KINEMATICS OF THE LCS MOBILE BEARING TOTAL KNEE ARTHROPLASTY

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Introduction:

The determination of three-dimensional femoral-tibial kinematics dramatically improved with the introduction of in vivo weight bearing fluoroscopic studies. It is now believed that these techniques are highly accurate and reproducible as compared to earlier non-fluoroscopic methods. From literature review, those older techniques included in vitro cadaver studies, invivo nonweightbearing radiographic studies, gait analysis, goniometric studies, and photogrammetry (RSA). Invitro cadaver studies measured the passive effects of the primary and secondary ligament constraints but were unable to add the physiologic muscle forces or the dynamic loading of actual human weight bearing. The disadvantage of gait studies and goniometric fixtures was the significant error introduced by nonstationary soft tissues which has been shown to be substantial. Roentgenographic stereophotogrammetry (RSA) can be stated as highly precise with accuracy of 0.03 mm but the method must be considered nonweightbearing as subjects are not able to walk, stair climb, deep knee bend, etc.

Without exception, all published invitro cadaveric studies have suggested that posterior cruciate retaining TKA specimens have the possibility of posterior femorotibial rollback as described by the normal knee. Schlepckow, et.al. measured the ligamentous versus prosthetic constraint of three different implant designs to compare unconstrained (LCS), semiconstrained (TriconM), and constrained (Mark II). Though posterior rollback and rotation of the total knees was stated, a concern about implant stability was noted with increasing flexion.[1] Menchetti and Walker utilized the radiographic cadaver technique described by Kurosawa to analyze a mobile bearing TKA (MBK). Posterior rollback from -1.4 to –7 mm (net 4.6mm) was seen from 0º to 120º flexion. Also increased lateral condyle translation accounted for tibial internal rotation.[2,3]

Garg and Walker used a computer generated model based on 23 anatomical specimens to assess flexion and rollback. They concluded that rollback was possible if the PCL was maintained and the posterior slope of the tibia matched that of the normal patient.[5] Using similar methods, Soudry, et.al. concluded that rollback was present in posterior cruciate retaining designs and was not influenced by weight bearing loads. Their study did not however examine weight-bearing loads.[4]

El Nahass,et.al. used a electrogoniometric fixture to assess anterior-posterior translation and internal-external rotation of the tibia in weight bearing gait and stair climbing. For total knees, there was 5º-10º of internal rotation and 9-14 mm of posterior femoral rollback from 0ºto 90º.[6] Andriacchi, et.al. reported recently that total knees had anterior-posterior translation of 2.9 cm with normal knees moving 1.9 cm. The method used was a point cluster system that possibly suffers error due to soft tissue translation.[7]

Nilsson used RSA to evaluate total knee kinematics placing tantulum markers in the bone about implants and obtaining perpendicular radiographs of the knees. Spatial calculations of the markers were used to determine femorotibial movements. This method was done nonweightbearing in the prone position with simple loads applied.[8] Nilsson studied a fixed (MG I) and mobile bearing (LCS) posterior cruciate retaining design and a posterior cruciate sacrificing design finding an increased posterior position in extension though there appeared to be significant posterior translation or rollback with increasing flexion. Prosthetic knees showed 3º to 4º of internal rotation with flexion while normal knees averaged 6.5º of internal rotation.[9] Lateral radiographs of these subjects confirmed the relatively posterior femorotibial contact position. Kim, et.al. performed a similar nonweightbearing study utilizing lateral radiographs at 0º and 90º flexion finding essentially no change in anterior/posterior position and concluded that there was no rollback.[10]

First Generation Invivo Video Fluroscopy

The idea of fluoroscoping a subject following total knee arthroplasty began with Banks and Hodge in 1991. They studied four LCS meniscal bearing implants and found a paradoxical anterior translation of femorotibial contact with flexion.[11] Stiehl, et.al. modified this technique slightly using a two dimensional computer vector analysis to study anterior/posterior translation of the lateral condyle in posterior cruciate retaining total knee arthroplasty.(Figure 1)

Figure 1

The lateral condyle was chosen from the belief that the greatest motion would be seen on the lateral side. That study found that the lateral condyle started on average about 10 mm posterior to the midsagital plane of the tibia in extension and translated anteriorly 15 mm to a point 5 mm anterior to the midsagital tibia. It was noted that the pattern of motion in total knees was highly variable and was irreproducible showing jerky discontinuous motion. In addition, the first evidence of lateral condylar liftoff using invivo fluoroscopy was demonstrated(Figure 2)[12]

Figure 2

It was postulated that in the normal knee, the ACL was maximally loaded in extension with a highly active quadriceps while the PCL was minimally loaded. The quadriceps without the restraint of the ACL tended to pull the femur posteriorly during full extension, hence the posterior femorotibial contact position. On weight bearing, the normally posteriorly directed shear force on the proximal tibia caused the prosthetic femur to translate anteriorly. An interesting feature of that early study was that five different posterior cruciate retaining "flat on flat" condylar total knee designs were evaluated from nine community surgeons. Despite the diversity of results, the patterns of motion were uniform reflecting the lack of the ACL and the pull of the quadriceps. This study suffered early criticism as it was felt that the surgeons were not skilled in correctly balancing the posterior cruciate ligament. Also, the analysis which was done only with a deep knee bend, was not felt to be a realisitic measure of normal gait, the most common ambulatory activity. We were drawn, however to the clear cut results, and the implication of not having reproducible posterior femoral rollback with these "flat on flat" condylar implants.

The LCS mobile bearing total knee was investigated with posterior cruciate retention(meniscal bearing) or sacrifice(rotating platform) again evaluating the sagittal plane kinematics of the lateral femorotibial joint.[19,20] The implant, which has very high conformity from 0º to 30º of flexion and diminished line contact with further flexion. The femoral implant has a total condylar shape with decreasing radii of curvature into deep flexion. The tibial implant has a highly conforming geometry to match the femoral side both in the coronal and sagital plane and a cone or runners to allow unrestrained rotational freedom. The only significant implant difference in this study was the surgical technique with reference to the posterior cruciate ligament. The posterior cruciate retaining LCS meniscal bearing implant demonstrated consistent femorotibial contact posterior to the midsagital tibial reference point. There was early posterior rollback up to 30º but anterior translation was noted at 60º and 90º of flexion. The posterior cruciate sacrificing LCS rotating platform design remained virtually midline on the proximal tibia throughout range of motion. There was however a minor trend for early rollback with anterior translation in deep flexion.(Figure 7)

Figure 7

Our interpretation of these studies was that the rotating platform knee demonstrated midline sagittal plane proximal tibia position throughout the deep knee bend and gait cycle which is optimal for congruency and weight bearing. The minor early posterior femoral rollback could be attributed to the high conformity of this design up to 30° of flexion, while the anterior translation seen from 60º to 90º related to the freedom due to the smaller radii of curvature of the posterior femoral condyles. The most desireable features were the midline position related to the design conformity and the lack of major anterior posterior translation over the proximal tibia which could be detrimental both for tibial base plate fixation and wear. The meniscal bearing LCS implant showed femoral tibial contact posterior to the midsagital plane of the tibia in virtually all positions. Again there was a fairly predictable posterior femoral rollback with early flexion up to 30º which could be attributed to the high conformity of the design in this position. After 60º flexion, there was anterior translation of the condyles that persisted with flexion up to 90º. Again this results from the decreased conformity of the design in higher degrees of flexion with the smaller radii of curvature of the posterior femoral condyles and from the freedom of excursion in the tracks.

Second Generation Invivo Video Fluoroscopy

Dennis, et.al. refined the computer vector analysis to utilize 3 dimensional computer assisted design models of the tibial and femoral components. A large library of 3 dimensional images (861) for the prosthesis then described spatial orientation through six degrees of freedom. The computer technician matched the appropriately oriented image to the two dimensional image, and then subtracted that image allowing computer analysis.[13] Though cumbersome and time consuming, it was then possible to evaluate three dimensional kineamtics of both femoral condyles from each video image.(Fig 4)

Figure 4

This was a major in technology jump with the ability to obain unlimited imaging information to fully understand the complex motions of implants through motion.

Dennis, et.al. evaluated and compared the kinematics of posterior cruciate retaining and posterior cruciate substituting total knee arthroplasties with normal knees and anterior cruciate deficient knee. Anterior cruciate deficient knees revealed a posterior femorotibial contact in extension followed by varying and erratic degrees of anterior translation from 30º to 90º of flexion.(Figure 3)

Figure 3

On average, this amounted to 0.5 mm but one case translated as far as 13.7 mm through flexion. According to Dennis, posterior cruciate retaining TKA started with an average position 5.1-mm posterior to the midsagital tibia in extension with anterior translation from 30º to 90º. One knee moved anteriorly 7 mm. Posterior cruciate stabilized total knees started at the midline and translated posteriorly on average 7.71 mm.

Appropriate conclusions from Dennis's study were that posterior cruciate retaining total knees suffered from anterior cruciate deficient kinematics and that weight bearing kinematics in total knees were substantially effected by both implant geometry and ligamentous constraints as determined by surgical technique. Thusly, tight posterior cruciate ligament tensioning caused the implant to remain posterior when the PCL is tight while laxity caused the femorotibial contact to translate anteriorly, occasionally in exaggerated fashion. Posterior cruciate stabilized total knees had femorotibial contact controlled by the geometry of the implant with a cam/post engagement causing posterior rollback with increasing flexion.

Dennis, et.al.evaluated invivo passive versus weight bearing range of motion in patients finding that all knees, including normal, posterior cruciate retaining TKA, and posterior cruciate substituting TKA had significantly less active weight bearing versus passive range of motion ($p<.02$). This could result from the increased constraint of combining ligament restraints with articular surface geometry, muscle contraction, and femorotibial kinematics. On invivo weight bearing, posterior cruciate retaining TKA had significantly less motion that posterior cruciate substituting TKA ($p<.05$) with a maximum flexion of 103º versus 115º in PS knees. From the authors' perspective, rollback or posterior translation seemed to be preserved in the PS TKA while paradoxical anterior femorotibial translation of PCR TKA may limit the amount of flexion possible.[14]

Stiehl, el.al. investigated medial and lateral femorotibial contact in a variety of total knees to assess invivo kinematics. The "flat on flat" condylar Whiteside prosthesis demonstrated posterior contact of both condyles in extension, exaggerated medial condylar sliding, and relative lateral condyle pivot on deep knee bend.(Figure 5)

Figure 5

Though not as prominent with gait, anterior medial sliding was still greater than lateral motion and no rollback was demonstrated. Rotation was unpredictable showing up to 9º of internal rotation and 1.5º of external rotation. Our greatest concern was the detrimental medial condyle sliding of considerable distance of 6-14 mm which could result in significant in significant pattern wear.[16] Blunn, et.al. have implicated a sliding, ploughing motion as the most likely cause of polyethylene implant delamination and catastrophic wear. We have a retrieval specimen of a Whiteside tibial insert after eight years of use that shows a large medial delamination zone with a small lateral "pivot" zone that would be similar to the predicted kinematics for this particular prosthesis. (Figure 6)

Figure 6

Retrieval studies of other "flat on flat" condylar designs have shown similar pattern wear.[17] Gabriel,et.al. suggested an additional problem with exaggeration of tibial fixation interface stresses resulting from posterior femorotibial contact.[18]

Stiehl, et.al. evaluated the results of a bicruciate or anterior cruciate retaining total knee arthroplasty, the Cloutier prosthesis.[21] This implant had spherical line contact but would be considered an unconstrained implant, similar to the Whiteside prosthesis. This implant overall resulted in posterior femoral rollback on early flexion with some anterior translation in deep flexion.(Figure 8,9)

Figure 8 and 9

However, all implant positions were posterior to the midsagital tibial line. The conclusion was that while about 50% of cases had an improvement over posterior cruciate retaining implants, the remainder probably had a nonfunctioning anterior cruciate ligament possibly due to inaccurate prosthetic placement or ligament balancing. A number of cases had a flexion contracture of 10º-15º which could represent a minor imbalance or tightness of the anterior cruciate ligament.

Third Generation Invivo Video Fluoroscopy

More recently, Komistek, et.al. have developed a sophisticated computer method of interactive model fitting that allows true three dimensional spatial determination. Initially, digitizing of the 3D CAD models was done manually by the technician(second generation). The current technique has an automated system where the computer seeks the best fit scenario of the 3D CAD model on the fluoroscopic image.(Figure 4) This third generation method allows calculation of all six degrees of freedom such as sagital plane anterior/posterior motion, internal/external (screw home) rotation and abduction/adduction (condylar liftoff). For purposes of this discussion, the most obvious enlightenment was simultaneous calculation of both coronal and sagital plane medial and lateral condyle femorotibial contact while prior studies had evaluated only one plane of imaging. The other technology advance was the use of automation of 3D CAD model matching that is done by the computer instead of the technician, thus dramatically facilitating the speed and accuracy of the method.[15]

Dennis, et.al. recently analyzed medial and lateral femorotibial contact positions of the PFC total knee arthroplasty with options of a flat, dished, or posterior stabilized tibial polyethylene insert utilizing gait and stair climbing modes.[15] Both flat and dished posterior cruciate retaining implants had posterior femorotibial contact in extension followed by anterior translation primarily of the medial condyle in midflexion and terminal flexion. Anterior translation was rarely observed on the lateral condyle. Nearly 50% of posterior cruciate substituting designs had some degree of medial condyle anterior translation but virtually 100% demonstrated lateral condyle posterior rollback from extension to 90º flexion compared with 51% flat and 58% dished tibial inserts. The cam post geometry of the posterior substituting implants explained posterior rollback similar to normal knees while the unconstrained posterior cruciate retaining knees had anterior translation consistent with earlier studies.

Argenson, et.al. investigated the results of a unicondylar total knee arthroplasty using video fluoroscopy.[34] Preoperative indications included the presence of a normal anterior cruciate ligament. During a deep knee bend, although the average motion was small, each subject having a medial or lateral unicondylar arthroplasty exhibited highly variable motions in the anteroposterior direction. The average contact position at full extension for subjects having a MUA was –0.8 mm (10.7 to –6.8), -1.4 mm (8.6 to –10.5) at 30 degrees of knee flexion, -2.4 mm (2.7 to –9.9) at 60 degrees of knee flexion, and -1.7 mm (3.3 to –5.4) at 90 degrees of knee flexion. At full extension, the average contact position for subjects having a LUA was –4.0 mm (1.2 to –9.2), -7.9 mm (-1.6 to – 15.3) at 30 degrees of knee flexion, -5.7 mm (-1.0 to –8.3) at 60 degrees of knee flexion, and –5.7 mm (-1.2 to –12.5) at 90 degrees of knee flexion. Seven subjects having a MUA and two subjects having a LUA experienced paradoxical anterior femoral translation during increased knee flexion. Only six subjects having a MUA and one subject having a LUA experienced anterior contact at full extension. The authors concluded that anteroposterior translation of unicompartmental arthroplasty (UKA) were more similar to TKA than the normal knee with posterior contact in full extension and paradoxical anterior femoral translation. The results suggest that progressive laxity of the ACL may occur over time and inconsistent ACL function following UKA could account for premature polyethylene wear occasionally seen in UKA.

Stiehl, et.al. investigated sagital plane patellofemoral kinematics in subjects while performing a weight-bearing deep knee bend under fluoroscopic surveillance.[24] The knees tested included normal knees, posterior cruciate retaining fixed bearing total knees and posterior cruciate substituting fixed bearing total knees with a dome shaped all polyethylene patellae, and the LCS rotating platform posterior cruciate sacrificing total knee, with or without a mobile bearing metal backed patella. Measures analyzed included the patellofemoral contact which determines a point superior or inferior to the sagital midpoint of the dorsal surface of the patella, patellar tilt angle which is the angle formed by the sagital plane longitudinal axis of the patella compared to the axis of the tibial shaft, and patellar separation measured in extension followed by flexing the knee to determine the engaged position. Total knee arthroplasty patellae experienced more superior patellofemoral contact and higher patellar tilt angles compared to the normal and ACL deficient knees ($p<0.05$). Patellofemoral separation at 5° (+/- 3°) extension was seen in 86% cruciate retaining and 44% cruciate stabilized total knees, and 8% anterior cruciate deficient knees, but not in the normal or mobile bearing TKA ($p<0.05$). The authors concluded that patella kinematic patterns for subjects having a total knee arthroplasty were more variable than subjects having either a normal or ACL deficient knee. However, the LCS patellae, most significantly the patella in unresurfaced total knees had kinematic performance closest to the normal knee than any other option. This may reflect the multiple design aspects of the LCS that favor the patellofemoral joint such as the 15º sloped distal cut in femoral preparation, the deep anatomical intercondylar femoral groove and optimized geometry that favors high conformity and articulation throughout motion. Ultimately, kinematic abnormalities of the prosthetic patellofemoral joint may reduce the effective extensor moment function after total knee arthroplasty.

With the ability to determine three dimensional kinematics has also come the possibility to precisely measure actual liftoff and screwhome rotation of total knees.[22,23] Stiehl, et.al. examined invivo kinematics of 20 patients with the rotating platform LCS and noted that 90% of patients had significant lift-off (>0.75 mm) during the stance phase of gait. Condylar lift-off was seen in both the lateral and medial condyles with the maximal medial liftoff of 2.12 mm while the greatest lateral liftoff was 3.53 mm. Screwhome rotation was quite variable and there could be internal tibial rotation in knee flexion as high as 9.6 degrees or external tibial rotation with a maximum observed of 6.2 degrees. The average screwhome rotation for the group was 0.5 degrees.[22] Most designers have considered the amount of rotation necessary for fixed bearing designs, on the order of 20 degrees, but this lead to the need for relatively flat articulations and line to line contact. The LCS implants tested demonstrated the extremes of condylar rotation, but an optimal performance from the design point of view as the LCS is rotationally unconstrained. Recently designed fixed bearing implants with higher "dishing" would have a tendency to diminish this rotation and to aggravate wear issues such as post impingement and "sliding" translation. Condylar liftoff is a more ubiquitious problem when one understands that it is obviously present in the normal knee. The LCS may have substantial liftoff while remaining in virtual normal conformity. This is opposed to "flat on flat" designs which may be prone to edge loading or peripheral pattern wear. Condylar liftoff in the extreme setting may be problematic and be a mechanism of late failure in the chronically unstable total knee. With the LCS, implants with liftoff greater than 9 millimeters are prone to implant dislocation.

Haas, el.al. analyzed the femorotibial kinematics of patients with either the LCS rotating platform or a rotating platform with a posterior stabilized cam and post mechanism.[25](Fig 10,11)

Figure 10 and 11

With deep knee bend, the rotating platform cruciate sacrificing implant showed midline positioning, slightly posterior to the midline tibia in extension. There was posterior translation to 60 degrees flexion with anterior translation to 90 degrees. During gait, translation was minimal with near midline positioning. The posterior cruciate stabilized implant had positioning slightly anterior to the midline tibia in extension. With deep knee bend, there was progressive posterior rollback of both condyles, greater on the lateral. Gait showed less posterior translation with medial condyle showing anterior translation in three knees. Positive screw home rotation or tibial internal rotation was seen with the posterior stabilized implant during deep knee bend and gait. The rotating platform had positive screw home with deep knee bend but negative screw home with gait. All implants showed medial condylar liftoff. Lateral condyle liftoff was seen with both implants on deep knee bend but only one rotating platform with gait. The comparison of the two implants demonstrated that posterior rollback with deep knee bend requires implant constraint of the cam/post mechanism but during gait, kinematics were similar for both implants.

Fourth Generation Invivo Fluoroscopy

The most recent evolution of video fluoroscopy in total knee arthroplasty has been to evaluate in different planes such as the frontal or coronal plane. This approach utilizes the same auto CAD technology but now uses special C-arm fluoroscopy machines that allow gait and deep knee bends done in the frontal plane. Stiehl, et.al. investigated 10 patients with either the LCS rotating platform or the posterior stabilized rotating platform evaluating both condylar liftoff and medial-lateral coronal plane translation.[26](Fig 12)

Figure 12

They found that the amount of medial/lateral translation and condylar liftoff was statistically different for the two groups($p<.05$). On average, subjects having a LCS PS TKA experienced only 1.7 mm (1.1-2.6) of medial/lateral translation. Subjects having a LCS RP TKA experienced 4.3 mm (3.4-7.4) of medial/lateral translation. This difference could be explained by the conflict of the PS post. On average, subjects having a LCS PS TKA experienced 1.2 mm (0.6-2.8) of condylar lift-off during the medial/lateral shift, while subjects having a LCS RP TKA experienced 2.0 mm (1.1-3.1) of condylar lift-off. The results from this study determined that during condylar lift-off, the contact of the condyle remaining on the tibia shifts away from the medial peripheral edge toward the center of the joint. The LCS rotating platform device allows for high conformity despite the lateral femoral displacement. With the posterior stabilized rotating platform tibial insert, both condylar lift-off and medial/lateral translation were limited by the spine/box interference. This study was unique in that the amount of tibial translation of the rotating platform was unexpected but not surprising given the prior results of both skeletal pin gait lab studies and stereoroentgenographic photogrammetry which have shown five to six millimeters of translation in the normal knee.[30-33]

Oakshott, et. al. have evaluated the kinematics of the AP Glide LCS which is a posterior cruciate retaining device.[27] That device performed in many ways similar to the original meniscal bearing LCS but with higher technical resolution of the kinematic fluoroscopy some interesting features were noted. The average range of motion of 10 patients was 119 degrees weightbearing and 129 degrees nonweightbearing. Condylar liftoff and rotation were comparable to other studies but there was a range of nearly 20 degrees of tibial rotation nonweightbearing while most of the rotation weight bearing was up to 10 degrees of external rotation. Finally, contact was significantly more anterior with greater degrees of flexion in nonweightbearing. This would highlight the potential problem of anterior impingement demonstrated by some surgeons using this implant and encourage a fairly accurate flexion space.

Discussion

The summary of known kinematic information regarding the knee can be stated as follows. From the magnetic resonance studies of Freeman, et.al.,the normal knee has a complex pattern of motion with tibial internal rotation on flexion related to posterior translation or rollback of the lateral condyle about a relatively fixed medial pivot point.[28,29] Posterior cruciate retaining total knees have abnormal kinematics that most likely relate to surgical technique, specific implant geometry, and absence of the anterior cruciate ligament. There is posterior femorotibial contact in extension followed by varying degrees of anterior translation with flexion and virtually no predictable rollback. Surgical technique determined whether or not the femorotibial contact positions would slide forward (PCL too loose) or remained in a relatively posterior position (PCL too tight) "Flat on flat" condylar designs were popularized to allow retention of the posterior cruciate ligament and a simplified surgical technique. Tibial insert design was flat to minimize constraint suggested to be the most likely cause of failure, ie. mechanical loosening of the tibial tray. Virtually no attention was given to the impact this approach may have to implant wear.

We have shown that range of motion of all knees, ie. normal and posterior cruciate retaining, posterior cruciate sacrificing, and posterior cruciate stabilized total knees have significantly less active weight bearing range of motion than passive non-weight bearing motion. Those total knees that have posterior rollback such as the posterior stabilized total knees have significantly more motion than those such as the posterior cruciate retaining total knees that do not. It is clear to see how the anterior femoral translation typical of posterior cruciate retaining implants could explain this problem. Therefore, we question the validity of non-weightbearing range of motion at least as it relates to predicting ambulatory function.

We have been able to demonstrate abnormal medial condylar sliding or roll forward seen with some "flat on flat" condylar designs. When combined with a young, high demand patient, this mechanism can explain the wear problems of osteolysis and catastrophic implant failure seen with these designs. An additional feature of abnormal kinematics is loss of normal “screwhome” rotation or internal rotation in certain cases. Whilest internal rotation of up to 10º has been confirmed in total knee arthroplasty, external rotation of over 6º is also seen. With abnormal tibial component placement, this irregularity can cause potential component wear in certain fixed bearing designs.

With our fourth generation modeling technique, we have been able to measure signficant condylar liftoff of one condyle in relation to the other. This phenomenon is seen in normal knees and most total knees regardless of method. We believe this finding will help explain pattern and peripheral wear identified in recent publications regarding implant retrievals. Current studies are being done to correlate wear patterns with abnormal condylar liftoff and femorotibial translation.

Those implant designs with high conformity such as the mobile bearing LCS, or posterior stabilized designs that have a cam/post mechanism for articulated anterior/posterior motion have obligatory posterior femoral rollback as a function of implant geometry. Stated simply, the design engineer can enforce a degree of posterior rollback by creating a unique design. In the LCS, this results from the maximal femorotibial conformity in extension which will tend to drive the contact posteriorly with flexion. The posterior stabilized designs rely on a cam post device which engages at about 50º flexion and drives the contact posteriorly.

The LCS system now offers multiple possibilities of surgical technique including the original bicruciate retaining device(ACL preserving) , the original meniscal bearing implant and the anterior-posterior glide insert (PCL preserving), the rotating platform insert (PCL Sacrificing), and the LCS revision system (PCL Substituting). The kinematic performance of these devices has been well described by the numerous above quoted studies. From a scientific investigation point of view, this experience is optimal as the prosthetic femoral, tibia and patellar geometry are virtually identical in all of these studies. Ultimately, knee function relates to a complex interaction of surgical technique, weight bearing forces, muscle contractions and kinematic features which are likely to be abnormal or non-physiologic in total knee patients. With a thorough understanding of these issues, the surgeon may make the optimal choices for surgical implementation in his patients and we can hope with the help of computered assisted surgery in the future.

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LEGEND

Figure 1. Illustration of invivo fluoroscopy technique with standard imaging table turned verticle with technician following knee on deep knee bend.

Figure 2. Lateral condyle femoral tibial contact patterns of four different total knees compared to normal on deep bend using original vector analysis. Note irreproducible jerky discontinuous motion of total knees. (Reprinted from Stiehl, JBJS(B) 1995)

Figure 3. Femorotibial contact patterns of five anterior cruciate deficient knees. Note variability with trend for anterior translation with flexion. (Reprinted from Dennis, CORR, 1996)

Figure 4. Automated image matching shows technique of placing CAD model onto the two dimensional fluoroscopic image in the appropriate spatial orientation.

Figure 5. Whiteside "flat on flat" posterior cruciate retaining total knee femorotibial invivo kinematics with a deep knee bend.(Reprinted from Stiehl, CORR, 1999)

Figure 6. Eight year retrieval of Whiteside tibial insert showing broad medial condyle delamination zone and small lateral "pivot" zone reflecting abnormal kinematics.

Figure 7. Invivo kinematic comparison of LCS posterior cruciate retaining (Meniscal Bearing) versus posterior cruciate sacrificing (Rotating Platform) assessing lateral condyle motion using second generation image matching technique.

Figure 8. Invivo kinematic analysis of average medial condyle contact positions comparing the Cloutier bicruciate (anterior cruciate retaining) and Whiteside posterior cruciate retaining total knees with deep knee bend.

Figure 9. Invivo kinematic analysis of average lateral condyle contact positions comparing the Cloutier bicruciate (anterior cruciate retaining) and Whiteside posterior cruciate retaining total knees with deep knee bend.

Figure 10. Invivo kinematic analysis of the LCS Rotating Platform with deep knee bend from 0º-90º flexion showing near midline position throughout.

Figure 11. Invivo kinematic analysis of the LCS PS Rotating Platform with deep knee bend from 0º-90º flexion showing gradual posterior rollback primarily on the lateral condyle

Figure 12. Frontal plane kinematics showing reference point of medial femoral condyle and measurement of liftoff and translation.