MAR Orthopedics & Trauma (2024) 6:1

Review Article

An Overview of Different Alignment and Balance Methods for Total Knee Arthroplasty

Syed Muhammad Tayyab Hassan*

***Correspondence to:** Syed Muhammad Tayyab Hassan, Saudi Arabia.

Received: 29 March 2024

Published: 12 April 2024

DOI: https://doi.org/10.5281/zenodo.10963370

ABSTRACT

When implanting a total knee replacement (TKR), measured resection and gap balancing are the two most commonly utilized procedures. Both approaches have a long history, are widely used today, and have demonstrated efficacy in practical applications. In addition, recent technological advancements have made it easier for surgeons to accomplish limb alignment and soft tissue balance. For a knee replacement to work well, proper alignment is essential. For this to function, it must be in the proper rotational and axial planes. Erroneous alignment can lead to patellofemoral instability, early wear, and prosthesis loosening. Modifying the orientation of the prosthesis could have an impact on the soft tissue tension in the surrounding area. After conducting a thorough evaluation of 50 research (Levels 1–4) that were published in numerous esteemed publications, we looked through databases such as MEDLINE, EMBASE, and PUBMED. In this study, we have tried to record the connection between soft tissue homeostasis and alignment and to provide an overview of our current understanding of this relationship.

Keywords*: Knee, Technology, Alignment, Homeostasis, Evalution*

Introduction

The line between the ankle joint and the middle of the femoral head is known as the mechanical axis of the legs. 1. The femoral and tibial axis can be shown by drawing lines over the intramedullary canals in bones. In relation to the body's midline, the tibiofemoral joint should be 3 degrees varus and the distal femoral joint 9 degrees valgus. TKAs that are positioned correctly result in a joint line that is perpendicular to the mechanical axis. This evenly distributes force across the medial and lateral surfaces of the component. This task was enabled using a mechanical axis. A full knee arthroplasty technique that is now widely used was invented by Insall 2. A healthy knee has a three-degree tibia varus and a nine-degree femur valgus. To mechanically align the limb, perpendicular incisions are made in the tibia and femur. This makes mechanical alignment easier. The longitudinal axis of the machine is perpendicular to both cuts. To realign the mechanical axis via the knee joint, the tibia is cut at a 90-degree angle to its anatomic axis and the femur at a 4-6% valgus angle. 2. With this procedure, the mechanical axis is positioned over the knee joint. The mechanical axis is moved to the knee center by this surgery. Insall's implant would fail following anatomic alignment, which involved severing the tibia at three varus sites. The load on the medial joint line would cause the implant to fail. This tactic was empirically supported by the Insall hypothesis. Anteromedial and posteromedial tibial surface stresses were shown to be elevated by varus tibial alignment, as demonstrated by Green et al. 3. Research discovered this. This was discovered by Green et al.

Limb placement affects the effectiveness of TKA over the long run. 4–6 Compared to normal alignment, postoperative varus limb alignment is associated with greater risks of total knee replacement failure. in contrast to standard alignment. Ritter et al. 7 discovered that with repeated posterior cruciate condylar TKAs, varus alignment resulted in 27 of 38 (71%) failed tibial fractures. This outcome was obtained in 38 cases. Radiolucent lines were discovered by Aglietti et al. in tibial components that had a varus tilt greater than 2 degrees. 8 A 90-degree tibia incision was necessary for the optimal healing of the tibial component. Berend and colleagues discovered that the chance of failure increased with tibial component alignment greater than 3.0 degrees of varus and whole limb alignment less valgus. HDPE wear rates were found to be strongly impacted by even a small five-varus deviation from the mechanical axis by Collier and colleagues 9. Even in cases when patient dissatisfaction is severe, mechanical alignment restoration is the gold standard in TKA. 10 According to other research, restoring a kinematic alignment as opposed to a neutral mechanical alignment may enhance patient satisfaction, more closely resemble the natural knee, and prevent failure rates. 11, 12 Neutral mechanical alignment does not increase survival, despite what the general public believes.

Alignment Kinematically

The concept of "knee kinematic alignment" describes how the knee should be positioned to match the body's anatomical or constitutional alignment. Kinematic alignment is the process of implanting the prosthesis so that it is in line with the ligament tension, the leg's axis, and the joint line. Complete knee arthroplasty is another term for this operation. Thirteen Thirteen kinematically aligned prostheses demonstrated improved function in the knee society scale and a higher degree of range of motion in compliance with Weber et al.'s recommendations. A knee that is positioned correctly kinematically has been linked to numerous benefits, as demonstrated by recent meta-analyses. Midway through the 10-year follow-up period, the rate of prosthesis retention was determined to be 97.5% as a direct result of employing this forward-thinking strategy.

We'll take into account the cartilage lost from chopping the tibia and femur. Compared to a TKA that is mechanically aligned, this portion of the surgery aligns the femoral and tibial components in 2-4 more valgus and varus. At this point, the anatomical angles of the hip, knee, ankle, and knee are largely uniform. According to Howell, kinematic alignment is the alignment of the articular surfaces of the tibia, femur, and knee with respect to each other and the knee's axis. This is the action of a unified force. The tibial flexion axis, which is measured from the two centers of the circular section of the posterior femoral condyles, determines the normal range of motion of the leg. 14, 15

The patellar flexion axis, which is located 12 millimeters proximal and 10 millimeters anterior to the tibial axis, defines the patella's natural arc of flexion and extension on the femur. 15 A third axis is provided via tibial rotation. The tibia's natural arc of rotation around the femur is also determined by this axis. To sum up, the functional outcomes of the mechanical alignment approach and the kinematic alignment strategy are similar. The outcomes of the midterm elections offer a great deal of hope. There have also been published long-term outcomes for mechanical alignment, showing 80% survival rates after 25 years; however, additional studies are required to validate the promising clinical results in kinematic alignment over an extended period of time. 16

Before any bone is sliced during the gap balancing procedure, ligaments are loosened. For irreversible damage, ligament release is a dependable treatment. This procedure is carried out in order to approximate the alignment of the affected limb, and it comes before assessing the rotation of the femoral component. 17 In essence, there are two ways to achieve gap balancing. Creating symmetry between the two flexion angles is one strategy. The second approach achieves this by reducing extension and increasing knee flexion to make up for the predefined extension gap.

Due to individual variations in femoral anatomy, bone landmarks used for measured resection devices may range from patient to patient. These variations may lead to femoral component malrotation. This problem can be avoided by using gap balancing since it does not only rely on anatomical cues. Furthermore, the gap balancing method has been demonstrated to improve flexion stability more successfully than measured resection. 18 This is most likely due to the fact that the gap balancing strategy produces a significantly smaller femoral condylar lift-off than the measured resection procedure. 19 Accurate balance is necessary to cut the proximal tibia. The femoral component may rotate inward with a varus cut and outward with a valgus cut. Whether the femoral and/or tibial components were over- or underresected affects the breadth of the flexion and extension gaps. 20,21

Resection Technique

Method of measured resection based on femoral landmarks including PCA, TEA, and AP. Principal component analysis (PCA), the most popular marker, is internally rotated from the TEA by 1.5 degrees. 19 The most precise landmark for assessing femoral rotation is the thigh eminence angle (TEA), which also shows the patient's natural rotation. However, identifying the TEE during surgery can be challenging and may necessitate extra soft-tissue dissection. This is true even though it's the most reliable marker for femoral rotation. even when trying to locate the TEA. 22, 23 The Whiteside line, which reaches the deepest part of the groove and crosses the TEA perpendicularly, more closely resembles normal external rotation in valgus knees than the PCA.

It was discovered this way. This remains true even though the Whiteside line crosses the deepest depression in the groove. 24 All three markers must be known by the surgeon in order to perform a TKA precisely. When doing a measured resection, the surgeon might choose to position the guides anteriorly or posteriorly. Anterior reference reduces the chance of notching by stabilizing the anterior point and avoiding any further bone loss as a result of variations in the size of the femoral component. Because the posterior femoral condyles have too much bone removed, the design may make flexion instability worse. This disadvantage can be avoided by choosing a design that doesn't call for bone removal during the procedure. Following jig setup, the posterior referencing process.

If the femoral component is abnormally tiny, excision of the anterior femoral bone may result in notching. Only the femur's lateral incision depth rotates with a medial pivoting device. Medial bone slices in lateral pivoting systems move independently of rotation because they have a fixed lateral point. The posterior femur bone cutting may be impacted by the center of rotation of central pivoting devices. The large variation in patient anatomy has led to a great deal of criticism directed towards measure resection. Due to the hypoplastic lateral femoral condyle, the femoral component of a knee with valgus deformity may spin inward during PCA. Numerous studies have revealed that the PCA has a considerable degree of variability. 22, 25 When PCA was utilized independently to determine rotation, Schnurr et al. 25 discovered that 49% of cases resulted in meal rotation. Further investigation revealed that the Whiteside line and the TEA were both very changeable, raising questions about their suitability as anatomical reference points. 25 By using all available femoral markers to ensure appropriate component alignment, this approach helps prevent malrotation of the femoral component.

Gap Balancing

It is possible to position the femoral component perpendicular to the excised tibia by applying firm pulls on both collateral ligaments. This can be accomplished by first finding balance in the flexion or extension gap, according on the surgeon's preference. The femoral component will be impacted if the tibial incision is not precisely made, which is necessary for this procedure to work. The removal of any osteophytes that may be present is part of gap balancing, and it should be done before femoral excision. Distractions from technology help maintain tension. Due to individual variations in femoral anatomy, it is possible that the landmarks utilized in the measurement of resection devices are not always accurate. This could lead to malrotation of the femoral component if it continues. Gap balancing uses more indications than only anatomical ones, therefore it gets around this problem. It has been demonstrated that gap balancing provides better flexion stability than the measured resection method. This is as a result of the femoral condyles experiencing reduced lift-off. 18, 19 Precise cutting of the tibia is necessary to stop the femoral component from rotating. Any additional varus or valgus may cause this. Removing too much femur could make it harder to control the flexion gap. Osteophyte removal and collateral ligament preservation are important because poor balancing can result in incorrect resections. For balance, one may need to employ distraction techniques, and it's important to keep a quantitative eye on one's stress levels. A tight extensor mechanism results in a considerable asymmetry in the flexion gap, which is necessary to prevent excessive resection of the femoral condyles. This prevents the condyles from being excessively resected. This must be kept in mind at all times during the process. 20,21

Instrumentation Tailored to the Patient.

Patient-specific equipment makes total knee arthroplasty (TKA) easier by using advanced preoperative imaging to generate customized cutting guides. Each patient is unique in their anatomy, thus this becomes crucial. With the use of these guides, the femur and tibia may be cut at the proper angles in order to install traditional, prefabricated implants. Imaging systems will record information from the patient's hips all the way down. Depending on the client, these systems may use CT or MRI technology.23

Since the implants must be ready before the procedure, patient scheduling must be carefully considered. Preoperative templating may result in lower outlier rates, better implant alignment, and less active physician decision-making. These are just a handful of the benefits. Cut down on how long a procedure takes in total and how many implant trays need to be sterilised in order to complete the procedure. Due to less blood loss during surgery, patients with femoral anomalies or implants that limit femoral canal instrumentation may benefit from not needing blood transfusions. Reductions in expenses, better alignment, and fewer problems are all assertions that have not received enough research. The relative effectiveness of implant alignment outlier reduction, better alignment, or greater functional ratings in comparison to conventional therapies is not extensively proven. Despite the lack of consistent research demonstrating a reduction in the duration of surgery, the prevailing consensus is that it has no therapeutic or financial impact. A study by Barrack et al. discovered a $1,500 premium over baseline equipment with only a $322 predicted savings, and there is no proof that cost savings occur. These findings go counter to the possibility of savings. Voleti et al.'s meta-analyses provide no convincing evidence that standard TKA reduces blood loss or transfusion rates. We failed to establish a statistically significant difference between the two different forms of TKA. Before making recommendations about the broad usage of patient-specific equipment in TKA, further substantial and long-term research must be conducted. 24

Computer Navigation and New Techniques

Navigating a computer The TKA could malfunction before its time if it is not aligned appropriately. This served as a primary impetus for the development of computer-assisted surgery, or CAS. A number of studies are available that can be utilized to support or refute the need for the various technologies now being employed to enhance surgical procedures. Comprehending the underlying workings of every system in CAS is essential for realigning the mechanical axis. Active systems frequently incorporate robotic control to complete a process phase. Passive systems, which are far more common than active ones and give the surgeon total control, involve the patient but not them actively participating in the surgical procedure.

In passive CAS, infrared light from optical apparatus is received by reflecting spheres implanted in the patient's tibia and femur. Then, by transmitting this light to a computer for examination, it would be possible to determine the precise location of the user in space. The primary cause of the technology's shortcomings is usually ascribed to the camera's inability to locate the reflecting spheres with sufficient accuracy. Magnetic locating techniques were widely used before ferromagnetic devices were widely available. These systems had distortion-related reliability problems despite not having line-of-sight problems with optical trackers. There are image-based and free CAS solutions available. Since CT and MRI are image-based technologies, using three-dimensional imaging is essential. These systems need the surgeon to find a preset number of landmarks before they may compare with the images on the screen. We are also exploring the prospect of mapping the geometry and establishing alignment using a mathematical computer algorithm. Using fixed reflecting spheres, medical professionals can locate the midpoint of the knee and the femoral head during a kinematic assessment of their range of motion. 25

Ankle landmarks on the medial and lateral malleoli or a kinematic study can be used to determine the ankle's anatomical midpoint. Numerous academic research have covered the benefits of CAS. The results of the meta-analysis showed improvements in femoral rotation and coronal plane accuracy and precision. These devices may be useful in the treatment of severe femoral difficulties when an intramedullary guide cannot be used due to severe femoral deformities or previously instrumented femurs. Adoption of CAS may reduce bleeding and fat embolism risk by eliminating the possibility of femoral or tibial intramedullary canal transection. This approach has been criticized because the Knee Society assessments at three, six, and five years did not differentiate between CAS and standard TKA. Similar to other medical procedures, surgery requires more time and has a high learning curve. 1.3% of femoral pin site fractures occur as a result of a transcortical pin inserted into the femoral pin site. Stress fractures of the tibia are an additional possible injury. The higher cost of the technology's essential components and the requirement for more experienced staff in the operating room contribute to the higher total cost of ownership. High throughput processes may lower these additional costs. There are 250 cases annually, and depending on whether the predicted reduced revision rate is taken into account when employing CAS, the savings may differ.

System of Inertial Navigation

Since they were just released onto the market, there isn't a lot of information on how to use them. Using information from accelerometers and motion sensors, the INS determines the location in space depending on the velocity and position of the vehicle. This helps to reduce the need for CAS sensors. KneeAlign, presently known as OrthoAlign Aliso Viejo, is one such INS. This device secures the accelerometer and makes the limb move in a way that may be utilized to determine its precise location. The iAssist (Zimmer Biomet) system is another gadget that collects alignment data via gyroscopes and sends it to a computer. When INS is used instead of traditional extramedullary guides, it has been shown to improve tibial alignment and reduce tibial slope outliers. Improved femoral component alignment, shorter tourniquet times, and retained tibial component alignment were the outcomes of using INS for TKA as opposed to

CAS. This was established by research that compared the two approaches side by side. The tibial excision procedure was significantly extended by using the accelerometer gadget. There is a reduction of 41 incisions needed because these instruments are contained within the operating room. In spite of this, very little INS data is available to the general public.

Adjusting for Pressure

The method for measuring the pressure inside the knee compartments is provided by microelectronics. For example, pressure in the medial and lateral compartments of the knee can be measured with the use of sensors implanted in the tibial spacer.

In addition to kinematic monitoring, these sensors capture dynamic femoral contact sites over the whole range of motion of the knee. One product in this category is the VeraSense Knee System by Orthosensor. More accurate surgical releases can be performed to provide better tracking and balance management. It is also possible to use dynamic feedback to increase the accuracy with which the knee balances in response to pressure applied at different locations within the knee. This technology should help to improve knee functionality, outcome evaluations, and the need for changes. Not much has been written about this novel approach up to this point. 42 patients who were balanced with this system (with a 15-pound differential between the two compartments) showed improved Knee Society Scores and patient-reported outcomes, according to Gustke et al. Future research may employ larger cohorts to validate the findings of earlier studies, potentially yielding a more accurate range for the recommended numbers for equilibrium. One of the disadvantages of the approach is its high cost. Longer time span statistics are not presently available. Even though this is a new and improved device, more study needs to be done to successfully understand about the soft tissue homeostasis of the knee.

Conclusion

These days, there is a huge range of surgical procedures accessible for TKA. Despite the fact that each of these treatments supports a different worldview, they all exhibit comparable patient satisfaction levels, and a sizable percentage of patients remain dissatisfied. Though modern technology is improving conventional procedures, these efforts have limited long-term effects. The complexity of total knee arthroplasty is increased by the anatomical deformations caused by arthritis, as the procedure already involves replacing a joint with highly variable three-dimensional design and mechanics. This article's discussion of technology and tactics is focused on improving component location for best long-term performance. But in order to assess how well these tactics work in determining the long-term impact in comparison to more conventional ones, more study is needed.

Reference

1. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. J Bone Joint Surg Br. 1991;73(5):709–14.

2. Insall JN. Total knee replacement. In: Insall JN, editor. Surgery of the Knee. United Kingdom: Churchill Livingstone; 1984. p. 587–696.

3. Green GV, Berend KR, Berend ME, Glisson RR, Vail TP. The effects of varus tibial alignment on proximal tibial surface strain in total knee arthroplasty: The posteromedial hot spot. J Arthroplasty. 2002;17(8):1033–9.

4. Bargren JH, Blaha JD, Freeman MA. Alignment in total knee arthroplasty. Correlated biomechanical and clinical observations. Clin Orthop Relat Res. 1983;173:178–83.

5. Lotke PA, Ecker ML. Influence of positioning of prosthesis in total knee replacement. J Bone Joint Surg Am. 1977;59(1):77–9.

6. Tew M, Waugh W. Tibiofemoral alignment and the results of knee replacement. J Bone Joint Surg Br. 1985;67(4):551–6.

7. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res. 1994;299:153–6.

8. Aglietti P, Buzzi R. Posteriorly stabilised total-condylar knee replacement. Three to eight years' follow-up of 85 knees. J Bone Joint Surg Br. 1988;70(2):211–6.

9. Collier MB, Engh CA, McAuley JP, Engh GA. Factors associated with the loss of thickness of polyethylene tibial bearings after knee arthroplasty. J Bone Joint Surg Am. 2007;89(6):1306–14.

10. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KDJ. Patient satisfaction after total knee arthroplasty: Who is satisfied and who is not? Clin Orthop Relat Res. 2010;468(1):57–63.

11. Parratte S, Pagnano MW, Trousdale RT, Berry DJ. Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. J Bone Joint Surg Am. 2010;92(12):2143–9.

12. Bonner TJ, Eardley WG, Patterson P, Gregg PJ. The effect of postoperative mechanical axis alignment on the survival of primary total knee replacements after a follow-up of 15 years. J Bone Joint Surg Br. 2011;93(9):1217–22.

13. Weber P, Gollwitzer H. Kinematic alignment in total knee arthroplasty. Oper Orthop Traumatol. 2021;33(6):525–37.

14. Stokes IA. Mechanical effects on skeletal growth. J Musculoskelet Neuronal Interact. 2002;2(3):277–80.

15. Coughlin KM, Incavo SJ, Churchill DL, Beynnon BD. Tibial axis and patellar position relative to the femoral epicondylar axis during squatting. J Arthroplasty. 2003;18(8):1048–55.

16. Evans JT, Walker RW, Evans JP, Blom AW, Sayers A, Whitehouse MR, et al. How long does a knee replacement last? A systematic review and meta-analysis of case series and national registry reports with more than 15 years of follow-up. Lancet. 2019;393(10172):655– 63.

17. Insall JN, Scott WN. Insall and Scott surgery of the knee. London: Church Livingstone/Elsevier; 2006.

18. Dennis DA, Komistek RD, Kim RH, Sharma A. Gap balancing versus measured resection technique for total knee arthroplasty. Clin Orthop Relat Res. 2010;468(1):102–7.

19. Dennis DA, Komistek RD, Walker SA, Cheal EJ, Stiehl JB. Femoral condylar lift-off in vivo in total knee arthroplasty. J Bone Joint Surg Br. 2001;83(1):33–9.

20. Matthew A. Measured resection versus gap balancing for total knee arthroplasty. Clin Orthop Related Res. 2014;472(7):2016–22.

21. Nagai K, Muratsu H, Matsumoto T, Miya H, Kuroda R, Kurosaka M. Soft tissue balance changes depending on joint distraction force in total knee arthroplasty. J Arthroplasty. 2014;29(3):520–4.

22. Poilvache PL, Insall JN, Scuderi GR, Font-Rodriguez DE. Rotational landmarks and sizing of the distal femur in total knee arthroplasty. Clin Orthop Relat Res. 1996;331:35–46.

23. Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res.

1993;286:40–7.

24. Arima J, Whiteside LA, Mccarthy DS, White SE. Femoral rotational alignment, based on the anteroposterior axis, in total knee arthroplasty in a valgus knee. A technical note. J Bone Joint Surg Am. 1995;77(9):1331–4.

25. Schnurr C, Nessler J, König DP. Is referencing the posterior condyles sufficient to achieve a rectangular flexion gap in total knee arthroplasty? Int Orthop. 2009;33(6):1561–5.