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

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

Chapter: **17**

Title: **The AP-Glide Knee Prosthesis – Rationales, Kinematics and Results**

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INTRODUCTION

The Low Contact Stress (L.C.S.) knee prosthesis, (Depuy, Warsaw, IN) was originally designed wiith a tibial component that allowed for posterior cruciate retention (meniscal bearing) or sacrifice (rotating platform).[1] The femoral component was designed with polycentric radii of curvature which approximated the condylar shape of the normal distal femur. Clinical reports have demonstrated comparable midterm clinical results with either posterior cruciate retention or sacrifice using this implant and osteolysis has been a rare event.[2,8,11,20] With longer follow-up beyond ten years, investigators found increasing rates of fracture, wear and dislocation of the original meniscal bearings as compared to the rotating platform tibial insert.[3] The rotating platform was originally developed for more difficult cases and early clinical results with this implant may have been biased from that factor.[1] However, the implant gained increasing popularity as long term results have been shown to be durable even in younger patients, and the surgical technique is generally simpler with less technical challenge.[13]

The LCS anterior posterior (AP) glide tibial insert was a later modification of the rotating platform which incorporated a control arm mechanism to articulate with the cone shaped insert tibial stem.(Fig.1)

Figure 1

By allowing unconstrained sagital plane motion, this device could then be inserted with posterior cruciate retention, which continues to be a desirable technique for preservation of function while minimizing anatomical alterations such as joint line elevation. Clinical investigations with this implant have been favorable though few published reports exist at this time. This chapter will discuss our fluoroscopic kinematic and clincal experience with the AP Glide implant.

FLUOROSCOPIC KINEMATIC ANAYLSIS

Knee kinematics were assessed for ten subjects implanted with a Low Contact Stress anterior/posterior glide (LCS AP Glide) mobile bearing total knee arthroplasty (DePuy International, Leads, England). All total knee arthroplasties were judged clinically successful (Hospital for Special Surgery Rating Scores > 90), with no ligamentous laxity or pain. The operative procedures were performed by one surgeon (RJO) who utilized an identical technique previously described for this posterior cruciate retaining system. All surgeries were done using a posterior cruciate retaining technique with initial resection of the proximal tibia followed with ligament and soft tissue balancing in extension.

Each subject was asked to perform two activities: (1) weight-bearing deep knee bends to maximum flexion, and (2) a non weight-bearing bend to maximum flexion. During the weight-bearing deep knee bend, each subject placed the foot, of their leg to be studied, on a designated marker. The subjects were initially fluoroscoped at full extension and throughout the flexion cycle.(Figure 2a)

Figures 2a and 2b

While under non weight-bearing conditions, the leg to be analyzed was passively manipulated to maximum knee flexion (Figure 2b). Patients were examined using a Siemens Siremobil 2000 Digital Xray image intensifier system (Iselin, NJ). The fluoroscopic images were stored on videotape for subsequent redigitization using a frame grabber. Weight-bearing and non weight-bearing knee kinematics was analyzed for all ten subjects using the RMMRL model-fitting software package. Using a model fitting approach, the relative pose of knee implant components was determined in three dimensions from a single-perspective fluoroscopic image by manipulating a CAD model in three-dimensional space. Individual fluoroscopic frames at specified degrees of flexion were digitized. The images were projected onto the image plane, and the corresponding implant models added to the scene. The operator manipulated the models to create an accurate fit. The correct fit was achieved when the silhouettes of the femoral and tibial implant components perfectly matched the corresponding components in the fluoroscopic image (Figure 3).

Figure 3

The pose of each component was then recorded and each measurement of interest was extracted using a CAD-modeling program. The process was performed at the flexion angles of 0º, 30º, 60º, 90º and 120º to determine knee kinematics (A/P contact, axial rotation and condylar lift-off. The distances from the medial and lateral condyles to the tibia plateau were measured and the difference between these two measurements was used to determine condylar lift-off.

An error analysis was conducted using a fresh cadaver. Discrete points were defined on the femoral and tibial components. Using an Optotrack system, these points were digitized and the femur was defined relative to the tibia, in the tibial reference frame. Each orientation of the femur, relative to the tibia was fluoroscoped. Using the 3D model-fitting software package, the relative orientation of the femur with respect to the tibia was predicted and compared to the known orientation determined using the Optotrack system. The relative error, derived for 75 orientations was consistently less than 0.5 degrees in rotation and 0.5 mm in translation.[7]

ANTEROPOSTERIOR TRANSLATION

Under weight-bearing conditions, on average, the subjects experienced a posterior contact of the medial (Average = -2.7 mm, range = 2.0 mm to – 6.7 mm) and lateral (Average = - 6.3 mm, range = 0.2 mm to – 12.3 mm) condyles at full extension (Figure 4).

Figure 4

From full extension to 30^{o} of knee flexion, on average, both condyles moved in the posterior direction to a medial contact position of –5.5 mm (-1.5 to – 10.2) and lateral of –9.3 mm (-5.6 to –12.8). At 60^{o} of knee flexion, both condyles moved in the anterior direction to an average medial position of –4.1 mm (1.8 to –8.3) and lateral position of –7.9 mm (-4.2 to –10.2). At 90^{o} of knee flexion, on average, both condyles experienced minimal motion change with a medial condyle contact position of –4.5 (1.2 to – 19.3) and lateral position of –7.2 mm (-3.6 to –16.0). At 120^{o} of knee flexion, on average, both condyles experienced an anterior change in contact position to a final medial position of –1.1 mm (2.6 to –3.3) and lateral position of –4.0 mm (-0.3 to – 6.8). Nine of 10 subjects were able to achieve at least 120^{o} of knee flexion under weight-bearing conditions. Only four of the subjects experienced a posterior motion of their medial condyles from full extension to 120^{o} of knee flexion, while all subjects experienced an anterior motion of their lateral condyles.

Under non weight-bearing conditions, on average, subjects experienced a posterior contact of the medial (Average = -1.8 mm, range = 1.7 mm to – 4.1 mm) and lateral (Average = - 3.2 mm, range = 0.7 mm to – 7.3 mm) condyles at full extension (Figure 5).

Figure 5

From full extension to 30^{o} of knee flexion, on average, the medial contact position moved in the anterior direction to –1.2 mm (3.5 to – 4.1), while the lateral condyle contact position moved in the posterior direction to –3.4 mm (2.3 to –9.8). At 60^{o} of knee flexion, both condyles moved in the anterior direction. Both condyles experienced an anterior contact position, where the average medial contact position was 3.4 mm (14.9 to –3.2) and lateral contact position was 0.2 mm (6.9 to –5.1). At 90^{o} of knee flexion, on average, both condyles again experienced an anterior contact position. On average, the medial condyle contact position was 3.5 mm (15.7 to – 4.3) and lateral position was 0.5 mm (6.9 to –4.7). At 120^{o} of knee flexion, on average, both condyles experienced a posterior change in contact position to a final medial position of –0.3 mm (12.6 to –11.2) and lateral position of –3.0 mm (4.4 to –8.2). All of the subjects were able to achieve at least 120^{o} of knee flexion under non weight-bearing conditions. Five of the subjects experienced a posterior motion of their medial condyles from full extension to 120^{o} of knee flexion and six of the 10 subjects experienced posterior femoral rollback of their lateral condyles.

From full extension to 90^{o} of knee flexion, the average A/P contact position for the subjects in this study were significantly more anterior under non weight-bearing conditions compared to weight-bearing conditions (Figures 6 and 7).

Figures 6 and 7

At 120^{o} of knee flexion the average contact positions during weight-bearing and non weight-bearing conditions were similar. Using a Student-T test the A/P position data was statistically different for the lateral condyle at full extension ($p=0.02$), the medial ($p=0.009$) and lateral ($p=0.003$) at 30^{o} of knee flexion, the medial ($p=0.0002$) and lateral ($p=0.0001$) at 60^{o} of knee flexion, the medial ($p=0.001$) and lateral ($p=0.001$) condyles at 90^{o} of knee flexion. There was no statistical difference in the position data at 120^{o} of knee flexion. The average variance for the weight-bearing data was 14.07 compared to an average variance of 19.58 for the non weight-bearing data.

AXIAL TIBIALFEMORAL ROTATION

On average, the subjects experienced normal axial rotation during non weight-bearing knee flexion, but opposite axial rotation during a weight-bearing deep knee bend. During non weight-bearing knee flexion, the average axial rotation from full extension to 120^{o} of knee flexion was 1.8^{o} (-9.1 to 10.8) (Figure 8).

Figures 8 and 9

Under weight-bearing conditions, the average axial rotation was –2.0^{o} (-11.9 to 1.6) (Figure 9). Under non weight-bearing conditions, seven of 10 subjects experienced a normal axial rotation pattern from full extension to 120^{o} of knee flexion, while under weight-bearing conditions, only four of nine subjects (one subject did not achieve 120^{o} of knee flexion) experienced a normal axial rotation pattern. Under non weight-bearing conditions, on average, subjects experienced a normal axial rotation pattern from full extension to 30^{o} of knee flexion (1.1^{o}), from 30 to 60^{o} of knee flexion (1.4^{o}) and from 90 to 120^{o} of knee flexion (1.0^{o}). From 60 to 90^{o} of knee flexion, on average, these subjects experienced –0.4^{o} of opposite axial rotation while performing non weight-bearing knee flexion. Under weight-bearing conditions, on average, subjects experienced a normal axial rotation pattern from full extension to 30^{o} of knee flexion (0.3^o). From 30 to 60^o of knee flexion, on average, subjects experienced no axial rotation. From 60 to 90^o of knee flexion subjects experienced an average opposite axial rotation pattern of - 1.4^o and from 60 to 90^o of knee flexion, on average opposite axial rotation pattern of -2.6^o.

Using a Student-T test, the axial rotation was statistically different for weight-bearing vs. non weight-bearing conditions at full extension (p=0.03), but was not statistically different at the other flexion angles (p=0.31 at 30^o, p=0.58 at 60^o, p=0.74 at 90^o, and p=0.69 at 120^o)

Condylar Lift-off

Nine of 10 subjects experienced condylar lift-off during weight-bearing and non weight-bearing conditions. Under non weight-bearing conditions, the maximum amount of condylar lift-off was 2.5 mm, which was lateral condyle lift-off occurring at 60^o of knee flexion. Under weight-bearing conditions, the maximum amount of condylar lift-off was 3.3 mm, which again was lateral condyle lift-off, occurring at 30^o of knee flexion. Under non weight-bearing conditions four subjects experienced greater than 1.0 mm of condylar lift-off just after full extension, 3/10 at 30^o of knee flexion, 3/10 at 60^o of knee flexion, 2/10 at 90^o of knee flexion and 5/10 at 120^o of knee flexion. Under weight-bearing conditions only one subject experienced greater than 1.0 mm of condylar lift-off just after full extension, 4/10 at 30^o of knee flexion, no subjects at 60^o of knee flexion, only 1/10 at 90^o of knee flexion and only 1/10 at 120^o of knee flexion. Therefore, although one subject experienced more than 3.0 mm of condylar lift-off during weight-bearing conditions, the incidence and magnitude of condylar lift-off was greater during non weight-bearing conditions.

Range-of-Motion

The average non weight-bearing range-of-motion was 129.3^o (120 – 138). The average weight-bearing range-of-motion was 118.8^o (84 – 135). If the one subject who only achieved 84^o of weight-bearing range-of-motion was removed, the average weight-bearing range-of-motion increased to 122.7^o.

<u>CLINICAL EXPERIENCE</u>

Since August 1997, 426 hydroxapatite (HA) impregnated AP glide tibial components were implanted by the one surgeon (RDO). The tibial implant was substantially different from the previous LCS tibial component involving a change to the area of porocoating and adding hydroxapatite. The first change was occasioned by attempting to increase the ease of revisability and involved reducing the metaphyseal cone to a smooth surface except for the proximal 2mm (allowing for a seal with the bone to prevent a 'sump pump' effect of polyethylene wear particles). The second change involved the addition of the HA to improve the bone/implant interface bonding.

Figure 10

This is of necessity a very preliminary report of the first 368 components with a follow up minimum of 6 months and maximum of 4 years. The average age was 65.8 (30-96 years) with 167 females and 201 males. Osteoarthritis was the primary diagnosis in 89% , rheumatoid arthritis in 3%, post-traumatic in 1%, and other in 7%. The pre-operative hospital for special surgery knee score (47.6) and American Knee Society clinical rating score (including the total knee score (24) and total function score (45.3) are also comparable to most published series. The ultimate post-operative scores are very reflective of co-morbidities amongst the patient population (HSS – 92.1 AKSR TK score 94.6 TFS 91.7). The outstanding feature however is the range of motion, which improved from a mean of 103.1º to 124.6º.

The majority of knees (91%) as expected were varus in alignment and required release of the medial capsule from the tibia with very occasional release of the posteromedial capsule. Additional bone resection of the femur for flexion contraction was required in 36% of knees due to the severity of the deformity. Lateral retinacular division occurred in less than 1% of cases (2 knees) and there were no patella replacements. The fat pad was significantly resected in all knees and patella osteophyte resection was mandatory with particular attention being given to the inferior pole to prevent impingement problems. The latter has been resolved with a change to the anterior prominence of the tibial polyethylene insert and the requirement for significant resection of the fat pad has also been almost eliminated. Interestingly the anterior cruciate ligament was absent in 8.2% of knees but there were no cases where the posterior cruciate was not present as this is an absolute contradictation to the procedure. No components were cemented (excluded from the series) and minor bone grafting occurred in 7% of cases.

There have been 4 *limited* revisions in the series; none of these have involved the removal of the metal components but only changes in the tibial polyethylene. 2 occurred within the same patient who had had bilateral simultaneous TKR's and who complained of a painful posterolateral click in the knee with active extension (not reproducible under general anesthesia). Arthroscopic evaluation and popliteus release failed to give relief and conversion to a rotating platform bilaterally totally eliminated the problem. A third patient required revision following a fall down stairs, on to a flexed knee, which resulted in a rupture of the posterior cruciate ligament. Subsequently she developed chronic synovitis and anterior knee pain when negotiating stairs and with other bent knee activities. Complete resolution of symptoms occurred with exchange of the polyethylene to a rotating platform variety. The fourth revision occurred with a patient who complained of anterior knee pain also, but in whom clinical evaluation and later operative inspection revealed an intact posterior cruciate ligament. Pre-operatively she had complained of significant anterior knee pain also and a bone scan (Tc 99) subsequently revealed increased activity levels in the patella. Some reduction in her pain occurred with change of the implant to a rotating platform in combination with a patella replacement.

In the first 30 patients there was a significant incidence (60%) of synovitis and recurrent effusion, which resolved after the first year without intervention in all but 2 patients. These patients both had arthroscopic fat pad resections, when it was realized that anterior impingement was the cause of their symptoms. Following these cases routine resection of the fat pad was undertaken as part of the primary procedure eliminating the problem. Further changes to the polyethylene have subsequently been implemented obliterating the necessity for such radical fat pad resection.

Radiologically, the tibial implant has done very well within the confines of this very preliminary report. There are no instances of complete lucencies (>1.5mm) under the plate in any zone on AP or lat fluoroscopic guided views. The metaphyseal cone is also devoid of lucencies suggesting that bone ingrowth on the compression surface has been excellent. There have been 6 cases of peripheral bone resorption at the limits of the most lateral and medial edges seen on the AP radiograph only which may have its origin in the process of HA as all cases were early in the series and the process has now been very much refined and assured. Despite the successful appraisal of the AP glide the tibial tray has been improved further with the introduction of 4 peripherally based pegs. This follows extensive stability testing conducted by Dr William Walsh of the Prince of Wales Hospital, Sydney, Australia, which convincingly shows that the Duofix tray, which has been developed from this tray, will be superior again.

DISCUSSION

Posterior cruciate retention as a surgical technique in total knee arthroplasty has been advocated to improve clinical function, optimize transmission of forces across interfaces, and limit anatomical distortion such as joint line elevation. However, recent concern has grown regarding articular surface wear of certain “flat on flat” posterior cruciate retaining total knee arthroplasties.[16] Line contact in these designs can cause high contact stress known to aggravate articular surface wear particularly if increased sliding distances occur with function. Kinematic studies of femoral tibial contact using video fluoroscopy and roentgen photogrammetry have demonstrated significant aberrations from the normal condition.[4,5,15,17] Stiehl, et.al. defined abnormal lateral condyle motion in posterior cruciate retaining total knee arthroplasties with femoral tibial sagital plane contact found to be posterior in extension followed by abnormal anterior translation with flexion on deep knee bend.[19]

Stiehl, et.al. evaluated the LCS meniscal bearing posterior cruciate retaining prosthesis finding posterior contact in extension compared to normal, but some degree of posterior femoral rollback up to 60º of flexion.[14] With deep knee bend, there was anterior translation of femoral tibial contacts from 60º to 90º of flexion. The early femoral rollback seen with the meniscal bearing prosthesis was attributed to the high articular conformity noted from 0º to 40º flexion. Nilsson, et.al. using RSA with 15 newton joint loads found a similar result with a posterior contact in extension followed by gradual anterior translation with flexion to 50º.[12]

The LCS AP-glide prosthesis demonstrated a posterior position of both condyles at full extension followed by mild posterior translation or femoral rollback to 30º flexion followed by anterior translation up to 120º flexion. This anterior position and translation was significantly greater from 0º to 90º flexion in non weight-bearing knees. We may hypothesize that this difference reflects the posterior tibial shear force exerted with active weight-bearing. With a flexion position of 120º, the femoral tibial contact points were similar under weight-bearing and non weight-bearing conditions.

Stiehl, et.al. have found significant condylar liftoff and screw home rotation with the LCS posterior cruciate sacrificing rotating platform total knee arthroplasty.[18] They found a maximal medial condyle liftoff of 2.1 mm whereas the greatest lateral liftoff was 3.5 mm. Screw home rotation was variable ranging from 9.6º of tibial internal rotation with knee flexion to 6.2º of external rotation. Nilsson, et.al. investigated the LCS meniscal bearing total knee prosthesis finding that initial extension started with a more externally rotated tibia than normal and had minimal internal rotation during flexion.[12] As previously suggested by Jonsson, et.al. and Karrholm, et.al. this may represent an alteration demonstrated by anterior cruciate deficient total knees.[9,10]

In the current study, the greatest amount of condylar liftoff occurred with the lateral condyle at 30º flexion, and 9 out of 10 patients experienced condylar lift-off. For screw home rotation, a similar variability was noted as compared to the prior LCS rotating platform study. Under non-weight bearing conditions, the total knees analyzed in this study had a range of 10.8º of internal tibial rotation to 9.1º of external tibial rotation, with increasing flexion. Under weight bearing conditions, only four of nine subjects experience normal axial rotation with one knee having external tibial rotation of 11.9º. The important findings of altered rotation and condylar liftoff relate to the need for contemporary total knee designs to accommodate these kinematic functions. The LCS AP-glide prosthesis is rotationally uncontrained and allows for condylar liftoff in the frontal plane without sacrificing conformity or developing edge loading.

Dennis, et.al. have previously evaluated non-weight bearing versus weight bearing range of motion with posterior cruciate and posterior stabilized fixed bearing TKA.[6] The average weight bearing flexion in that study was 103º for the posterior cruciate retaining fixed bearing TKA and 113º for the posterior stabilized fixed bearing TKA. The present study demonstrated substantially greater flexion compared to a fixed bearing PCR TKA with an average non-weight bearing flexion of 130º and weight bearing of 119º. We attribute this finding to at least two potential factors. The surgical technique was optimized by a highly experienced surgeon with subtle balancing of each knee. This may be confirmed by the fact that none of our knees were tight in flexion with persistent posterior femoral tibial contact and all demonstrated laxity to allow anterior translation. Secondly, patient selection for the kinematic study was optimized where patients with severe deformity and decreased postoperative motion were not considered. From our prior studies, it is likely that greater range of motion may be expected with a well-done posterior cruciate retaining technique compared with the cruciate sacrificing rotation platform prosthesis.

The final issue of the kinematic analysis is the potential safety of the AP-glide prosthesis compared with earlier devices. Anterior soft tissue impingement has been noted anecdotally by European surgeons who have used this implant, which has lead to the recommendation of fat pad excision. Our experience with this problem was significant early on and as noted above, an alteration of the tibial insert was needed to help resolve this issue. The AP-glide prosthesis is totally unconstrained in the sagital plane and the kinematic study has shown the potential for anterior translation in the non-weight bearing condition. Flexion space balancing must be accurate and not too tight to allow adequate flexion, but if too loose may allow for abnormal anterior translation and potential fat-pad impinement. Another problem has been potential instability that may result from posterior cruciate disruption. Surgeons have preserved a bone block at the insertion of the posterior cruciate ligament to prevent late ligament failure. From the current study, such an abnormally increased flexion gap could lead to abnormal anterior-posterior motion and clinical symptoms requiring revision.

In conclusion, we have investigated the kinematics of a posterior cruciate retaining mobile bearing total prosthesis finding typical abnormal anterior-posterior translation, condylar liftoff and screw home rotation compared with other reports. Range of motion and potential instability were greater under non-weight bearing conditions, clearly demonstrating the difference that load bearing adds to these functions. As this prosthesis is unconstrained with sagital plane translation or rotation and relies primarily on ligamentous balancing for proper articulation, surgical technique with appropriate extension and flexion spacing must be done. We have shown that goal to be achievable with this prosthesis.

The AP glide prosthesis clinically and radiologically has proven to be as successful as its design rationale suggested. The marriage of the concepts associated with the benefits of the meniscal bearing design and the rotating platform have produced a stable kinematically correct TKR with appropriate roll back in flexion, a medial pivot and an superior range of motion. It demands however, an appreciation and embracing of the ‘soft tissue balance – first’ philosophy and is not the universal panacea for all arthritic knees.

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LEGEND

Figure 1. AP Glide Prosthesis showing control arm and metal track for the tibial insert. a.)Diagram of AP Glide Prosthesis; b.) Control Arm; c.) Position of control arm within the polyethylene tibial insert; d.) Unconstrained anterior/posterior motion; e.) Unconstrained rotational motion.

Figure 2. Subject performing a weight-bearing deep knee bend (a) and a non weight-bearing knee flexion (b). See Slide 1 (Figure 1)

Figure 3. Example of a fluoroscopic image and a 3D overlay . See Slide 2 (Figure 2)

Figure 4. Average medial and lateral condyle anterior-posterior contact while performing a weight-bearing deep knee bend. See Slide 2 (Figure 3)

Figure 5. Average medial and lateral condyle anterior-posterior contact while performing a non weight-bearing knee flexion. See Slide 2 (Figure 4)

Figure 6. Example of a subject under weight-bearing conditions displaying a posterior contact position. Shown is the fluoroscopic image , the 3D overlay , sagittal view . See Slide 2(Figure 5)

Figure 7 Example of a subject under non weight-bearing conditions displaying an anterior contact position. Shown is the fluoroscopic image (a), the 3D overlay (b), sagittal view (c). See Slide 6 (Figure 6)

Figure 8. Average axial rotation for the subjects during the non weight-bearing flexion activity. See Slide 6(Figure 7)

Figure 9. Average axial rotation for the subjects during the weight-bearing flexion activity. See Slide 6 (Figure 8)

Figure 10. Modifications of LCS tibial base plate cone with removal of porocoat from the and the addition of hydroxyappatite to the base plate. This slide must come from Depuy Australia!