CLASSIFICATION OF MOBILE BEARING KNEE DESIGN: MOBILITY AND CONSTRAINT

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INTRODUCTION

Restoration of normal knee joint function through surgical reconstruction is dependent upon load sharing between the implant and surrounding soft tissue structures. Mobile bearing knee designs offer the advantage of maximum conformal geometry while diminishing constraint forces to fixation interfaces through plateau mobility. The degree of mobility afforded by these designs in the anterior-posterior, medial-lateral and rotational directions defines the required interaction between soft tissue and design geometry to maintain a stable articulation.

This study characterizes nine, contemporary mobile bearing designs in terms of the force generated during a prescribed displacement. Among the designs evaluated, only the LCS Deep Rotating Platform is available for clinical use in the United States.

METHODS AND MATERIALS

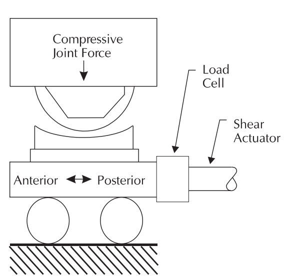
A dynamic testing system capable of applying biaxial loads (Instron Testing Machine, Model 1115, Instron Corporation, Canton, Massachusetts) was utilized to assess the intrinsic performance characteristics of nine, non-hinged, mobile bearing knee designs. Anterior, posterior, medial, lateral and rotational constraints were determined for each total knee design under a compressive load consistent with normal walking gait.[4,6] A compressive load of 4 x body weight and 0 degrees flexion was chosen to represent a position of gait where maximum shear forces act in the posterior and lateral directions as well as in rotation.[4,6] Anterior and medial shear forces are presented at the same gait position for completeness. A body weight of 163 lbf was used in this evaluation, which corresponds to the average for a 60-year old, 5′8″ male subject.[5]

ANTERIOR-POSTERIOR AND MEDIAL-LATERAL SHEAR TESTING

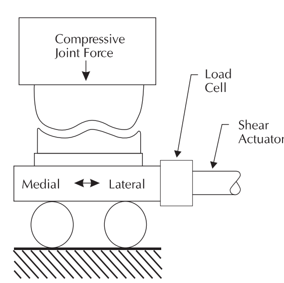
Three tibial inserts were evaluated in each test direction for each system. Under an *in vivo* compressive load, shearing displacements were applied to the system until the implant subluxed. Anterior, posterior, medial and lateral subluxation is defined as the dislocation of the tibial component relative to a stationary femoral component. The shear forces determined provide a measure of the maximum ability of the knee design to constrain displacement during gait.

ROTATIONAL TESTING

Under an *in vivo* compressive load, the system was rotated both internally and externally in the transverse plane and the torque versus angular displacement recorded. Three tibial inserts were evaluated for each system. These results provide a measure of the ability of the knee design to constrain rotation during gait.



Anterior-Posterior Test Assembly



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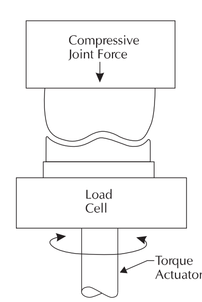
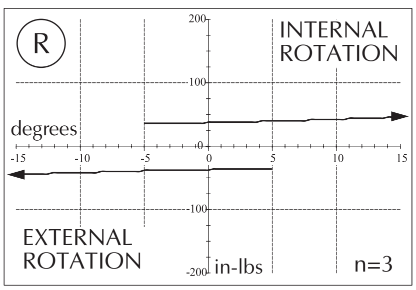


Rotational Test Assembly

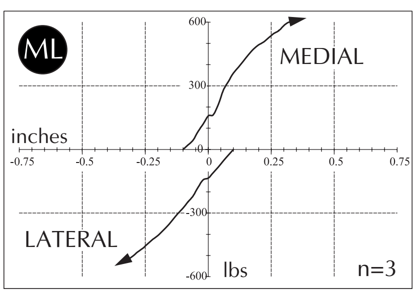
LCS Deep Dish Rotating Platform

R ML AP

Rotational Constraint



M-L Constraint



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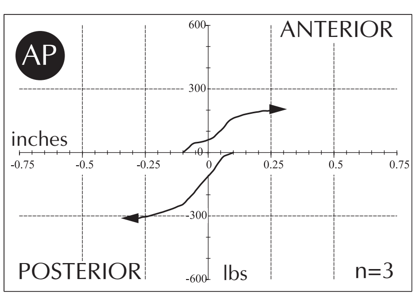
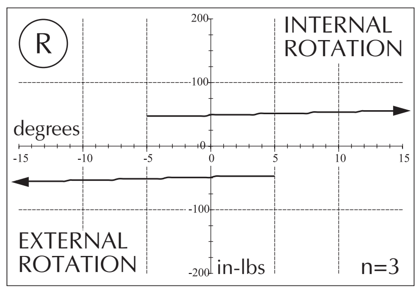


T.A.C.K.

R ML AP

Rotational Constraint



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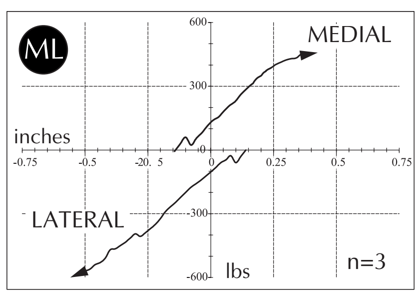

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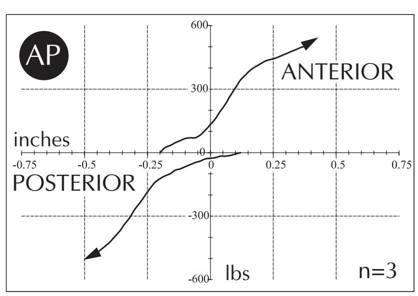
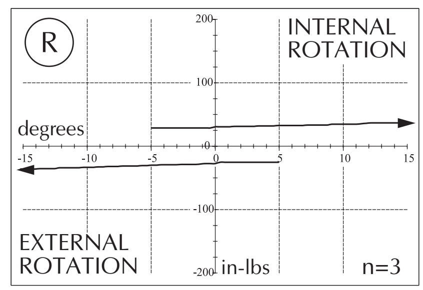


SAL

R ML AP

Rotational Constraint



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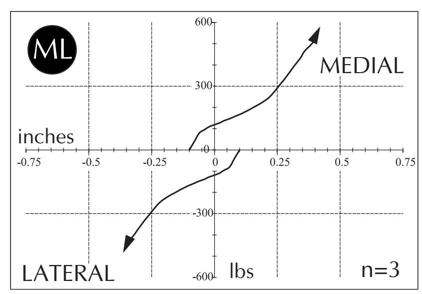

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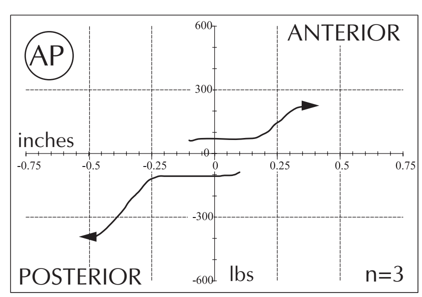


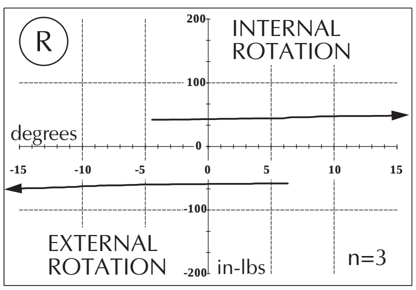
○ = Unconstrained ◐ = Semi-constrained ● = Constrained

R = Rotational ML = Medial / Lateral AP = Anterior / Posterior

TRAC

R ML AP

Rotational Constraint



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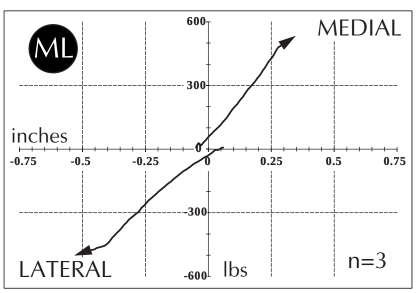
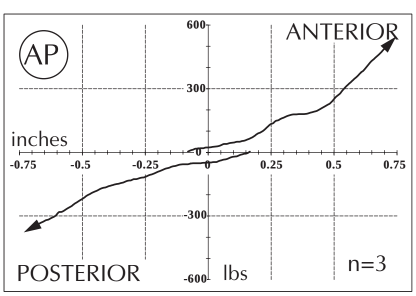
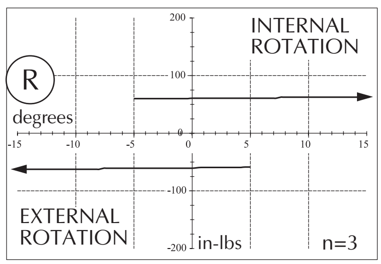


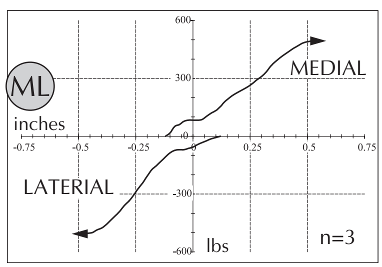
A-P Constraint



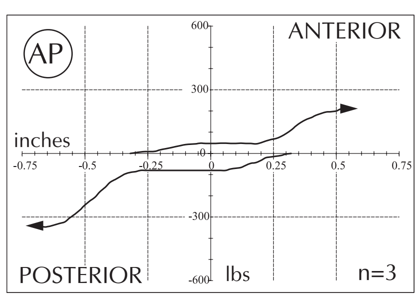
Genesis II

R ML AP





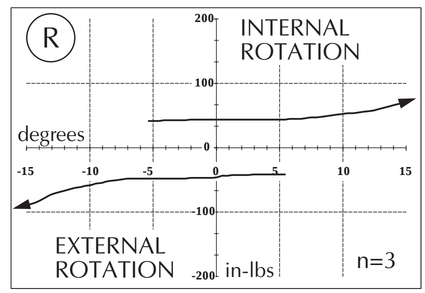
A-P Constraint



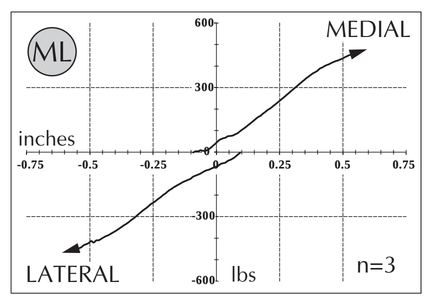
Interax I.S.A.

R ML AP

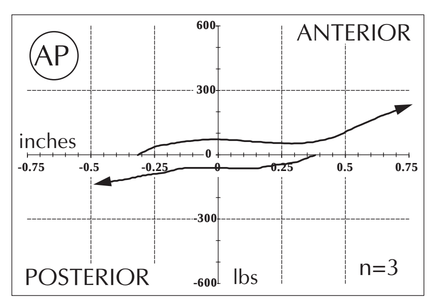
Rotational Constraint



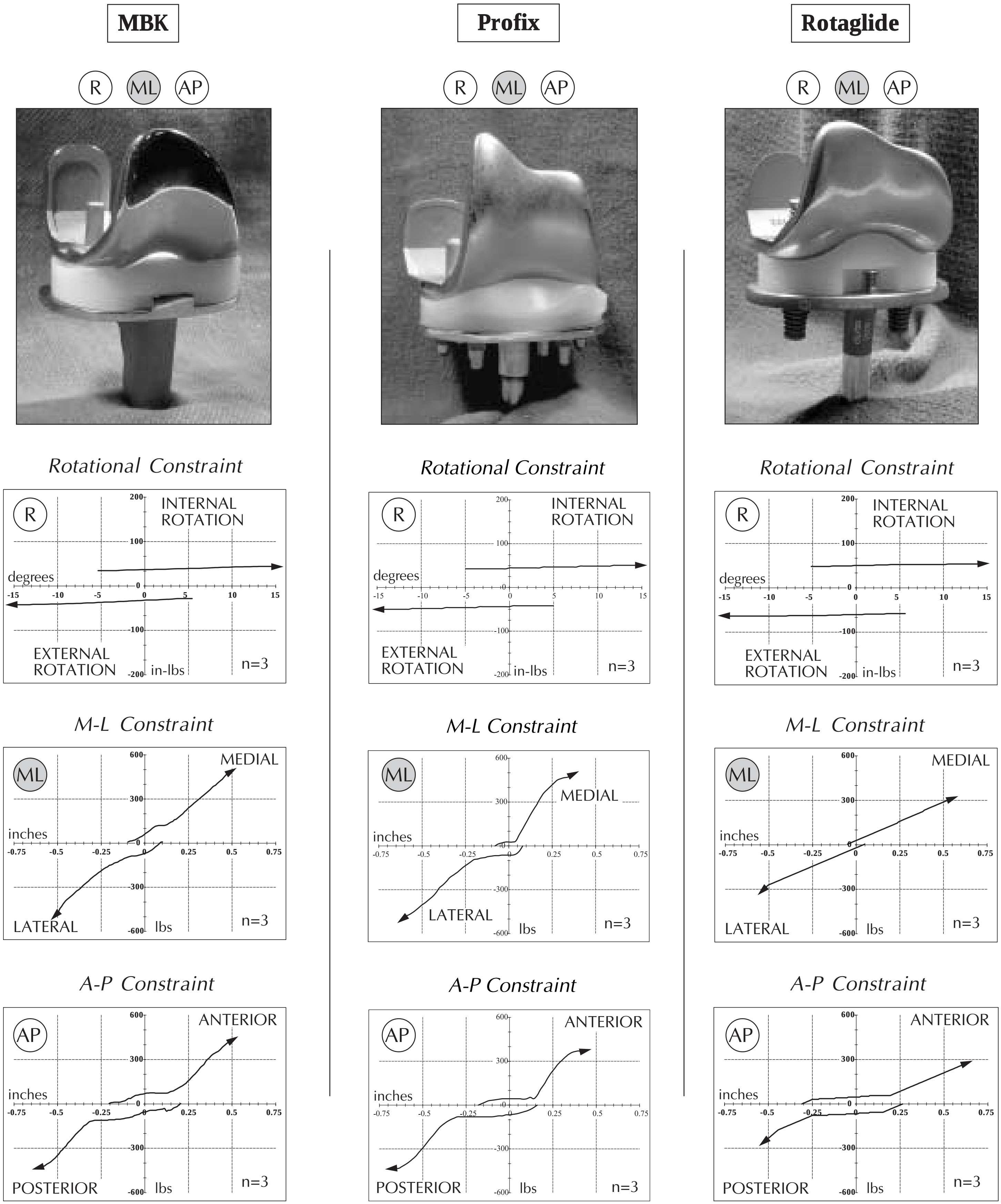
M-L Constraint



A-P Constraint



○ = Unconstrained ◐ = Semi-constrained ● = Constrained
R = Rotational ML = Medial / Lateral AP = Anterior / Posterior



= Unconstrained
= Semi-constrained
= Constrained

R = Rotational
ML = Medial / Lateral
AP = Anterior / Posterior

INTRINSIC CONSTRAINT

Stability is achieved in non-hinged, total knee replacements through geometric variation of the condylar surfaces. The intrinsic constraint of an implant system is defined as the capacity of the implant to limit rotational, anterior-posterior, and medial-lateral displacements to within normal ranges. In the absence of gross material deformation, intrinsic constraint due to geometric variation may be described in terms of the shear forces and torques which act orthogonal to the physiologic compressive contact loads between the femoral and tibial components.

RESULTS

The graphs presented for each design are the force-displacement plots measured in the anterior, posterior, medial and lateral directions. The rotation plots represent the amount of torque produced during angular displacement of the tibial component. The values reported are the average, constraint forces for each specific knee design, (n=3).

In general, the graphs provide a visual description of the mobility and constraint offered by each total knee design. All plots begin well before neutral and proceed in the direction of testing. For example, the testing of posterior constraint starts with joint contact significantly anterior of neutral and proceeds in the posterior direction.

The maintenance of a relatively low shear force over a defined displacement is indicative of low constraint motion such as sliding, with only friction providing resistance. This frictional resistance is characteristic of sliding between the tibial tray and insert as well as sliding between the tibial insert and the femoral component when the condylar geometry is flat. Conversely, rapidly increasing constraint is evidence that the femoral component has engaged a sloped region of the insert that is now immobilized by mechanical stops on the tibial tray.

DISCUSSION

One of the principle features of mobile bearing knee designs is to promote load sharing through displacements between the tibial and femoral components. Simply put, these designs allow the torques and shear forces of gait to be transferred via displacements to the soft tissues in a fashion similar to the normal knee. The potential advantages to load sharing are many. Load sharing reduces loosening stresses transferred to the implant-bone interface and promotes soft tissue strengthening. These tissues, unlike the inert prosthesis, have the capacity to respond and remodel to the challenges of expanding activities as the pain-free patient rehabilitates. Finally, load sharing may well reduce articular wear of these devices by reducing joint loads. In general, soft tissue involvement should be encouraged in order to decrease the dependency on intrinsic constraints afforded by condylar geometry.

The significance of this study lies in the analysis of the mobility offered by mobile bearing knee systems, and the extent to which a design can exploit the benefits of soft tissue load sharing while maintaining joint stability during gait.

In mobile bearing knee systems mobility can occur at either the femoral/insert articulation (as is found in fixed plateau designs) or the insert/tibial tray articulation and in many cases both articulations. From a holistic approach, where mobility occurs is irrelevant when addressing load sharing. Although it is important to issues concerning wear location and insert entrapment, these topics are outside the scope of the current study.

There are substantial differences in the degree of mobility offered by these designs. A unique classification system has been implemented to group the designs according to the clinical implication of their mobility in each of the directions tested. The six directions of mobility were reduced to three, 1) internal/external rotation (R), 2) medial/lateral displacement (ML) and 3) anterior/posterior displacement (AP). Directional constraint was grouped into one of three categories based on known physiologic constraints and displacements: a) unconstrained (○), b) semi-constrained (◉), and c) constrained (●). Unconstrained (○) designs are characterized by very low constraint over the entire range of normal displacements. Semi-constrained (◉) designs have near physiologic constraint that rises over the range of normal displacements. Constrained (●) designs are characterized by constraint that exceeds physiologic levels and rises sharply over the range of displacements. The values for these constraints and displacements will vary from patient to patient, however normals gleaned from the literature are included in the table below.

Test Direction	Physiologic Displacement	Physiologic Constraint
Int./Ext. Rotation	15 degrees[4]	100 in-lbs[4]
Medial / Lateral	0.25 inches	122 lbf[6] / -163 lbf[6]
Anterior / Posterior	0.50 inches[1]	163 lbf[6]/ -326 lbf[6]

By applying these criteria to the constraint versus displacement plots for each system three distinct groups emerge.

GROUP 1 R ML AP	GROUP 2 R ML AP	GROUP 3 R ML AP
LCS Deep Dish Rotating Platform	SAL	Genesis II
T.A.C.K	TRAC	Interax I.S.A.
		MBK
		Profix
		Rotaglide

Rotation in the transverse plane is a primary requirement of normal gait. All of the mobile bearing designs (Groups 1, 2 and 3) demonstrated unconstrained (R) mobility within a total of 15 degrees internal/external rotation. This appears to be the primary characteristic that defines mobile bearing designs, and a feature important in promoting longevity at the fixation interface. Designs exhibiting unconstrained rotational constraint demand soft tissue involvement, particularly balanced collateral ligaments, to achieve knee stability.

No design evaluated demonstrated unconstrained ML mobility. Group 3 presented with semi-constrained (ML), while Groups 1 and 2 had constrained ML (ML) mobility. Constrained and semi-constrained ML mobility is a characteristic that is common among all knee designs, fixed and mobile. This characteristic, although not promoting soft tissue load sharing, does not adversely affect clinical performance, and may be advantageous in situations of minor varus/valgus malalignment.

Major differences in the AP constraint between the groups were found. AP mobility was constrained (AP) in Group 1 and unconstrained (AP) in Groups 2 and 3. Groups 2 and 3 require competent soft tissue, balanced collaterals and/or the PCL, to insure joint stability. Although Group 1 designs do not require significant soft tissue for stability, the benefits of load sharing are not fully appreciated.

Mobile bearing knee designs offer the orthopaedic surgeon a unique option for restoring the patient to a normal, pain-free activity level. Because of the mobility they provide, slight positional malalignment of the components should not significantly affect the expected *in vivo* service life of the device as long as that malalignment corresponds with a region of mobility. In addition, this compliance to position, within the mobility displacement envelope, which is defined by the soft tissue structures and device interaction, should allow these designs to function in patients with minor aberrant gait patterns.

CONCLUSION

When analyzing mobile bearing total knee systems it is important to understand the actual mobility that is being offered by each design. All of the designs tested permitted uninhibited physiologic rotation of the tibial plateau, but the amount of displacement permitted in the anterior-posterior and medial-lateral directions was highly variable. Not all mobile bearing knee systems are the same and to achieve clinical longevity in total knee arthroplasty it is important to attain the correct balance between the intrinsic characteristics of the device and the patient's presenting pathology.

These ongoing laboratory evaluations assist an understanding of the anticipated performance of contemporary mobile bearing implant designs.[2,3] The results are intended to aid the surgeon in device selection when considering patient factors. Further, they provide the manufacturer with design criteria and assist regulatory agencies in determining the safety and efficacy of specific knee designs.

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