Kinematic alignment in total knee arthroplasty

Osiowanie kinematyczne w artroplastyce stawu kolanowego

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Abstract

The ultimate goal of total knee arthroplasty (TKA) is to produce a well aligned and balanced knee replacement. The current standard is to create the neutral overall alignment of the lower limb with a joint line perpendicular to the mechanical axis disregarding native joint line orientation and constitutional alignment which are the philosophies of mechanical alignment (MA). Recent studies have questioned if a mechanical aligned knee may cause problems related to ligament dis-balancing that could explain the high rate of disappointed patients, of almost 25% in some reports. As restoration of the mechanical axis of the leg (neutral hip-knee-ankle angle) is not targeted restoring knee kinematics to normal, kinematic alignment (KA) has been developed in order to improve ligament tension and balance and consequently a patient’s knee function and pain control. The aim of this article is to describe the philosophy of KA including biomechanical aspects, surgery techniques and to compare with MA as well.

Key words: mechanical alignment, kinematic alignment, TKA, mechanical axis

Streszczenie

Głównym celem endoprotezoplastyki stawu kolanowego jest wytworzenie prawidłowego balansu więzadłowego i prawidłowej osi stawu kolanowego. Obecnym standardem jest dążenie do uzyskania neutralnej osi całej kończyny dolnej z linią stawową prostopadłą do osi mechanicznej – filozofia osiowania mechanicznego (mechanical alignment – MA). Najnowsze badania stawiają pytanie, czy mechaniczne osiowanie protezy kolana nie stwarza problemów związanych z niewłaściwym balansowaniem więzadłowym, co może być odpowiedzialne za wysoki odsetek pacjentów rozczarowanych wynikiem zabiegu (według niektórych badań, do 25%). Ponieważ odtworzenie mechanicznej osi kończyny dolnej, neutralnego kąta między stawem biodrowym, kolanowym i skokowym (hip-knee-ankle angle HKA) nie odtwarza naturalnej kinematyki stawu kolanowego, powstała idea osiowania kinematycznego (kinematic alignment – KA). Ma ona na celu poprawę napięcia i balansu więzadłowego, a przez to poprawę funkcji kolana oraz kontroli bólu. Celem niniejszego artykułu jest przedstawienie filozofii osiowania kinematycznego (KA) z uwzględnieniem aspektów biomechanicznych, technik operacyjnych oraz porównania jej z osiowaniem mechanicznym (MA).

Słowa kluczowe: osiowanie mechaniczne, osiowanie kinematyczne alloplastyka kolana, oś mechaniczna
Biomechanical rationale of the knee and considerations relating to KA

The kinematics of the knee joint describes the relationship of the femur and tibia during any angle of flexion. Three main axes determine the movement of the patella and tibia with respect to the femur.

Both, the primary transverse axis in the femur about which the tibia flexes and extends and the longitudinal axis in the tibia about which the tibia internally and externally rotates on the femur were identified by Hollister et al. in 1993 [1]. They are oriented perpendicularly to each other.

The third axis was described by Coughlin [2]. It is the transverse axis in the femur about which the patella flexes. It is oriented parallelly to the primary transverse axis (Fig. 1).

Recent MRI studies have shown that the femoral "roll back" occurs mostly laterally so it could be postulated that the longitudinal axis runs through the medial compartment of the knee joint (Fig. 2) [3].

The explanation for existence of the primary transverse axis can be found in the shape of the posterior condyles. If the MRI scans are customized, so that the oblique sagittal image plane is perpendicular to the primary axis in the femur about which the tibia flexes and extends, the contour of the posterior femoral condyles from 10 to 120 degrees forms a single radius of curvature (Fig. 3).

Fig. 1. Coronal and lateral projection with the knee in extension. The primary transverse axis (green). The second transverse axis about which the patella flexes (magenta). The longitudinal axis about which the tibia rotates (orange).

Fig. 2. The primary transverse axis (green). The second transverse axis about which the patella flexes (magenta). The longitudinal axis about which the tibia rotates (yellow).

Fig. 3A-D. Composite of the coronal (Fig 3A) and axial (Fig 3B) few. Femoral joint line (green line), primary transverse axis which about the tibia flexes and extends (red line). In MRI during image acquisition the coronal and axial localizer should be adjust parallel to the joint line for aligning the nonorthogonal oblique sagittal scan. Resulting sagittal plane of the medial (3C) and lateral (3D) condyle. Under this conditions the best-fit circle (green) has the same radius in medial and lateral condyle.
It becomes apparent, from a kinematic perspective, that the lateral femoral condyle is not hypoplastic regarding medial condyle even in a valgus knee, and the asymmetry between the radii of the medial and lateral femoral condyles is small (<0.2 mm) which is clinically insignificant [4].

On the three-dimensional computer knee model Eckhoff et al. were able to demonstrate that the geometry of the posterior condyles is cylindrical (Fig. 4). The axes of the two cylinders form a line. It implies that the condyles share a single axis of rotation through an arc of 10°–120° even if the medial condyle demonstrates a slightly larger radius of curvature than the lateral one [5].

Another important issue is that the line joining the center of the condyles (primary transverse axis which the tibia flexes and extends) do not equal the trans-epicondylar axis (TEA) and there is a 5° average difference between them. The TEA is not an axis on which the tibia flexes and extends over the femur (Fig. 5) [6].

In single-leg stance the lower leg (especially in varus deformity) is inclined toward the midline by 3° or more [7]. Under this condition the joint line is horizontal. Therefore the joint line is 87° or more to the mechanical axis and mostly parallel to the floor.

If the tibial cut is perpendicular to the mechanical axis the TKR is actually implanted with 3° of valgus malalignment. Otherwise 98% of normal subjects do not have a neutral hip-knee-ankle axis because the longitudinal shape of the femur and tibia are very variable [8].

The tensioning of the ligaments in the native knee shows that the flexion and extension gap differ from each other. In extension the knee resembles a rigid body. The deviation under varus and valgus forces averages 0.7° and 0.5° respectively. In 45° and 90° of flexion the joint opened medially 1.4° and laterally 3.1° [9,10].

Creating a gap which is equal in flexion and extension (as in the gap-balancing technique) alters the kinematic of the native knee.

What is different in Kinematic Alignment?

The aim of KA is to preserve the native knee joint line orientation and soft tissue laxity by restoring three kinematic axes in the native knee.

KA follows the concept of “measured resection” technique with the use of calipers to measure the thicknesses of the distal and posterior bone resections from the femur. The femoral component will be shape-matched to the articular surface of the femur. It restores the primary transverse axis in the femur by which the tibia flexes and extends (Fig 6 and 7) [11].
On the tibial side the resection follows the same principles as on the femur. It means that the thickness of the resected bone medially and laterally (regarding the cartilage and bone deficiency) equates the thickness of the tibial component including the insert.

It makes it possible to align the flexion-extension plane of the tibia perpendicular to the primary transverse axis in the femur by which the tibia flexes and extends.

The natural joint line and leg axis equal the pre-arthritic situation. KA restores motion and balance of the knee joint without releasing of the collateral ligaments [9]. Patella tracking is improved because of restoring of the natural leg alignment and femoral anatomical joint line [11].

Unlike MA the aim of KA is not to create a straight leg but to restore the patient’s natural alignment. The straight mechanical axis does not reflect normal morphology and leaving a limb within a natural range of varus does not reduce implant survival [8,12].

Operative Technique

The described technique for KA is caliper measured KA using conventional instruments. Nevertheless all basic principles of KA are doable with computer assisted tools (robotic, PSI and navigation). For better assessment of the cartilage defects on the worn side of the distal condyle the remaining cartilage should be removed to bone with a curette.

The femoral resection, wear and kerf equals the thickness of the condyle of the femoral component (Fig. 8). The cartilage wear averages 2 mm distally and rarely more than 1 mm posterior [4].

If the distal femoral component measures for example 9 mm, the distal resection on the worn side should be 5.5 mm thick, after accounting for cartilage wear and saw blade kerf, which is 1.25 to 1.5 mm thick, depending on the thickness of the saw blade. On the unworn side the resection should be 7.5 to 8 mm thick.

A special instrumentation can be used to account for the cartilage loss on the worn side of the distal femur (Fig. 9).

The posterior referencing is neutral. In case of posterior bone and cartilage wear a slight external or internal rotation should be performed. Without cartilage loss the amount of resection on both sides is 6.5 mm if the component measured on the posterior condyles equals 8 mm (Fig. 10).

The main difficulty of KA is the proper alignment of the tibial component. The angle wing will be placed in the slot to assess the anterior-posterior slope of the tibial cut (Fig. 11).
The varus-valgus orientation is adjusted by rotating the tibial cutting guide until a symmetrical bone resection of the plateau is performable (regarding the cartilage and bone loss on the worn side).

After all cuts have been exercised the knee is examined with trial components. Mainly five situations are possible if the knee is not correctly balanced (Fig. 12). In case of flexion-extension space mismatch, soft tissue balance is achieved through bone adjustments. No ligament release is necessary. Bone recuts are done respecting the decision tree.

Stiffness in flexion and extension requires a tibial recut. The lack of extension requires, next to removing of posterior osteophytes, the release of the posterior capsule and last but not least the decrease of posterior tibial slope. Additional resection of bone from the distal femur to restore extension is not recommended in KA. The effect is pure because one millimeter of distal femoral resection restored only 1.8° of extension and the proximal movement of the femoral com-
ponent, primary transverse axis of the femur, and joint line, kinematically malaligns the knee and limits flexion [13].

For tight flexion an increase of posterior slope on the tibia should be done. 1°–2° of additional slope on the tibia opens the flexions gap by 1-2 mm.

If the knee is tight medially or laterally, a recut of 1°-2° in varus or valgus respectively may be performed. Alternatively the tibia can be medialized on the trial base plate [11].

Comparison of kinematic and mechanical alignment techniques in primary total knee arthroplasty.

The “classic” alignment method described by Freeman and Insall in the late 1960s, which include the principles of mechanical alignment, makes a straight leg and the jointline perpendicular to the mechanical axis. It produces a 3° varus malalignment of the femur and a 3° valgus malalignment of the tibia. To avoid lateral instability in flexion the femur must be externally rotated by 3° [7]. Asymmetric bone resections lead to imbalance of the collateral ligaments [14].

It was suggested that MA distributes the load more evenly on the tibial compartments and provides reliable long-term fixation and functional improvement [15]. However this method changes the natural axis, obliquity and level of the joint line.

If the thicker resection happens distally and posteriorly on the same condyle (medially or laterally) and if thickness of the resected bones are equal, it provides to a correctable ligament imbalance. The use of a thicker liner on the over resected side and release of the collateral ligament on the tight side can solve this problem. But if the thickness of the distal and posterior medial femoral condyles are unequal, the ligament imbalance becomes uncorrectable. For example, if the distal resection is thicker than the posterior resection, then the collateral ligament is slacker in extension and tighter in flexion. A thicker tibial liner to eliminate slackness in extension increases the tightness in flexion. Releasing the collateral ligament to reduce the tightness in flexion increases the slackness in extension again.

Release of the ligaments is imprecise. Insall himself made the observation that obtaining a balanced rectangular gap in extension is not always possible [16].

However, the MA technique can lead to unfavorable results leading to unsatisfactory outcomes in up to 25% of patients and requires in 10% revision surgery within 10 years following the surgery [17,18,19, 20, 21].

The goal of kinematically aligned TKA is to restore the patient’s natural alignment.

The principles for placing the components are different. In KA the orientation of the three functional axes are unchanged from that of the normal knee. It implies the restoration of the patient’s natural distal posterior femoral and tibial joint lines as well as natural alignment. It lowers the frequency of ligament release [9]. Restoration of neutral lower limb alignment is not the aim of KA. The KA technique is associated with improved postoperative satisfaction, function and early recovery [22,23,24].

In terms of kinematics in the patellofemoral joint neither of these two methods matched the native trochlea anatomy. Current femoral implants are developed with a valgus oriented trochlea groove but the native groove is close to be perpendicular with the distal femoral joint line (DFJL) [25].

KA produced larger angles of femoral component [26]. Due to realigning the natural DFJL into 3° valgus KA reduces the valgus orientation of the femoral component groove in the frontal plane (Fig. 13). MA and KA techniques create prosthetic trochleae that is understuffed and with a groove more valgus oriented, but in KA trochleae is closer to the native patient-specific anatomy [27]. It has been shown that KA might reduce the incidence of anterior knee pain [24].
Discussion

Although mechanical alignment is still the gold standard in TKA, KA becomes a more interesting alternative technique. Nevertheless, there are concerns that restoring natural varus alignments might compromise function and place the implants at a higher risk for failure, especially varus subsidence of the tibial component [28,29,30,31].

Among the authors exists a huge disagreement about the influence of the upper limb alignment regarding the survivorship of the implants and functional outcome after TKA [32,33,34,35,36,37]. Also Ishikawa et al. reported about high contact stresses on the implants in KA [38].

KA restores native left to right symmetry of the HKA angle, Distal Lateral Femoral Angle (DLFA), and Proximal Medial Tibial Angle (PMTA) within 0 ± 3° in nearly all patients [39]. Although the component alignment differed from that of MA-TKA, the overall alignment of the limb is similar in both [40]. Because of the wide variability of the angle formed by the anatomical and mechanical axes of the tibia and femur in a healthy population, so called outliers (according to the MA criterion) occur in KA-TKA due to restoration of the native joint alignment [41,42]. KA-TKA had a high 10-year accepted implant survival rate of 98.5% [43,44,45].

Most recently Niki et al. reported that in KA-TKA in varus knee, leads to lower knee adduction moment compared to MA-TKA. The conclusion is that the oblique joint line and residual varus deformity reduce mechanical loading in the medial compartment [46], which is advantageous compared to MA [46].

Another study shows that forces in both tibial compartments after KA-TKA without ligament release are similar to the native knee and 3-6 times lower than after MA-TKA with ligament release and mimics the native knee [47,48].

Meta-analysis compared the clinical and radiographic outcomes and complications between the KA and MA techniques in primary TKA and showed no significant differences in postoperative complications. The overall functional outcome was better in KA than in MA [49].

In terms of postoperative outcome KA shows significant improvements in WOMAC, KSS Oxford score, SF12 physical score and knee function score [50,51,52]. The good functional outcome may be explained through the physiological kinematic after MA-TKA because this technique targets the restoration of the native knee joint. It was reported that the tibial contact point of the femur translate in both the medial and lateral compartments posteriorly, lateral more than medial, during passive flexion. This reproduces the physiological “roll back” [47].

It is surely simplified to assume that only KA is able to produce a successful total knee arthroplasty. However, satisfactory results are related to multifactorial causes.

Proper indication and difference between patient’s and surgeon’s expectations are the most important. Additional factors are: depression, anxiety, lower socioeconomic status, and errors in surgical technique [53,54].

Conclusion

Kinematic alignment is still under evaluation but it becomes increasingly popular among surgeons. New techniques and instruments are introduced and further improvements are in progress. In the USA KA has been approved by the FDA [55]. It is to be expected that KA specific implants, especially under consideration of the position of the trochlea, will soon be introduced to the market.

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