

## The Genucentric Knee Orthosis—A New Concept

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The Genucentric Knee Orthosis<sup>3</sup> (Fig. 1) offers a unique polycentric (Genucentric) joint as an alternative to

single axis or conventional polycentric joints for patients with mediolateral instability or genu recurvatum. Con-

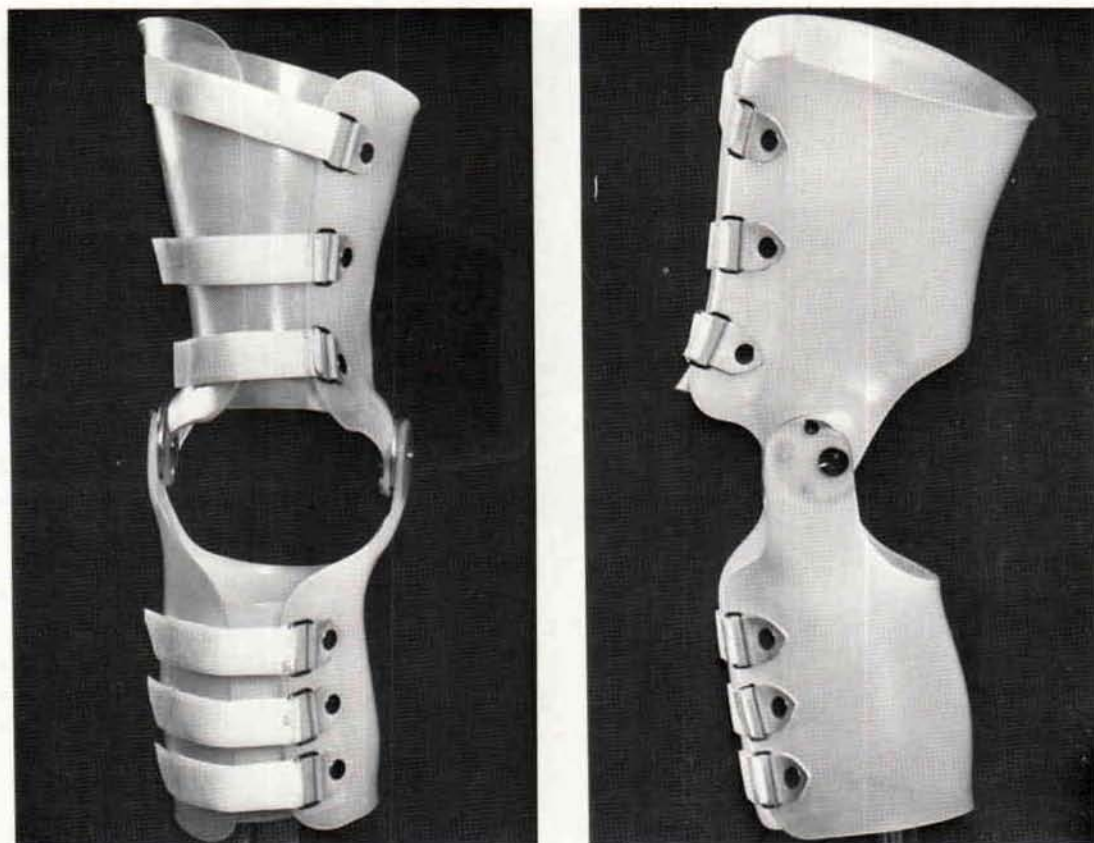


Fig. 1. Anterior and medial view of the Genucentric Knee Orthosis.

ceived by the authors and developed at the Veterans Administration Prosthetics Center (VAPC), this orthosis features lightweight construction, improved cosmesis, supracondylar-suprapatellar suspension, and a knee-tracking capability that eliminates pistoning and migration. The most distinct feature is the Genucentric joint (Figs. 2 and 3), with its ability to approximate its instantaneous center of rotation with the structurally sound and/or pathologically deranged knee. Clinical results thus far indicate that the intended goal of designing a polycentric joint to accommodate the anatomical knee, such as to eliminate completely the joint as a source of pistoning at the orthosis-limb interface, has been achieved.

### The Genucentric Joint

A detailed description of the mechanical aspects of the Genucentric joint must

begin with a discussion of the movements of the anatomical knee, since mimicking the anatomical knee is the desired result. Although considerable research has been devoted to the biomechanics of the knee joint, it is beyond the scope of this article to restate this research in full. We will, however, discuss briefly points found pertinent to the development of the Genucentric joint.

Kapandji (2) states that movement of the femoral condyles upon the tibial plateau is accomplished by a combination of rolling and sliding. A purely rolling motion requires a tibial plateau of approximately twice the width that actually exists to prevent dislocating the knee. A purely sliding motion would cause the femur to strike the posterior aspect of the tibial plateau, bringing flexion to a premature halt. The ratio of rolling to sliding varies throughout the flexion range. Beginning with rolling for the first 10 to 15 deg. for the

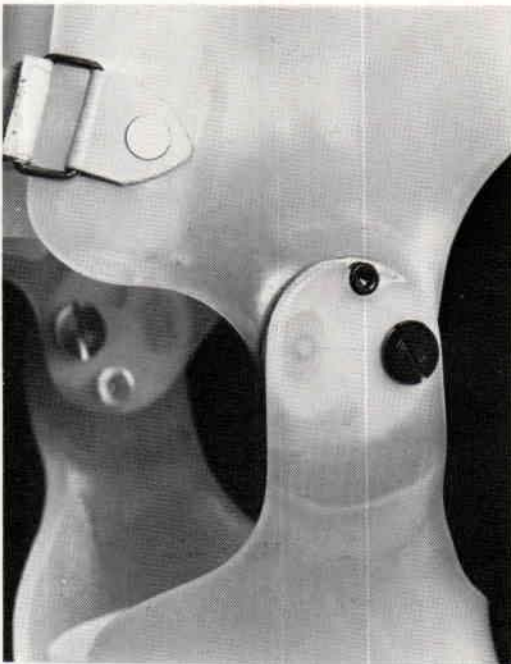


Fig. 2. Close-up view of Genucentric Joint.

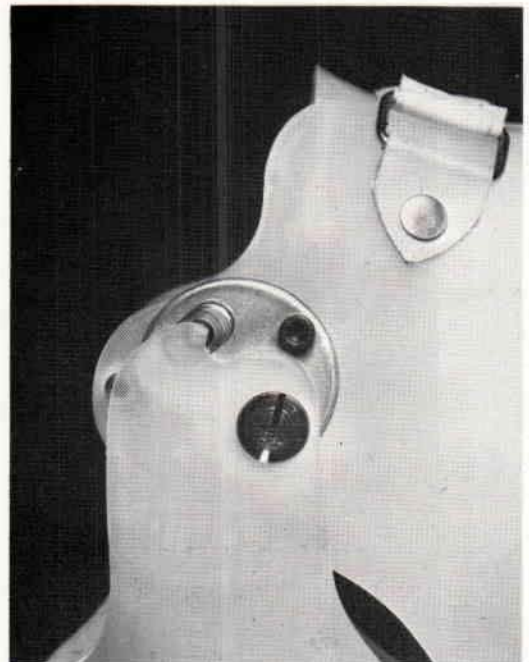


Fig. 3. Close-up view of Genucentric Joint fully flexed.



medial condyle, and 20 deg. for the lateral condyle, sliding becomes progressively more important until it becomes the only motion toward the end of the flexion range. The difference between the rolling-to-sliding ratio of the medial and lateral condyles explains why the lateral condyle covers a greater distance than the medial condyle, and accounts for the transverse rotation found at the knee joint.

The changing radius of curvature of the surface of the femoral condyles causes the instantaneous center of rotation of the knee to displace during flexion and extension. It is never displaced beyond a 2.3 cm circle about the lateral femoral condyle, unless severe structural derangement is present.

Frankel and Burstein (1) state that "It has been well-documented that normal motion (of the knee) involves a moving instant center of rotation. Therefore, it is unreasonable to expect that normal motion may be forced or created by the use of a well-fitted, single-hinged knee brace. If there is sufficient clearance or play between the elements of the brace and the leg, normal motion may be permitted providing the joint itself is capable of producing it by being displaced. However, if it is desirable to force normal motion with well-fitted braces or hinged casts, a knee which produces a moving instant center of rotation is necessary."

The inherent problem in using a single-axis joint to brace the multi-axis knee is that the single-axis joint tends to become displaced in its effort to follow the moving center-of-rotation of the anatomical knee. This movement is transmitted to the cuff sections and produces an angular change in the cuff sections that causes them to shift up and down along the limb (pistoning). Discomfort and slippage are the result.

Polycentric joints commonly used

today utilize a moving center-or-rotation to reduce pistoning. However, they provide only one ideal path of instant centers and lack the flexibility needed to conform to individual variations found in healthy as well as pathologically deranged knees. By contrast, the slotted disk sandwiched between the thigh and calf sections permits the instant center of the Genucentric joint to move through a variety of paths, thereby allowing the joint to follow the path of the individual anatomical knee while providing the necessary support (Figs. 4 and 5). Plots of the instant center, using the methods outlined by Frankel and Burstein, show a concentrated locus of centers that lie within a 2.5 cm circle, indicating that the motions of the Genucentric joint can mimic the motions of the anatomical joint. Like the anatomical knee, the Genucentric joint has a sliding as well as a rolling component in its motion. Transverse rotation of the anatomical knee was not considered significant in the design of the Genucentric joint since this motion is adequately absorbed by the soft tissues between the skeletal members and the cuff sections.

Polypropylene is used in the construction of the Genucentric joint because it afforded the opportunity to make the joints continuous with an intimately fitting polypropylene calf and thigh cuffs (Fig. 5). This was accomplished during molding by extending the thigh piece below the knee center on the cast, terminating in a semicircle. The calf piece was extended an equal distance above the knee center and thigh piece, terminating in a similar manner. This provided a circle of overlapping plastic about the knee center within which to construct the joint. Sandwiched between the plastic cuff extensions are aluminum disks with two holes drilled in a horizontal plane. (See fabrication sequence below.) The holes provide the required



joint pivot points that are matched by a single hole in each of the plastic cuff extensions. Two stops (cap screws) are then added to each joint, one to the distal end of the thigh extension, the other to the proximal border of the aluminum disk, that are matched by slots in the adjacent structures. The stops keep the joints in proper alignment while donning and doffing the orthosis, and provide a halt to extension at full extension or at the desired degree of flexion.

This manner of construction offers significant advantages over conventional orthoses. The time consuming processes of bending, polishing, aligning, and riveting sidebars to cuffs are eliminated. And, by removing the bulky sidebars, a lighter-in-weight, more streamlined, and most cosmetically appealing appliance is produced.

Suspension is accomplished by a combined supracondylar-suprapatellar system in which tissue is compressed above the patella and the condyles. A built-in flare for the displaced tissue in

the distal posterior section of the thigh cuff at the level of the suspension improves the effectiveness of the suspension and enhances comfort.

The Genucentric Knee Orthosis incorporates many improvements over the conventional knee orthosis while maintaining the basic biomechanical principles of the conventional orthosis. This orthosis, like the conventional orthosis, relies on a three-point pressure system to stabilize desired motions of the extremity while preventing undesired motions. Clinical results indicate that the Genucentric Knee Orthosis can be worn with significant improvements in comfort when compared to more common knee orthoses, with pistoning reduced to the point of becoming undetectable, and with migration eliminated.

#### Casting and Modification Procedures

1. Take standard measurements of limb. To utilize supracondylar suspen-

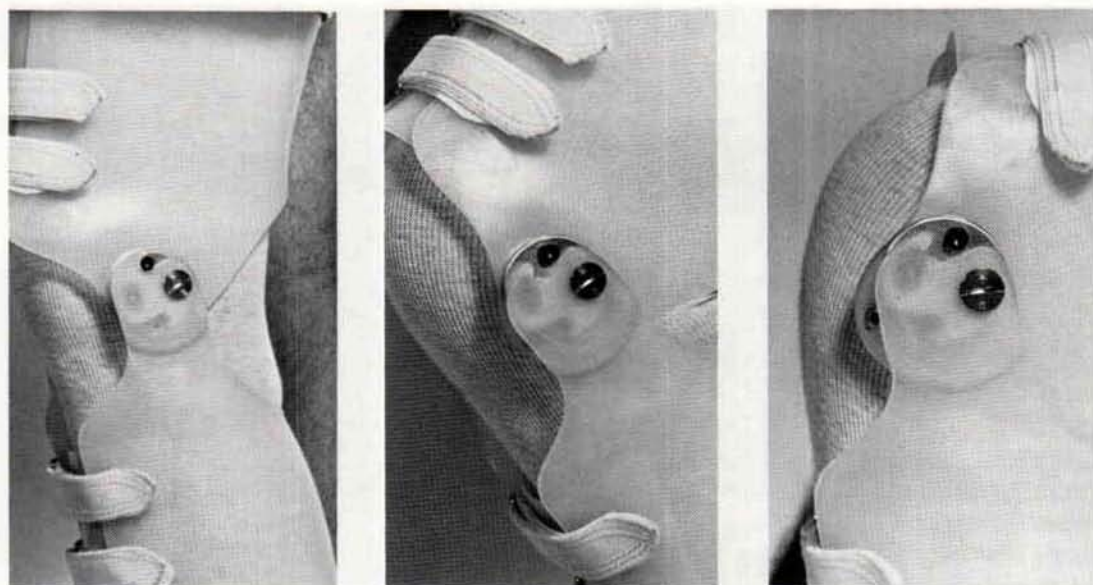


Fig. 4. As knee is flexed, its instantaneous center of rotation is duplicated by the Genucentric Joint.

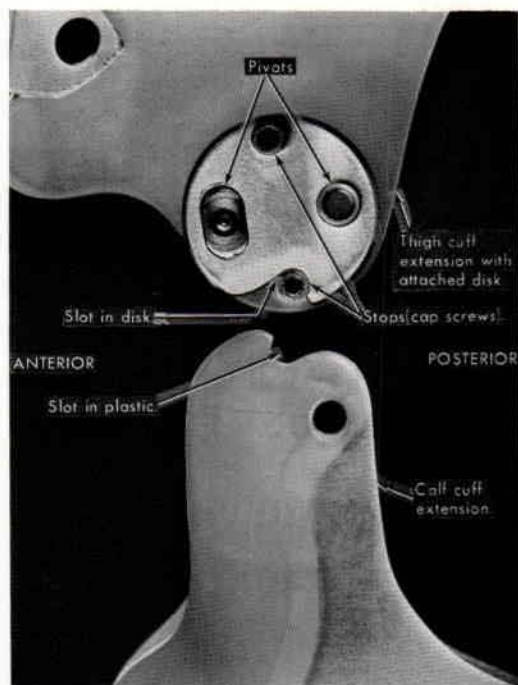


Fig. 5. Exploded view of the Genucentric Joint.

sion, take a tight mediolateral measurement above condyles.

2. Place Tubegauz on limb and secure from moving. Use latex tubing to help facilitate cast removal in the usual manner.

3. Mark the following anatomical landmarks with indelible pencil: patella, proximal borders of femoral condyles, knee center (determined by adding 18 mm ( $\frac{3}{4}$  in.) to the medial tibial plateau height), iliotibial band, head of fibula, tibial crest, and any pressure sensitive areas.

4. Cast limb with all deformities corrected as much as possible. To accentuate bony prominences, cast the knee in five deg. of flexion and with only partial weight-bearing while standing.

5. Use elastic plaster bandage to obtain a smooth cast. Start the wrap distally below mid-calf and extend proxi-

mally above mid-thigh. Compress areas immediately above condyles with palms of hands as plaster begins to set to accentuate suspension areas.

6. Once cast is set, draw a vertical reference line on anterior surface of cast. This line should be parallel to the mid-sagittal line.

7. Remove cast and prepare for pouring.

8. After plaster sets, use an awl to penetrate wrap on vertical reference line to transfer it to positive mold.

9. Remove wrap and smooth positive mold of all irregularities. Take care not to remove indelible marks, especially those indicating knee center.

10. Take M-L dimension above condyles down to within 3 mm of the measurement. Ensure that all circumferences are brought down to measurements and blended into the contours of the limb. Pressure sensitive areas are relieved with standard plaster buildups.

11. Because tissue is squeezed above the condyles and patella for suspension, it tends to bulge posteromedially and posterolaterally. To avoid flesh from being pinched by the edges of the orthosis, extend the modified cast in these areas (Fig. 6). The amount extended depends on the amount of subcutaneous tissue present. Cast should be extended 12 mm on slender patients, and 25 mm on heavyset patients.

12. The joints of the Genucentric Knee Orthosis are built as continuations of the cuff moldings (Fig. 6). Each cuff overlaps the other at knee-center level. Flat, circular build-ups on the cast are needed to create flat surfaces for joints. The build-ups should be 42 mm in diameter, parallel to both the mid-sagittal line and the line of progression, and build-ups should not increase the epicondyle M-L measurement. Extend the build-ups distally by 18 mm beyond circular portions of the joints, to allow offsets to be created in calf cuff and



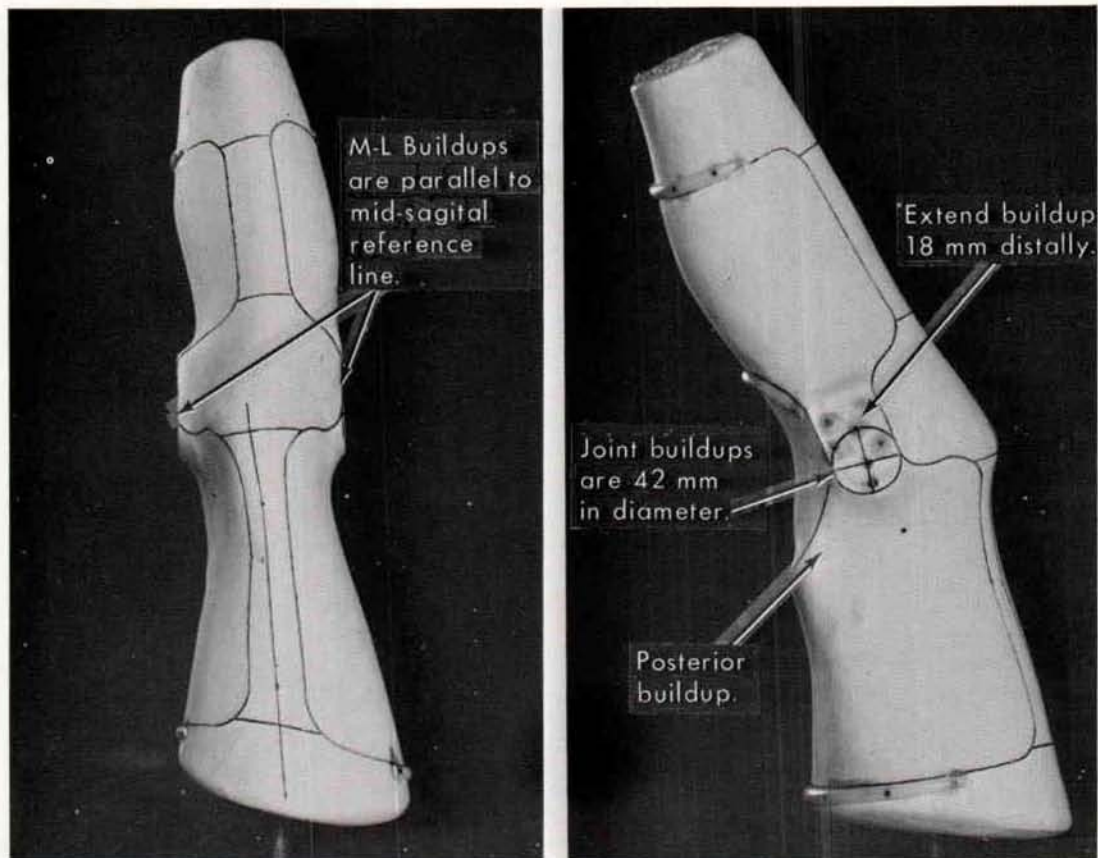


Fig. 6. A. Anterior view of positive model showing buildups parallel to the anterior reference line. B. Medial view of positive model showing joint buildups, flare extensions, and trim lines.

thereby allow the thigh cuff to flex to 135 deg.

13. Place trim lines and flares on cast. Mark each joint buildup with vertical and horizontal reference lines that will be used to align disks later.

#### Fabrication Procedures

Cast is prepared for both vacuum drape molding and standard hand molding without vacuum.

1. Use 5 mm-thick polypropylene to vacuum mold thigh cuff. Set vacuum to 15 psi.

2. After cooling, remove plastic from cast, trim it to trim lines, and place back on cast.

3. Tape a 3 mm-thick blank aluminum disk that is larger in diameter than proposed joint diameter, to knee-joint position on thigh cuff (Fig. 7A). Mold calf cuff over both thigh cuff extension and disk (Fig. 7B).

4. Remove calf cuff after cooling and trim to trim lines.

5. Hand-mold tongues on cast using 2 mm-thick low density polyethylene. Skive tongues where they fit under cuffs.

6. Attach reinforced Velcro straps, tongues, and 25 mm stainless steel loops reinforced with laminated Dacron tape, to cuffs.

7. Place completed cuffs on cast: 3 mm spaces parallel to both the mid-

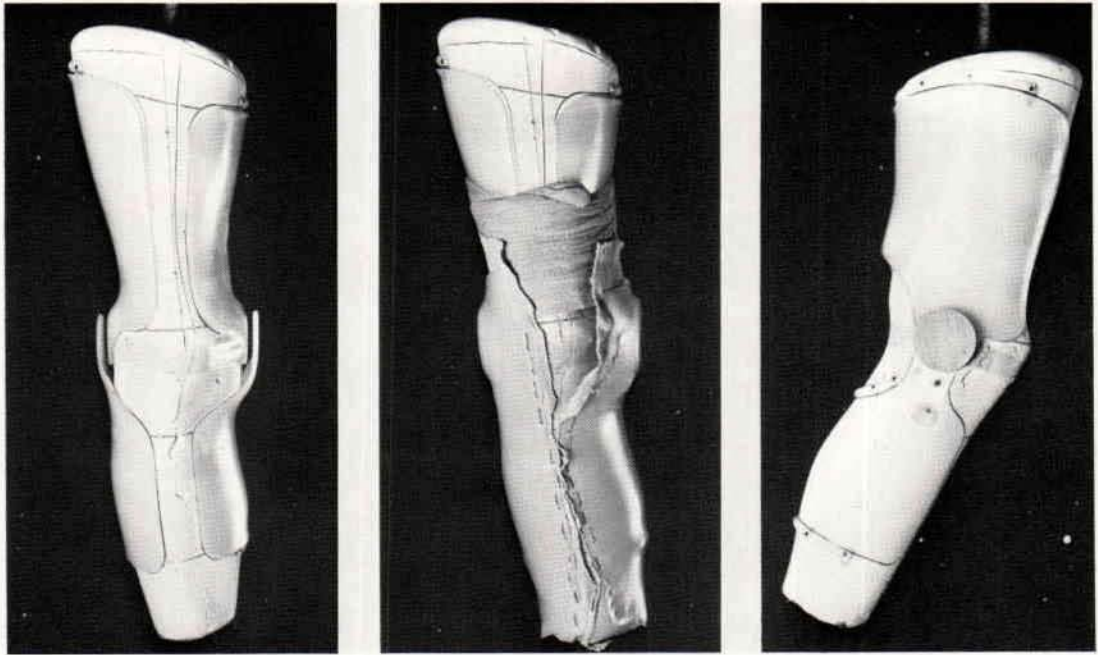


Fig. 7. A. Thigh cuff with blank aluminum disk on cast. B. Calf cuff molded over thigh cuff and blank disk. C. Both cuffs in position after trimming and polishing. Joint spaces for aluminum disks should be parallel in all planes.

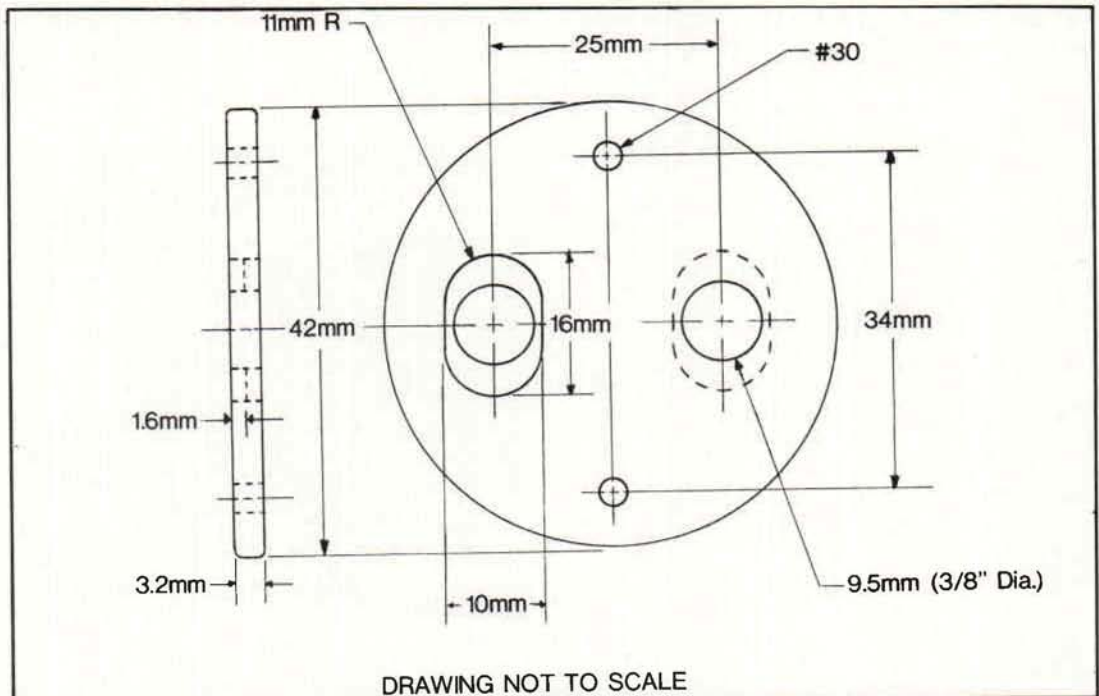


Fig. 8. Dimensions of the disk.



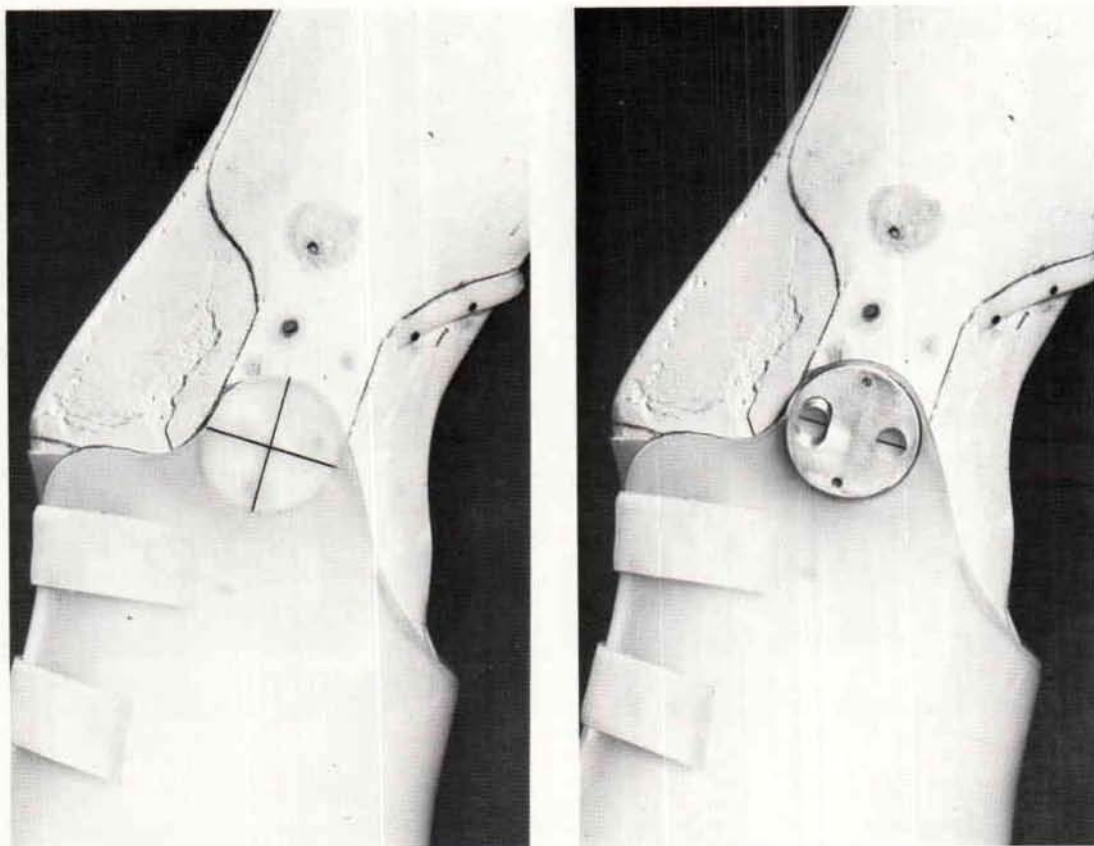


Fig. 9. A. Reference lines transferred from positive model to thigh cuff. B. Disks are positioned over reference lines. Anterior pivots and distal #30 holes in disks are marked and drilled through plastic.

sagittal line and the line of progression at joint surfaces should be observed (Fig. 7C).

8. The spaces created are for two 3 mm-thick aluminum disks. Each disk will have two pivots and two stops (Fig. 5). Fabricate disks as shown in Fig. 8.

9. Remove calf cuff while maintaining thigh cuff in place on cast. The somewhat translucent plastic will permit reference lines previously drawn on cast to show at knee-joint area (Fig. 9A). Position disks so that holes line up with reference lines (Fig. 9B). The anterior pivot point of each disk should be marked and drilled through plastic with a 9 mm (3/8 in.) drill. Attach disks to thigh cuff using standard ankle joint bushings and screws.

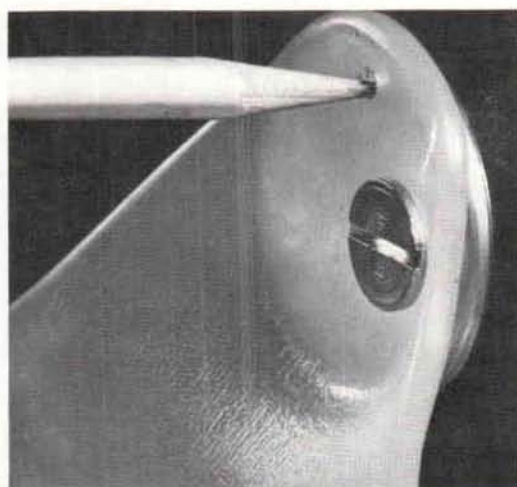


Fig. 10. Close-up of disk being rotated about anterior pivot. A pencil is used to scribe path that stop travels through.



Realign disks, mark, then drill lower #30 holes in plastic. Insert a pencil through plastic joint (Fig. 10) and scribe an arc on disks as they are rotated around anterior pivots. Remove disks and expand lower #30 holes by drilling in disks to 7 mm or 9/32 in. Using the scribed arcs as guides (Fig. 11A and B), cut slots into disks (Fig. 5) to permit 6 mm cap screw heads to run smoothly within slots. Enlarge #30 holes by drilling in plastic to #4 size holes so that post screws can be inserted into plastic. Place cap screws and post screws into plastic thigh cuff, then attach disks and rotate them. There should be no binding. Place thigh cuff back on cast.

10. Secure disks against cap screws with masking tape (Fig. 12A). Attach calf cuff to cast. Use holes in disks for reference marks since disks now obscure reference marks on cast (Fig. 12B). Mark posterior pivot points and upper #30 holes onto plastic calf cuff. Remove calf cuff and drill posterior pivots in same manner as anterior pivots. Drill upper #30 holes into plastic. Remove disks from thigh cuff and attach to calf cuff at posterior pivot points. Insert pencil through #30 holes in disks, rotate disks about posterior pivots, and scribe arcs onto plastic as previously done for thigh cuff in step 9 above. Enlarge #30 holes by drilling in plastic cuff to 10 mm or 5/16 in. Use arcs on plastic as guides to cut slots in plastic (Fig. 5) and thereby permit cap-screw heads to run freely within slots. Enlarge upper #30 holes by drilling in disks to #21 size holes and tap holes for 10-32 threaded cap screws.

11. Reassemble orthosis. No binding should be present and joints should be square in all planes.

12. The orthosis is now ready for fitting. No localized pain or skin pinching should occur. However, some initial discomfort over condyles may be experienced owing to snug fit for suspension. A piece of tubular stockinet may provide

relief until patient becomes accustomed to orthosis (Fig. 4).

13. Since only minor alignment changes can be carried out on the orthosis, all steps should be followed carefully.

### Clinical Experience

The Genucentric Knee Orthosis was delivered to patients with mediolateral instability and/or genu recurvatum of the knee. Following are reviews of four case studies of patients who have worn the device for sufficient periods of time to obtain meaningful results.

1. Patient B.C., a 24-year-old active male, an automobile body-and-fender man, sustained gunshot wounds of the left femur in 1970. Resulting deformities include: limited range-of-knee motion (15 to 100 deg.), genu varum of 22 degrees, and a one-inch shortening. The patient's major complaint was pain at the lateral aspect of the knee on standing, walking and squatting, which resulted in loss of time from work. B.C. was originally provided with a double bar KAFO with corrective pads. However, due to weight, bulk and overall extensive bracing, he refused to wear the device. An elastic hinged knee orthosis was then prescribed, but while the patient liked the weight and freedom of the orthosis, his condition worsened.

The clinic team, in April 1978, decided to provide B.C. with a Genucentric Knee Orthosis. After wearing this orthosis for five weeks, the patient was seen in the clinic for follow-up examination. He was able to walk and stand with less pain and his deformities were controlled. In addition, he found the orthosis to be lightweight, cosmetic and comfortable, and it provided sufficient freedom for his needs. During seven months of wearing this orthosis, the patient has experienced no problems concerning function or wear of components.

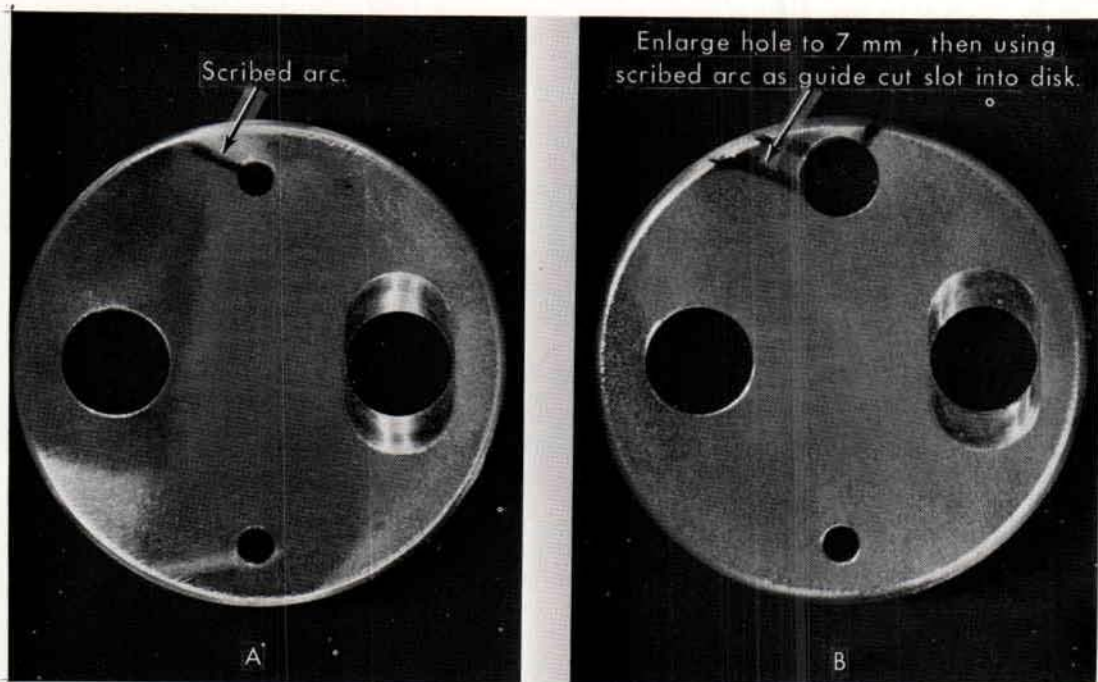


Fig. 11. A. Disk having scribed path of stop on it. B. Slots in disks permit cap screw heads to run freely within them.

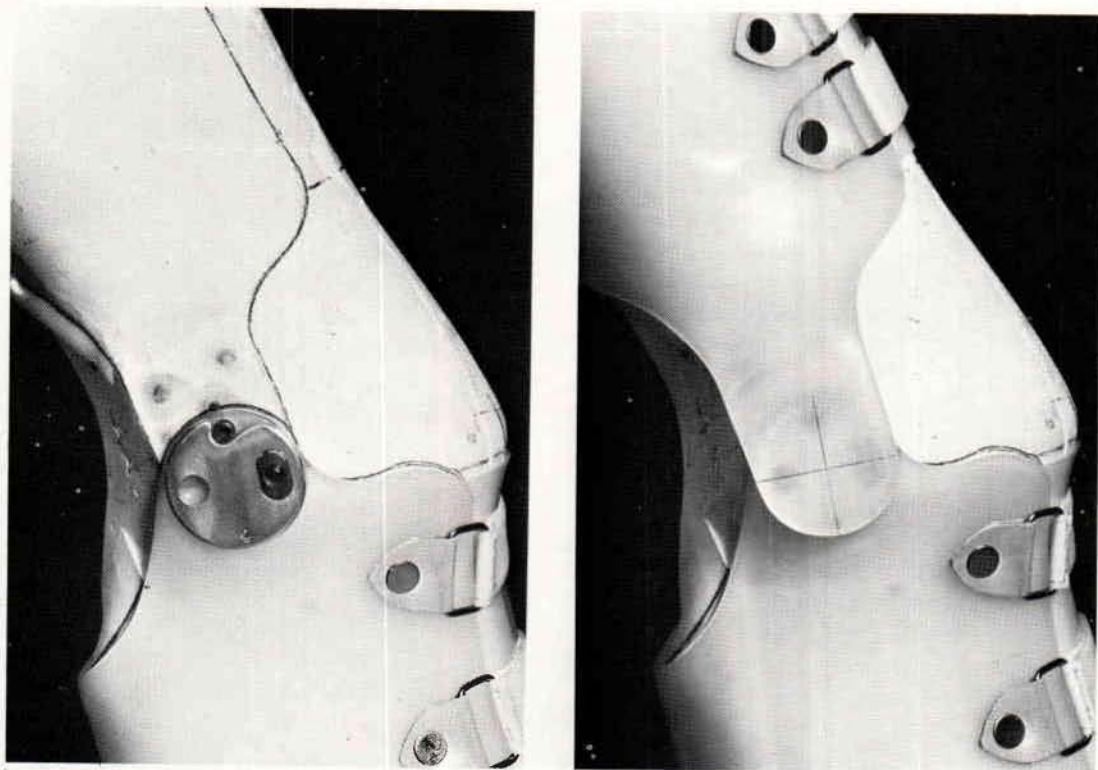


Fig. 12. A. Disk assembly on thigh cuff. B. Calf cuff positioned over disk. Posterior pivots and proximal #30 holes are marked and drilled through plastic.



2. Patient J.A. (Fig. 13), a middle-aged male, injured his right knee after falling from a truck in 1953. The resulting trauma created mild laxity in both the A-P and M-L planes. In addition, the patient has pain, atrophy and a moderate limp. Active range-of-knee motion is limited from 0 to 100 deg. due to severe pain and joint damage. Since the onset of this condition, the patient has worn various knee supports; the latest being an elastic knee orthosis with medial and lateral pads. Disabling pain, however, persisted.

The patient was provided with a Genucentric Knee Orthosis in May 1978, and was seen for a follow-up examination five weeks after the orthosis was delivered.

Although J.A. still had pain, he no longer experienced the sharp pain he had with previous devices. Laxity in both A-P and M-L planes were well controlled; the patient found the orthosis to be lightweight and cosmetic, and it did not piston as previous devices had (Fig. 14).

3. Patient M.L. (Fig. 15), a 55-year-old male, suffered a head injury in 1945, secondary to shell fragment wounds, with resulting hemiplegia on his right side. He walks with a spastic equinovarus deformity of the right foot. His quadriceps are good and he is stable while standing and walking. M.L. was provided with a single bar AFO with 90-degree plantar stop and varus corrective strap. With the passage of time, stresses

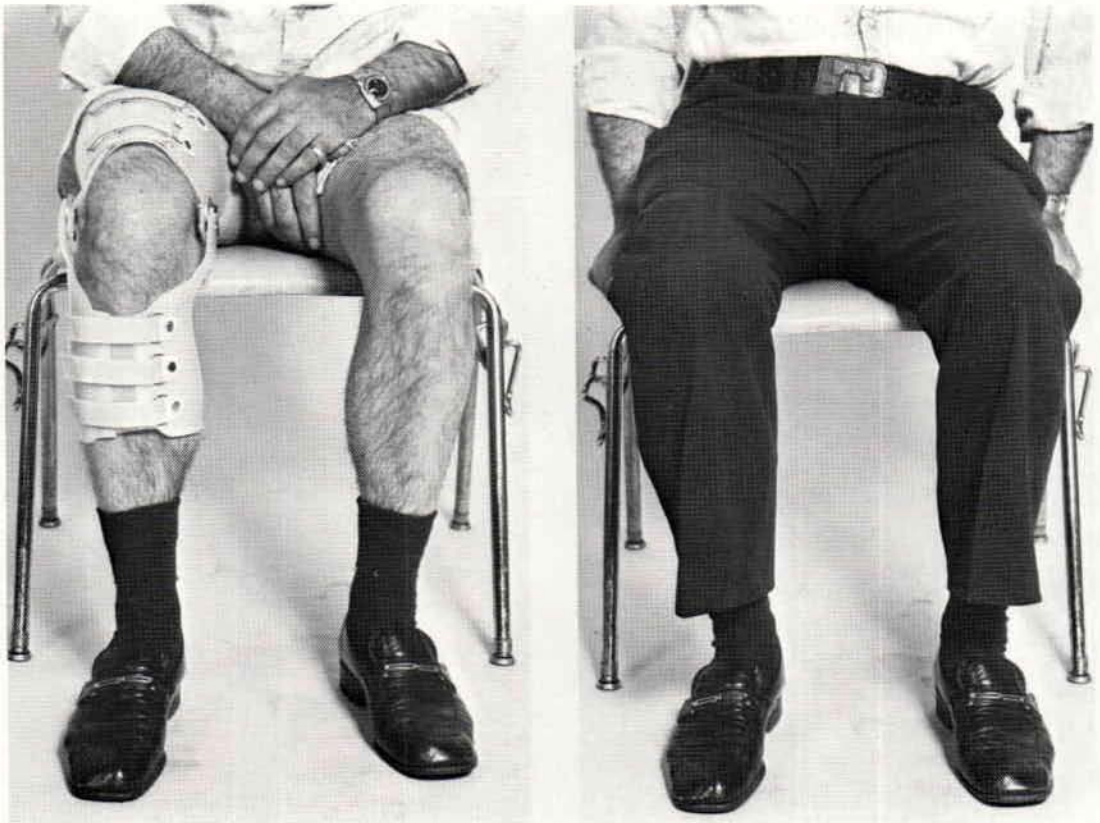


Fig. 13. Patient J.A. Normal knee motions are unrestricted even while he is seated, enhancing both comfort and cosmesis.

acting on the right knee caused posterior ligament stress, anterior knee compression, and excessive hyperextension, all resulting in pain and fatigue.

The clinic team, in April 1978, decided to provide M.L. with a KAFO utilizing a polypropylene shoe insert and a Genucentric Knee Joint. The orthosis was fitted, but due to upper extremity involvement and spastic equinovarus, the patient could not don the device independently. However, when assisted in donning the device, the patient functioned well with it on. The orthosis was modified by maintaining the knee section and replacing the shoe section with an aluminum medial upright, caliper stirrup with 90-degree plantar stop, and varus corrective strap. With these modifications, M.L. was able to don and doff the orthosis independently. Five weeks after delivery, a follow-up examination revealed that the patient was doing well; genu recurvatum was controlled, pain and fatigue were eliminated.

4. Patient G.H., a 44-year-old active male truck driver, injured his left knee when he fell from a ladder in 1956. Cartilage was removed from the medial aspect of the knee. G.H. has marked atrophy of the thigh, limited range-of-knee motion (15 to 90 deg.), pain, and some A-P instability. He was given a Jones knee cage, with drop locks for occasional use. The VAPC Knee Orthosis, prescribed in October 1974, was lighter in weight, provided good function, and had no locks. The patient was seen in May 1978 for a new orthosis because the VAPC Knee Orthosis was no longer serviceable.

The clinic team decided to use the Genucentric Knee Orthosis to eliminate pistoning. The patient found the new design to be lighter in weight, more cosmetic, and better in function than previous devices.

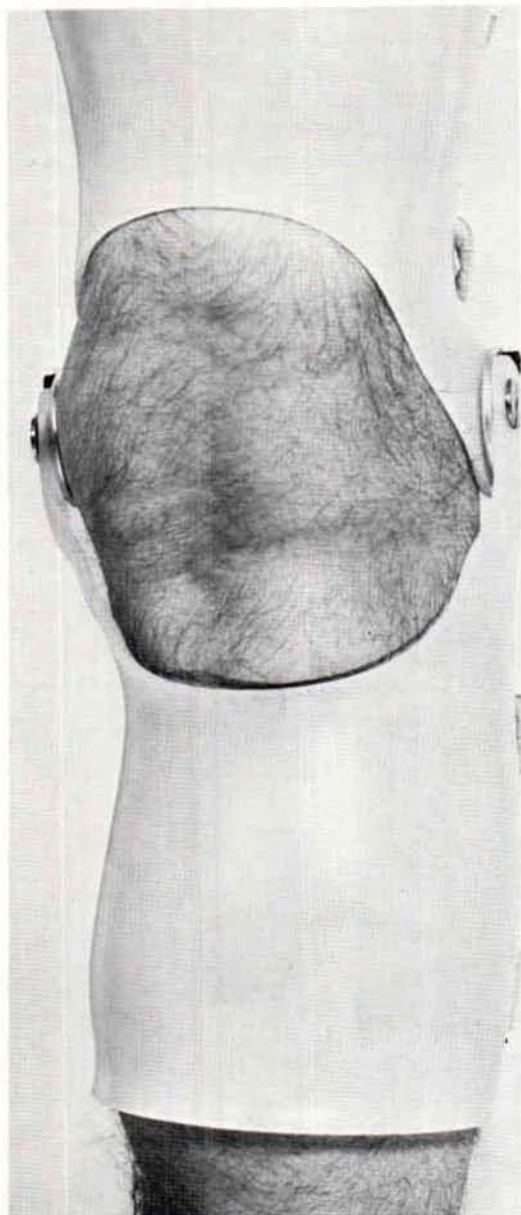


Fig. 14. Intimate fit can be obtained with Genucentric Knee Orthosis.





Fig. 15. Patient M.L. wearing plastic KAFO with Genucentric Knee unit. Cosmesis of this device is excellent.

### Summary

The Genucentric Knee Orthosis employs a unique new joint to eliminate pistoning. This is due to the capability of the joint to duplicate the motion of the individual anatomical knee it controls. With pistoning eliminated, and with a firm foundation provided by its supracondylar-suprapatellar suspension system, migration of the orthosis becomes clinically undetectable, even after lengthy periods of active use. In addition, to further enhance patient comfort and acceptance of this unique rehabilitation approach, the orthosis is fabricated of lightweight plastic utilizing vacuum-forming and drape-molding techniques.

The Genucentric Knee Orthosis is presently being clinically tested on patients with various knee problems; four patients have thus far worn the device for sufficient periods of time to compile definitive results. In each case, the patient found the orthosis to be comfortable and non-restrictive to the desired motions of the limb. Neither wear nor mechanical failure have been observed, even though some of these patients are young and quite active.

### Acknowledgments

The authors would like to express their appreciation to Kenneth LaBlanc, Senior Technical Specialist, and Max Nacht, Technical Writer, for their cooperation and assistance in preparing

this article; to Michael Lamberti, Photographer, for his outstanding photographic work; and to Gary Fields, Technical Assistant to the Director of the VAPC, and Dr. Gustav Rubin, Clinic Chief, for their encouragement and interest.

### Footnotes

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<sup>3</sup>The term "Genucentric" has been coined to distinguish our unique polycentric joint from the polycentric joint now in common use.

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