-motion or locked ankle joints to achieve direct weight transmission from the ischial tuberosity to the floor. If weight-bearing is accomplished efficiently on the ischial seat, the hip joint can be at least partially protected against vertical impact trauma. The difficulty with this orthosis is that many patients will not tolerate the required extent of localized pressure on the ischial tuberosity and will release the anterior strap of the orthosis to allow the ischial tuberosity to slip forward and down (4).

Double-Bar KAFO With Dial Knee (Fig. 20)

The Dial Knee is employed to achieve gradual correction of a knee flexion contracture which is still amenable to correction and not rigidly fixed. The dial permits the knee to be locked into increasingly greater degrees of extension.

Double-Bar KAFO With Knee Flexion Stop And Extension Aid (Fig. 6)

This orthosis is useful for unilateral knee flexion instability, in the presence of poor or absent quadriceps function and an intact opposite extremity. A flexion stop at no more than 60 deg. will give the patient an opportunity to recover from sudden knee flexion collapse, and the extension aid, plus gravity, will then help him restore stability by bringing the leg to extension against the stop of offset knee joints (Fig. 6) (13).

The Quadrilateral Socket KAFO (Fig. 21)

This design provides ischial, gluteal, and proximal thigh-bearing; i.e., the socket, as it encompasses the thigh, provides supportive features. The upward forces on the hip joint are therefore greater than in the case of a properly worn ischial ring orthosis, and toleration by the patient is also greater. This orthosis is useful for partially unweighting the femur just below the hip, and useful to a more limited degree for unweighting the hip joint itself (7).

As indicated in Section G of Figure 2, under the column labeled “Elaboration,” when a lesser degree of unweighting is required
Fig. 14. The ORTHO-WALK pneumatic orthoses

than would be provided with the quadrilateral socket KAFO, a gluteal corset KAFO may be employed. When the patient has good control of extensor power at the knee, offset knee joints can be used. Otherwise the orthosis should be fabricated with knee locks. The orthosis illustrated in Figure 22 was fabricated for a patient who could not wear the PTB orthosis because of peripheral neuritis and absence of sensation in the PTB cuff support area. This device is quite similar to the immediate precursor of the VAPC PTB orthosis (8).

Bilateral Double-Bar KAFO's 
For the Paraplegic (Fig. 23)

In KAFO's for the paraplegic patient, the knees must be locked in the neutral position, ankles must be dorsiflexed about 10 deg., and the patient must lean his pelvis forward and his trunk backward to allow the patient to balance with the center of gravity over the mid-foot, as illustrated by the Scott-Craig orthosis (5, 11). Because of the retention of proprioception the poliomyelitis patient knows where his lower limbs are but the spinal cord patient must learn to sense position, and, as a result "polio patients accomplish greater levels of ambulation than spinal cord injured patients with the same motor deficit" (3).

Single Lateral-Bar Quadrilateral 
Socket KAFO (Fig. 24)

The single-lateral bar quadrilateral socket KAFO is not only useful for the patient with hemophiliac knee arthritis (6) as recorded on the chart, but, when not used with a quadrilateral socket, lightweight patients who need bilateral orthoses will frequently find single lateral-bar KAFO's more comfortable. The impact of medial bars against
each other is obviated. In the specific instance of the patient with hemophilia, the elimination of the medial bar removes a potential source of contusion of the opposite limb.

In the case of the hemophiliac knee with a quadrilateral socket KAFO, it may be found worthwhile to hinge the socket laterally rather than medially, to avoid the possibility of inadvertent contusion against the scrotum as the patient swings the socket open, a problem which we have encountered.

**Summary**

An attempt has been made to outline in a concise form our Clinic Team's basic approach to lower-limb orthosis prescription. The word "basic" should be empha-

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Fig. 15. A polypropylene knee orthosis combined with the VAPC shoe clasp type of ankle-foot orthosis to provide a knee-ankle-foot orthosis.

Fig. 16. A hinged elastic knee orthosis

Fig. 17. The Lenox Hill Derotation Orthosis
sized since the Clinic Team does not limit itself to the devices described here, but have used, at various times, other devices as they are reported. These have not been discussed since an encyclopedic approach has not been attempted. It has been our purpose to present our point of view, and, therefore, the charts included illustrate the foundation upon which we build. They are intended to have one function only—that of teaching tools. The authors do not presume to instruct certified orthotists or physicians with long experience in prescription procedures.

Bibliography


4 Lehmann, J. F. and G. G. Warren, Ischial and patel-
Fig. 20. The Dial Knee Unit disassembled.

Fig. 21. Anterior and posterior views of a KAFO with a quadrilateral cuff.
Fig. 22. Lateral view of a KAFO with a gluteal corset.


Fig. 23. Double bar KAFO’s for a paraplegic patient.

Fig. 24. The patient is wearing a lateral-bar KAFO with a quadrilateral cuff on the left side.

Footnotes

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Fig. 23. Double bar KAFO’s for a paraplegic patient.
This paper describes the orthotic treatment of an elderly female who lacked a proximal section of the femur and the hip joint on the left side.

**Patient History**

Recently, a 65-year-old Caucasian female with diabetes was seen who had a chronic, recurring problem with her left hip and thigh for the past four years. Initially, she suffered an injury to the left hip that developed into degenerative osteo-arthritis of the hip joint. A total hip replacement of the Charnley-Muller type was provided. She did well for a period of nearly two years until she fell at work and suffered a complex comminuted fracture of the femur below the stem of the femoral prosthesis which required hospitalization and treatment involving traction. The fracture failed to unite, and an intramedullary rod was inserted in the femur alongside of the stem of the prosthesis. Acrylic cement was used to provide additional fixation.

The fracture failed to unite, and the rod was removed several months later. Osteoporosis of the proximal femur made it extremely difficult technically to provide adequate immobilization. However, a new prosthesis was inserted. Ultimately, the prosthesis was removed and a new, custom-made prosthesis with an extremely long stem was provided (Fig. 1) approximately one and one-half years ago. The patient did well for a time but gradually developed increasing evidence of deep abscess formation and drainage. After repeated incision and drainage of recurring abscesses in the left thigh and prolonged antibiotic therapy over a period of a year, it was concluded that the prosthesis would have to be removed before additional treatment could be rendered (Fig. 2).

**Goals and Treatment**

It was decided to provide this patient with an external orthotic appliance to allow her to become ambulatory and as functional as possible.

Following the removal of the final hip prosthesis, skeletal traction was applied to the proximal tibia, to assist in maintaining leg length. The affected limb measured 6 cm. shorter than the sound side, at the time that orthotic treatment was initiated. The patient
Fig. 1. X-rays showing the final hip prosthesis that was attempted.

was not obese, and seemed highly motivated.

The design of the orthosis consisted of an ischial weight-bearing, adjustable, plastic, total-contact quadrilateral thigh section, which was to be attached to a knee-ankle-foot orthosis with offset, drop-lock knee joints, free ankle joints and an external prosthetic above-knee hip joint with a leather pelvic band (Figs. 3, 4). A cast was taken, using a polyethylene quadrilateral brim, extending well over the femoral epicondyles. Approximately 15 pounds of distraction were applied to her affected limb during the casting to increase thigh length.

After the plaster had set, a tracing and measurements were taken of the entire limb and hip.

Fabrication

The thigh section was modified and tension values established similar to the above-knee total-contact standards taught at Northwestern University. The anterior-posterior dimension (ischium to adductor longus tendon) was reduced considerably because the adductor longus was only partially intact.

The quadrilateral socket was fabricated in two sections. The posterior two-thirds was an 80 percent rigid—20 percent flexible polyester resin laminated over a previously vacuum-formed polypropylene anterior shell. The anterior piece was attached laterally by three Dacron hinges. Velcro fasteners made the anterior-posterior dimension adjustable.

Fig. 2. X-rays of hip region following removal of the final hip prosthesis.
to insure a proper placement of the ischium on the seat. An above-knee extension adjustment was incorporated in the system.

The external prosthetic hip joint placement was not critical since there was no anatomical hip joint present. The pelvic band was placed high on the ilium to create a long lever arm from the hip joint axis.

Results

After two days of familiarizing herself with the orthosis, the patient was able to negotiate stairs in physical therapy with the aid of forearm crutches. She was discharged within a week after receiving her appliance.

The patient has used the orthosis for four months in carrying out normal daily activities which include driving an automobile and doing her own shopping. She wears a fracture cast sock on her limb for comfort. Virtually no adjustments to her orthosis have been necessary to date.
The medical opinion for this patient is that no further reconstructive surgery be done as it is not necessary or possible. The infection is under control, and adequate pain relief has been achieved.

Considering the number of total hip surgeries currently being performed, it is logical to conclude that serious problems will develop from time to time.

The orthotic system described in this paper was successful, and it effectively prevented deformities of the limb frequently associated with hip reconstructive arthroplasty procedures. The orthosis provides a functional, stable, pain-free joint, and would be applicable to many postsurgical problems that do arise. This orthosis might also be applicable for stabilization of the limb following removal of a segment of the femur secondary to infection or carcinoma.

Footnotes
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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-
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

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**Fig. 1. The vertical load on a caliper.**

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[Diagram of typical vertical force of lower limb (Normal Gait)]
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, considerable 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-
nificant vertical load. By the same reasoning, a stabilizing orthosis cannot be expected to support the patient in the same way as a load-bearing orthosis would do, and to expect 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 different 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 metal or plastic, a design complication may arise...
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 accommodate the shape of the limb). This in turn will reduce the support which the structure would give to the knee joint, e.g. an orthosis 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)

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-
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.
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>
<thead>
<tr>
<th>Patients Who Can Walk Unaided</th>
<th>Used A Weight-Relieving Orthosis</th>
<th>Used A Non-Weight-Relieving Orthosis</th>
</tr>
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<tbody>
<tr>
<td>16</td>
<td>8</td>
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| Cannot Walk Unaided Without An Orthosis | 11 | 1 |
It was assumed that all weight-relieving orthoses prescribed were necessary, which was, a priori, an unacceptable assumption. More reasonable would appear the premise that those who could not walk unaided without 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 contributory factor to the inability of those patients 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 significant (1 cm) shortening of the affected limb. No other physical finding was constant in any particular group of patients. We concluded that there was no apparent relationship 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 prescription.

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 orthosis 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 unreliable guide to the type and strength of orthosis 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 general 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 increased when the deformity is fixed. Secondly, the hip 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 limiting 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 exertions, e.g. hill-walking, will subject his orthosis 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 orthosis fails. It is not possible, of course, to take account of all such unusual or excessive forces, but the point must be made and considered. Even in everyday living, an orthosis is subjected to many "abnormal" forces—descending stairs, (particularly if taken two at a time), jumping off a moving bus, swerving on the pavement, not to mention the physiological 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.

Literature Cited


Footnotes

1 Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, England.

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A HEAT GENERATING SOCKET

John Ficociello, C.P.¹
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A problem encountered often in northern climates is adaptation to cold environments. For amputees, this can be a severe problem because the laminated resin socket transmits heat readily from the residual limb to the cold environment.

In an attempt to improve the patient's tolerance to extended periods of outdoor activities, such as snowmobiling and skiing in extreme weather conditions, means of providing heat in addition to the heat generated by the body within the prosthesis was investigated and an auxiliary heating system was developed for a very active below-elbow amputee.

A number of solutions were considered and rejected before success was realized. The use of a commercially available heated foot sock proved to be inadequate because of the pressure of the wires on the residual limb as well as wrinkling of the sock inside the socket. Insulating the inner socket from the outer lamination with polyurethane foam, though functionally quite adequate, presented a cosmetic problem as a result of the increased size of the prosthesis.

The solution that seemed to be the optimum was the use of high resistance electrical wires within the laminated wall of the socket and an external source of electricity. This system worked satisfactorily for a short period of time, but wires soon fractured at the point where they emerged from the socket, rendering the embedded wires unusable. After additional research, we now have what we feel is a practical and durable heat generating system.

We used the conventional procedures for casting, modifying the cast, and we used a check socket. After an accurate, positive mold was obtained, we began with a layup of one layer of Perlon stockinet.

To this initial layer, we spot-glued #25 gauge, non-coated wire (Fig. 1). The wire was initiated at the distal end of the mold and brought proximally, in a spiral fashion, care being taken not to cross the wire on itself. A #20 gauge, coated wire was then soldered to the #25 gauge wire at the distal end of the model and then brought directly proximally to a female plug receptacle at the trim-line (Fig. 2). The proximal end of the #25 gauge, non-coated wire was also brought to the receptacle and both wires were soldered to it.

Because the proximal trim line of the socket was determined accurately at the time of the check socket fitting, we were able to spot glue and laminate the receptacle so that only
Fig. 1. A No. 25 gauge non-coated resistance wire is spot-glued to the initial layer of Perlon stockinet of the below-elbow socket. A No. 20 gauge coated resistance wire is soldered to the No. 25 gauge wire at the distal end of the model and brought proximally to a female electrical receptacle located at the trim line of the prosthesis socket to be fabricated.

Fig. 2. Another view of the assembly shown in Figure 1.

the two plug holes were exposed at the proximal edge of the socket (Fig. 3).

The rest of the lay-up and lamination was carried out along conventional lines. Extreme care should be taken when breaking the mold out of the socket. Obviously when any part of the wire is damaged, the system will not function.

To the male plug, we soldered #16 gauge, coated wire (Fig. 4). The #16 gauge wire was then hooked to a six-volt dry cell battery, which our patient preferred for his purposes. For skiers, hunters, or anyone that does not want the inconvenience of the six-volt dry cell, this system could easily be modified to utilize the power packs used to power myoelectric prostheses. Such a system permits location of the power source within the prosthesis or on the person.

This system, when followed correctly, supplies heat sufficient to warm the residual limb, but not enough to burn the amputee, or to affect the cured laminate. The amputee simply “plugs” in the prosthesis when the residual limb feels cold, and “unplugs” it when the residual limb is warm enough (Fig. 5). We feel that this system is not limited to upper-limb prostheses, but will be useful in lower-limb applications as well.

Footnotes
1 Roy's Orthopedic, Inc., 33 North Avenue, Burlington, Vermont, 05401.
Fig. 3. The male electrical plug in this view taken during the fabrication process shows the position of the female receptacle at the trim line of the prosthesis socket.

Fig. 4. Close-up view of electrical connection at the socket brim. This arrangement avoids breakage of wires that could be expected if the wires were simply brought out between the laminates.

Fig. 5. The completed prosthesis with the power source plug in place.
SOME BIOMECHANICAL CONSIDERATIONS IN THE DESIGN OF ANKLE-FOOT ORTHOSES

David N. Condie
C. B. Meadows

The proliferation of new designs for ankle-foot orthoses fabricated with thermoplastic materials presents a bewildering picture for the clinician faced with the prescribing of a particular device for an individual patient. Indeed, the orthotics specialist with his special knowledge may require to adopt a trial and error policy extending over a considerable number of patients before the advantages of the various designs become apparent and a practical prescription philosophy can be formulated.

Two important factors that appear to govern the success or failure of a fitting with a particular device are the accuracy with which the patient's requirements have been assessed and the ability of the device to fulfill these requirements. A successful orthotic prescription may thus be considered as a process of patient-orthosis matching involving measurement of the patient's functional deficit and selection of an orthosis whose characteristics, also determined by measurement, are such as to reduce the patient's deficit to the minimum.

Characteristics of the Jointed Orthoses

It is possible to illustrate the meaning of the term "characteristic" of the device by reference to the conventionally constructed ankle-foot orthosis (AFO) fitted with a fulcrum lever and toe-raising spring.

The effect of the spring is such that as the foot is pushed into an attitude of plantarflexion the spring will tend to create an opposing dorsiflexing effect or "moment," which will increase as the deflection of the foot is increased. This characteristic of the orthosis may be measured accurately and recorded in the form of a graph, and in this case will result in an approximately straight line (Fig. 1). The stronger the spring stiffness, the greater will be the moment it develops for a particular deflection and hence the steeper will be the slope of the line on the graph. Thus the orthosis with a free joint has a characteristic of zero slope as illustrated by the horizontal line on the graph and a joint which is locked has as a characteristic an infinite slope as illustrated by the vertical line.

Obviously it is possible to apply this system to define the behavior of an orthosis in other planes of deflection such as inversion or eversion, and, as in the case under examination, this would result in a straight vertical line since the conventionally constructed AFO may be considered to be virtually rigid in this plane when subjected to the loads encountered in walking.
Clearly, it is relatively simple to predict the characteristics of conventional orthoses with their readily identifiable joints and controls. The plastic AFO’s however which have no discrete joints are not so readily open to predictions regarding their behavior.

Because of this difficulty equipment has been developed at the Dundee Limb Fitting Centre to measure the characteristics of an orthosis (Fig. 2). The AFO is clamped in the machine at the cuff and foot piece and deflected throughout its normal range of motion. The stiffness/deflection characteristic developed in this fashion is plotted directly on a graph plotter. It is thus possible to compare the characteristics of differing types of orthoses (Fig. 3), and to examine also the altered behavior of an individual orthosis achieved by varying its trimline (Fig. 4).

**Characteristics of Thermoformed Orthoses**

The first design of an AFO fabricated from a thermoplastic material to achieve significant acceptance was the Teufel posterior leaf-spring orthosis (4) made of Ortholen, a high density polyethylene. The Teufel orthosis was described as being appropriate for “flaccid conditions of the foot.”

**The Teufel AFO**

The first design of an AFO fabricated from a thermoplastic material to achieve significant acceptance was the Teufel posterior leaf-spring orthosis (4) made of Ortholen, a high density polyethylene. The Teufel orthosis was described as being appropriate for “flaccid conditions of the foot.”

**The Hartshill AFO**

In 1968, Yates (5) published his description of the use of polypropylene in the construction of ankle-foot orthoses. The method of construction adopted required no cast rectification and resulted in a rather rigid de-
vice extending forward to the medial malleoli. At fitting, the orthosis was normally flexed vigorously into extreme dorsiflexion to reduce significantly the resistance which the device would afford to movement in that direction while retaining the high resistance to plantarflexion inherent in the geometry of the device. In the United Kingdom this device is customarily referred to as a “Hartshill” AFO. According to the developer, this orthosis is intended for use primarily in cases of flaccid “drop foot” or where there is minimal spastic muscle behavior.

The TIRR AFO

The potential of this new material was recognized immediately by many other developers, notably in North America, and further variations emerged, one of the best known of which was the polypropylene AFO with corrugations, developed at the Texas Institute for Rehabilitation and Research (1). The developers of this device suggested that it was indicated for “a lack of dorsiflexion.”

Prescription

Thus it seems at least three different new AFO’s are available which appear to be appropriate for the same group of patients. These claims will now be investigated by examining the “characteristic” of the orthoses.

Simple Drop Foot

If the patient’s disability may be truly described as a drop foot, that is to say, isolated weakness of the dorsiflexor muscles, the requirements of the matching orthosis should be rather simply specified. Firstly, the orthosis should replace the action of the dorsiflexors following heel contact, thus avoiding a foot slap, and secondly, by raising the foot at toe-off to ensure foot clearance during the swing phase. For this comparatively simple requirement there appears to be no doubt that the TIRR and the Ortholen devices with their comparatively low plantar/dorsiflexion stiffness characteristics are a much more appropriate prescription than the more rigid Hartshill device. Similarly, both of these alternative devices provide the least unnecessary resistance to the movements controlled by the unaffected musculature of the ankle.

Drop Foot With Other Weaknesses

The choice of an ankle-foot orthosis becomes more complex when one considers cases of more generalized ankle-foot functional deficit including weakness of the muscles controlling plantarflexion and the movements at the subtalar joint. A further important consideration will be the presence of spasticity in the affected musculature.

In 1972 Lehneis (2, 3) presented his design of a spiral brace fabricated in Plexidur which was intended for use with these kinds of patients. Regretably experience with this device has been marred by repeated fracture problems and many prescribers have been forced to consider alternative solutions. The policy adopted at the Dundee Limb Fitting
Centre has been to adapt the basic Hartshill design of AFO to produce an orthosis capable of providing the greater degree of control required for this group of patients. This effect is achieved principally by selecting a trimline which leaves slightly more material around the ankle joint (Fig. 5).

The increase in the stiffness characteristics which are achieved by this simple measure may be demonstrated easily by reference to the graph lines obtained from the testing equipment, which show an increased slope. An example, in this case the plantar/dorsiflexion characteristic, is illustrated in Figure 3.

**Foot Length Discrepancy**

Complicating disabilities such as limb or foot length discrepancy may be treated simultaneously by adopting a particular foot attitude and using a plastic foam build-up on the sole piece. Similarly, a foam plastic calf restoration may be built into the shank section of the orthosis for cosmetic reasons (Fig. 6).

**More Severe Cases**

There are however some patients for whom the orthotic prescriptions already considered would appear to be still inadequate. These patients may be considered in two categories: those patients where more severe spasticity will require larger forces to achieve full correction; and those patients where the joint deformities are not fully correctable and may indeed become increased when the patient attempts to bear weight upon the foot.
Severe Spasticity

Severe spasticity is commonly encountered with the more severely involved hemiplegic patient. Experience has demonstrated to us that even the modified polypropylene ankle-foot orthosis is unable to control adequately the typical equino-varus deformity.

A careful study of this problem suggested that a further increase in the stiffness of the device would be unlikely to improve its effect upon the patient unless the fit were modified to apply the corrective forces in a much more specific manner than is customarily achieved by standard casting and fabrication procedures.

It was this consideration in mind that the hemispiral orthosis was developed at the New York University Institute for Rehabilitation Medicine (3). This orthosis, made also from Plexidur, is designed to impose a three point system of corrective forces upon the patient's leg and foot to control an equino-varus deformity, and, when correctly fitted, can be very effective. It does unfortunately have several disadvantages. It is difficult and time-consuming to produce and therefore relatively expensive. It can also be awkward for the patient to apply, especially when many of the potential patients have the effective use of only one hand. Consequently, in Dundee it was decided to attempt to produce a further modification of the polypropylene AFO which would utilize a similar three-point force system to control this type of deformity.

The extent of the correction which can be achieved is assessed by manually applying...
Fig. 5. Polypropylene, Ankle-Foot Orthosis as used at the Dundee Fitting Centre.

Fig. 6. Polypropylene AFO with compensations for length discrepancy and calf restoration.

the necessary three-point force system. Obviously, where fixed deformity exists, this position may be short of plantigrade. Additionally in cases of severe muscle spasm the force required to maintain a fully corrected position may not be tolerable.

The wrap cast is taken in the usual manner in the position thus determined and the required force system applied by hand as the cast sets. The orthosis is formed on the resulting positive cast which may have been further rectified to achieve the desired pressure distribution (Figs. 7 & 8).

In those cases where the final attitude is not plantigrade the sole of the orthosis is wedged with high density foam plastic to ensure correct shoe contact with the ground.

This modified AFO is only marginally
more difficult for the patient to don than the standard polypropylene AFO, and the production techniques are only a little more demanding.

**Joint Deformity**

The three-point pressure technique may also be adopted "in reverse" to treat those patients with uncorrectable valgus deformities of the foot which are otherwise difficult to control, and cases of this type successfully treated include both children with spina bifida and cerebral palsy. In these cases an identical production technique is adopted with the pressure points positioned to achieve the required control.

**Conclusion**

The range of modern thermoplastic AFO's exhibit a wide spectrum of functional characteristics. In spite of the apparent simplicity of the orthoses, the factors governing their functional characteristics are exceedingly complex. A deeper understanding of
the means of obtaining specific characteristics will permit more accurate matching to the patient's requirements.

Summary

This paper presents a biomechanical approach to development of prescription criteria for ankle-foot orthoses based on a system of measuring the "characteristics" of an orthosis. The result of applying this system to the existing range of AFO's of both conventional and molded plastic construction are described with the consequent prescription practices. Finally, some further development is described in the use of the molded polypropylene AFO to control severely deforming varus/valgus conditions of the ankle-foot complex.

Literature Cited


Footnotes

1 Senior Bioengineer, Dundee Limb Fitting Centre, 133 Queen St., Broughty Ferry, Dundee, Scotland.

2 Bioengineer, Dundee Limb Fitting Centre, 133 Queen St., Broughty Ferry, Dundee, Scotland.
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The following resolution was adopted by the Board of Directors of the American Orthotic and Prosthetic Association at its meeting in San Diego October 3, 1973:

WHEREAS by Act of Congress it has been determined that the United States should proceed towards adoption of the metric system as used almost universally throughout the rest of the world, and

WHEREAS the technological professions and many segments of the health professions have commonly used the metric system over an extended period of time, and

WHEREAS it is important for members of the orthotic/prosthetic professions to interact with their colleagues in the medical and technological communities for optimum patient service be it hereby

RESOLVED that the American Orthotic and Prosthetic Association endorses the use of the metric system by its members and other orthotic and prosthetic practitioners in the United States, and in witness of this endorsement and Association urges the editors of its journal Orthotics and Prosthetics to commence the dual reporting of weights and measurements in both the English and metric systems at the earliest possible date with the objective of employing the metric system solely by the time of the 29th Volume in 1975.
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2. Knight-Taylor Garment Front
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4. Knight-Taylor Garment Front (no side uprights)
5. Knight Apron Front
6. Knight Garment Front
7. Knight Apron Front (no side uprights)
8. Taylor Apron Front
9. Taylor Garment Front
STRESS (OR PRESSURE)

To convert from
pounds-force/square inch (psi)
pounds-force/square inch (psi)
pounds-force/square inch (psi)

To
newton/square meter
newton/square centimeter
kilogram-force/square centimeter

Multiply by
6894.8
0.68948
0.070307

TORQUE (OR MOMENT)

To convert from
pound-force-feet
pound-force-feet

To
newton meter
kilogram-force meters

Multiply by
1.3559
0.13826

ENERGY (OR WORK)

Definition
One joule (J) is the work done by a one-newton force moving through a displacement of one meter in the direction of the force.

1 cal (gm) = 4.1840 joules

To convert from
foot-pounds-force
foot-pounds-force
ergs
b.t.u.
foot-pounds-force

To
joules
meter-kilogram-force
joules
cal (gm)
cal (gm)

Multiply by
1.3559
0.13826
1 x 10⁻⁷†
252.00
0.32405

TEMPERATURE CONVERSION TABLE

To convert °F to °C

°C = \frac{°F - 32}{1.8}

°F   °C
98.6  37
99   37.2
99.5  37.5
100  37.8
100.5 38.1
101  38.3
101.5 38.6
102  38.9
102.5  39.2
103  39.4
103.5  39.7
104  40.0

*A slug is a unit of mass which if acted on by a force of one pound will have an acceleration of one foot per second per second.
## METRIC SYSTEM
### Conversion Factors

### LENGTH

**Equivalencies**
- angstrom = $1 \times 10^{-10}$ meter (0.0 000 000 001 m)
- millimicron* = $1 \times 10^{-9}$ meter (0.000 000 001 m)
- micron (micrometer) = $1 \times 10^{-6}$ meter (0.000 001 m)

**To Convert from**
- inches
- feet
- yards
- miles

to***
- meters
- meters
- meters
- kilometers

Multiply by
- 0.0254
- 0.3048
- 0.9144
- 1.6093

### AREA

**To convert from**
- square inches
- square feet

to
- square meters
- square meters

Multiply by
- 0.00063616
- 0.092903

### VOLUME

**Definition**

1 liter = 0.001† cubic meter or one cubic decimeter (dm$^3$)

(1 milliliter = 1† cubic centimeter)

**To convert from**
- cubic inches
- ounces (U.S. fluid)
- ounces (Brit. fluid)
- pints (U.S. fluid)
- pints (Brit. fluid)
- cubic feet

to
- cubic centimeters
- cubic centimeters
- cubic centimeters
- cubic centimeters
- cubic centimeters
- cubic meters

Multiply by
- 16.387
- 29.574
- 28.413
- 473.18
- 568.26
- 0.028317

### MASS

**To convert from**
- pounds (avdp.)
- slugs*

to
- kilograms
- kilograms

Multiply by
- 0.45359
- 14.594

### FORCE

**To convert from**
- ounces-force (ozf)
- ounces-force (ozf)
- pounds-force (lbf)
- pounds-force (lbf)

**To**
- newtons
- kilogram-force
- newtons
- kilogram-force

**Multiply by**
- 0.27802
- 0.028350
- 4.4732
- 0.45359

*This double-prefix usage is not desirable. This unit is actually a nanometer ($10^{-9}$ meter = $10^{-7}$ centimeter).

† For practical purposes all subsequent digits are zeros.
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