Hamelynck, Karel J., Amsterdam, NL and Stiehl, James, B., Milwaukee, USA (Eds.)

with a Foreword by Frederick .F Buechel and Michael J. Pappas:

LCS Mobile Bearing Knee Arthroplasty
- 25 Years of Worldwide Experience -

Chapter 14

Design Considerations of Existing Mobile Bearing TKA

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Introduction:

The emergence of the mobile bearing articulating polyethylene surfaces in total knee arthroplasty reflects the effort of designers to optimize wear while dealing with complex function. Invivo dynamic video fluoroscopy has provided extensive knowledge of the precise mechanisms of articulation in total knee arthroplasty.[1,2,3,4,6,7,8,9,11] The convergence of kinematic data with the analysis of prosthetic retrievals from failed total knees has given a clear understanding of the functional requirements for improved mobile bearing total knee devices.[4] Design issues include femoral condyle geometry, single versus polycentric radius of curvature, devices that restrict certain bearing motions and disarticulation such as stops or pegs, a medial versus more central longitudinal axis of rotation on the proximal tibia, surgical technique, implant stability, contact area, and patellofemoral design. The question of posterior cruciate retention, sacrifice, or stabilization in regards to mobile bearing designs remains an unresolved variable. Current mobile bearing designs will be reviewed with available technical information.

Mobile Bearing Design Considerations:

With over twenty five years of continuous successful use with an unmodified design, the Low Contact Stress (LCS) Mobile bearing knee system has become the gold standard by which all future designs are to be compared. This design had an anatomical femoral component that allowed virtually complete area contact in extension up to 30º of flexion and decreasing radii of the posterior femoral condyles to optimize the ability for flexion. The geometries of the tibia and patella were matched to articulate with a common area on the anterior distal femur. The femoral intercondylar groove was deepened to match the normal anatomical position. Finally, tibial trays and polyethylene inserts were developed that allowed bicruciate retention, posterior cruciate retention, or cruciate sacrifice. A more recent modification was the AP-Glide rotating platform device designed for use with a rotating platform shaped insert, such that posterior cruciate retention was possible. The tibial insert is allowed to rotate and translate based on the use of a contral arm that has a cone that fits into the original tibial tray.

At least fifteen different mobile bearing devices have been developed in recent years following the clinical success of the LCS Knee. With limited and unproven track record in the majority, it is unknown if they will perform satisfactorily to the level of the LCS or other fixed bearing designs with over 20 years follow-up. Therefore, analysis of general design features and surgical technique may offer important insight to the potential for long term performance and function.

Single Versus Polycentric Radii of Curvature of the Femoral Component

With the idea of maximizing area of contact throughout the range of motion, engineers chose a single radius of curvature in certain designs. This was considered reasonable as the posterior condyle seems to define a fairly circular sagital shape and the implant would mimic this shape. The disadvantage however is that the total radius must be significantly smaller than that of the normal distal femoral surface which may reduce area contact and cause a degree of instability in extension. High conformity in flexion may be desirable for contact area but leads to an inflexible articulation that must follow the kinematics of femoral tibial contact. Dennis has shown that some posterior cruciate retaining total knees that are tight in flexion cause the femoral tibial contact to remain far posterior on the proximal tibia.[12] A lesser constrained polycentric curvature has greater accommodation for this motion while the single radius design may "slide off the back" as was shown by the original Oxford meniscal bearing design. A second related issue is "jumping distance" for disarticulation that must be lower for the single radius design. For the diminished polycentric radius, the condyle must "go up the hill" and travel further to disarticulate.[15]

Recently, a fixed bearing knee prosthesis was developed with a medial pivot joint that has a near fixed radius of the medial femoral condyle to minic the relatively fixed articulation of the normal medial condyle. The object of the medial pivot is to replicate the longitudinal axis of rotation of the normal knee that Freeman has shown to be medial to the center of the proximal tibia.[14] The down side of the equation is the potential for abnormal kinematics of medial condylar sliding associated with anterior cruciate deficiency that may overload the medial pivot joint.

Similiarly, certain designs have changed the center of rotation from a central position such as the LCS rotating platform to a more anterior position to accommodate the insert post into the tibial base stem that has been located more anteriorly. This creates an eccentric position for the rotation of the tibial insert offsetting the insert position for a given amount of tibial rotation. Certain abnormal kinematics which have been shown to occur, such as tibial external rotation would place the tibial insert more medial than normal, which if compounded with the normal proximal lateral translation of the femoral condyle could result in exaggerated contact on a medial tibial eminence or post.

Stops, Articulations, Mechanical Restraints

Mobile bearing tibial inserts require certain degrees of freedom that are absent with fixed bearing devices. The original Oxford and LCS clinical experience demonstrated the problem of bearing dislocation and “spinout” associated with poor surgical technique. These problems can be diminished with capture pegs**,** sliding control arms (LCS AP Glide is more unconstrained than the meniscal bearing LCS) and capture rims. The downside is contraint and associated polyethylene wear that could be expected with certain “pin on slot” designs. Also, designs that will articulate with normal motion (such as a post cam) can be expected to wear over time. Abnormal kinematics from poor surgical technique or unaccommodated normal kinematics will likely cause exaggerated wear. An example of the later is the TRAC II total knee that is highly conforming in the coronal plane. With coronal medial-lateral translation known to occur in the normal knee, this implant will wear much like a constrained condylar revision device.

Surgical Technique

The options are bicruciate retention, posterior cruciate retention, posterior cruciate sacrifice, and posterior cruciate substitution or stabilization. Experience with the Oxford unicondylar meniscal bearing device has shown that bicruciate retention is essential for success of this implant. The LCS experience has shown that posterior cruciate retention with the meniscal bearing is possible but must be implemented very carefully because of the risk of flexion instability. Too tight or too loose in flexion will lead to implant dislocation. The primary disadvantage of the “distal femoral cut first” method is the inability to accurately adjust the flexion space on final trialing. The LCS technique has evolved into a “tibial cut first”, spacer block technique as pioneered by Insall. This has been an important element to the long clinical success of that implant. Posterior cruciate sacrifice with the tibial cut first technique has proven to be easy for most surgeons, reproducible, and clinically durable over the long term for the LCS.

Posterior cruciate stabilization is a common feature of the majority of new rotating platform designs. The primary advantage is the ability to enforce a degree of posterior femoral rollback that will improve flexion. In addition, an element of stability is added from the jumping distance of the post/cam mechanism that ranges from 1.1 to 1.4 cm. There are however known liabilities of the post/cam mechanism that include decreased patellofemoral articulation of the area of the box and the potential for soft tissue impingement or clunk in the box. Recent retrievals of posterior stabilized inserts have demonstrated a significant wear potential, which interestingly may involve the medial and lateral post surfaces as well as the posterior surface where spine wear would logically be seen.[10]

Patellofemoral Articulation

The patellofemoral articulation has been problematic for posterior stabilized designs with a high incidence of patella fracture, subluxation, or implant loosening. Possible causes with some of these older designs include an inherent “boxy” shape of femoral components that do not anatomically restore the patellofemoral groove. The loading forces of the patellofemoral joint are poorly understood, hence question arises regarding the future performance of new posterior stabilized designs in this regard. For the LCS design, patellofemoral problems are rare in most series despite a relatively thick, mobile, metal backed patella. This could relate to the anatomical positioning of the femoral prosthetic intercondylar sulcus that relies on the unique shape of the LCS design and the 15º distal cut required for implantation.

Other issues that affect patella performance include the surgical technique and abnormal functions that may arise from abnormal kinematics. Clearly, femoral components placed in exaggerated internal rotation and tibial components with internal rotation in relation to the tibial tubercle will cause the need for lateral release, and may exaggerate problems of patellar subluxation and implant failure. Kinematic studies have shown exaggerated abnormal tibial external rotation, which when combined with abnormal lateral condylar liftoff, must strain the extensor mechanism and place a lateral thrust on the patella.

Implant Stability

Implant stability may become an issue for certain designs if there is not high conformity especially in the frontal plane. This has been a problem with early designs such as the Minn prosthesis. As noted from kinematic studies, the potential for abnormal motions is significant in total knee arthroplasty. Surgical technique is an important factor in this regard, as the design must be able to accommodate difficult problems in the hands of lesser experienced surgeons. With the LCS, and other mobile bearing implants, careful attention to flexion-extension gap spacing and ligamentous balancing are essential to eliminate this problem. Measured bone resections, typical of current fixed bearing designs have the inherent weakness of error in certain cases that fall out of the normal range of anatomy. This will likely compromise the success of surgical technique in certain cases.

Contact Stress

Wear can be related directly to the contact stress of two articulating bodies and from the engineering literature had a direct relationship to the differences of the principle radii of curvature. This obviously relates as well to the area of contact, such that two articulating surfaces with similar conforming radii with high area of contact will have lower contact surface stress than those of dissimiliar radii and much lower area contact. An interesting contradiction however is that the applied load relates only to the cube root of the material stiffness and area of contact such that increases in load or body weight in total knees does not dramatically increase the contact stress. Reducing contact stress then is the other principle benefit of a mobile bearing articulation by dramatically increasing the area of contact. In regards to current mobile bearing designs, the LCS which has very high conformity in full extension has a contact area of 902 mm^2 for the rotating platform while the MBK with a single radius of curvature has 530 mm^2 of contact area. The latter reduction is both a function of design and the fact that a single radius of curvature in total knees must be diminished with smaller contact area compared to polycentric radii. Early wear simulator studies have shown that the LCS has diminished polyethylene wear compared to typical fixed bearing designs by a factor of three. Recent wear simulation studies have shown that the wear of fixed bearings with complex out of plane motion such as sliding translation and liftoff may be four to five times that of simple linear articulation. It remains to be seen if newer mobile bearing designs with much lower contact area and conformity compared to the LCS will have the favorable long term outcome in terms of wear reduction. A comparative table and representative photos of currently available mobile bearing prostheses is shown. Table 1

CONCLUSION

Recent advances in the understanding of kinematics and materials properties have increased the interest in mobile bearing articulations in total knee arthroplasty. The gold standard of these implants is the Low Contact Stress mobile bearing design. Factors that may have a significant impact on the performance of newer designs, include choice of single versus multiple radius of curvature femoral component, presence of articulating stops and pegs, surgical technique, the patellofemoral articulation, implant stability, and the ability of the design to optimize contact stress and functional kinematics.

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LEGEND

1. LCS Rotating Platform “spinout” or dislocation after flexion instability after total knee replacement in valgus deformity.(Image 12,tif)

2. Kinematic comparison of femoral tibial contact of the LCS meniscal bearing (posterior cruciate retaining) versus the rotating platform (posterior cruciate sacrifice) using a second generation video fluoroscopy that decribes lateral condyle motion with deep knee bend.(Image 21,tif)

3. Diagram of LCS Rotating Platform shows potential for both condylar liftoff and medial lateral translation while maintaining high conformity in extension.(Image 33,tif)

4. LCS System of Implants including bicruciate, cruciate sacrificing, cruciate retaining, and unicondylar arthroplasty.(Image 29, tif)

5. LCS AP Glide prosthesis showing the control arm used with the rotating platform insert to allow for posterior cruciate retention.

6. Posterior cruciate retaining fixed bearing TKA showing posterior femoral tibial contact in deep flexion. (Image 54, tif)

7. Multiple radii of curvature allow for deep flexion and increase “jumping distance” in deep flexion.

8. Single radius of curvature increases contact area throughout range of motion at the expense of total area in extension and a lower jumping distance with greater instability in deep flexion.

9. A.)“Pin on slot” designs are potentially a high stress area for increased polyethylene wear especially if the articulation is a normal motion restraint; B.) Interax mobile bearing demonstrates pin on slot mechanism

10. TRAC mobile knee demonstrates tight condylar constraints which prevent functional frontal plane translation. A.) Femoral Component; B.) Tibial Component