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Mastering the Geometry of Joint Preservation: A Comprehensive Review of Preoperative Planning, Multiplanar Alignment, and Patellofemoral Dynamics in Medial Opening Wedge High Tibial Osteotomy

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Abstract:

A biological substitute for arthroplasty, medial opening wedge high tibial osteotomy (MOWHTO) has resurfaced as a dependable technique to stop the advancement of medial compartment gonarthrosis [1]. When surgeons treat the surgery only as a coronal plane repair, it has a reputation for being unpredictable despite its potential [2]. The implant by itself cannot ensure success; careful patient selection and precise geometrical planning are necessary [3]. In order to address the anatomical and radiological conditions necessary for real joint preservation, this analysis moves away from implant biomechanics [4]. We examine contemporary changes in body mass index (BMI) and age indicators, prioritizing physiological potential over temporal constraints [5]. Preoperative templating is thoroughly examined, with a particular comparison between the contemporary computerized tracking of the weight-bearing line and the traditional Miniaci method [6]. We also investigate the osteotomy's unexpected effects on the sagittal plane [7]. Unexpected changes in the posterior tibial slope significantly change the kinematics of the knee, endangering the integrity of the anterior cruciate ligament and changing contact mechanics [8]. We also assess the patella infera, or inevitable patellofemoral descent, that results from elevation of the joint line [9]. Orthopedic surgeons can predictably transmit load to the lateral compartment without developing new, iatrogenic joint diseases by mastering these multiplanar factors [10].

Keywords: High Tibial Osteotomy; Fujisawa Point; Tibial Slope; Patella Infera; Preoperative Planning; Joint Preservation.

1. Introduction

The middle-aged patient's active lifestyle is often destroyed by knee osteoarthritis, producing a clinical conundrum that traditional treatment algorithms typically fail to gracefully resolve [11]. Total knee replacement frequently appears inevitable when conservative treatments including physical therapy, activity adjustment, and injections are unsuccessful [12]. However, future revision procedures are guaranteed when a native joint is replaced in a 45-year-old laborer or competitive athlete who is in high demand [13]. Even with improvements, the lifespan of contemporary implants is still far short of that of a young, active person [14]. For this population, joint preservation is still the best course of treatment [15]. A biological reprieve is provided by medial opening wedge high tibial osteotomy (MOWHTO) [16]. Surgeons modify the lower limb's mechanical axis by surgically severing and hinging the proximal tibia [17]. The moment of destructive varus vanishes [18]. The load safely moves into the preserved lateral compartment and away from the damaged medial cartilage [19].

Closing wedge osteotomies were the most common procedure in the past [20]. To straighten the leg, surgeons cut a wedge of bone from the lateral tibia [21]. There were severe consequences for the strategy [22].

Future total knee replacement would be an awful nightmare due to the need for fibular osteotomies, the possibility of catastrophic peroneal nerve palsy, and the removal of important bone stock [23]. These problems were circumvented by the opening wedge approach [24]. Bone stock is preserved [25]. The lateral neurologic structures are avoided [26]. Nevertheless, the closing wedge method did not provide the intricate mathematical difficulties that come with accessing the medial cortex[27].

The majority of the research focuses on holding the bone open with different plates and screws, discussing the advantages of titanium over steel or locked versus unlocked fixation [28]. This review follows a different path [29]. If the preoperative strategy is defective, hardware is meaningless [30]. When an osteotomy is improperly planned, a perfect plate will not work [31]. We will examine the essential requirements for a successful MOWHTO, which include carefully managing the frequently disregarded sagittal and axial planes during the opening procedure, choosing the appropriate patient, and mapping the precise degree of correction on preoperative images [32]. The knee's fate is determined by the cut's geometry[33].

2. The Evolution of Patient Selection

The osteotomy's survivability is determined by the patient [1]. Regardless of surgical accuracy, operating on the incorrect joint ensures quick clinical failure [2]. The traditional standards established in the latter half of the 20th century were inflexibly dogmatic [3]. Surgeons required patients to have at least 90 degrees of flexion, be under 60 years old, and have a body mass index (BMI) of less than 30 [4]. We have had to change these characteristics from strict checkboxes to a comprehensive evaluation of joint biology due to current clinical evidence [5].

2.1 Chronological Versus Physiological Age

Age limitations are no longer unchangeable [6]. Although the traditional limit was 60 years old, biological age is more important than birthdate [7]. If the bone quality is adequate, a 64-year-old with isolated medial compartment disease who is physically fit and very active frequently has good results [8]. On the other hand, a 45-year-old smoker who is sedentary and has little bone stock is likely to fail [9]. The choice is based only on activity requirements and bone density [10]. Elderly people with reduced demand can benefit from arthroplasty [11]. The high-demand patient who wants to run, jump, or engage in strenuous physical labor is served by MOWHTO [12]. The patient's willingness to adhere to a lengthy rehabilitation regimen, which is far more difficult than a knee replacement, must be evaluated [13].

2.2 The Weight Limit Dilemma

Surgical realignments are actively destroyed by obesity [14]. The lateral cortical hinge's mechanical strength is readily overcome by high axial loads [15]. After MOWHTO, the obese population suffers from early hardware failure, subsidence, and loss of correction [16]. A BMI over 35 is still a strong relative contraindication, even though some surgeons push the boundaries [17]. Obese patients' altered stride mechanics frequently make it impossible to offload the medial compartment as intended, making the osteotomy's design pointless [18]. Losing weight before surgery is not just advised but structurally required for the hinge's integrity [19].

2.3 Intra-articular Prerequisites

The lateral compartment ought to be spotless [20]. Medial knee pain is simply replaced by lateral knee discomfort when the mechanical axis is moved into a sick lateral compartment [21]. To confirm the integrity of the meniscus and lateral cartilage, preoperative magnetic resonance imaging (MRI) or diagnostic arthroscopy is still required [22]. Additionally, a thorough evaluation of the patellofemoral joint is necessary [23]. It is OK to have mild anterior knee pain [24]. Due to inevitable changes in patellar height following an opening wedge surgery, severe, bone-on-bone patellofemoral arthritis will flare up violently [25]. Another important consideration is ligamentous stability [26]. If the posterior slope is increased after the osteotomy, instability may result from an inadequate anterior cruciate ligament (ACL) [27]. A combination technique or an other surgical approach may be necessary in cases of varus deformity with ACL deficit [28].

3. The Geometry of Preoperative Planning

In the surgical room, glancing at the correction invites catastrophe [29]. The patient experiences ongoing medial pain as a result of undercorrection [30]. Overcorrection results in significant cosmetic dissatisfaction, fast lateral compartment disintegration, and an excruciating valgus deformity [31]. The precise millimeter width of the opening wedge is determined by precise preoperative templating [32]. This is engineering, not art [33].

3.1 The Fujisawa Point

What is the precise location of the new weight-bearing line (WBL)? [1]. The WBL in a typical knee goes straight through the middle of the joint, approximately where the tibial spines meet [2]. It moves medially in an osteoarthritic varus knee, putting pressure on the afflicted compartment [3]. Surgeons must push the line laterally in order to accomplish therapeutic offloading [4]. The gold-standard objective was created by Fujisawa [5]. According to his proposal, the mechanical axis should intersect the tibial plateau at the 62.5% point, which is measured from the medial margin [6].

The knee is somewhat overcorrected into 3 to 5 degrees of valgus when this precise coordinate is struck [7]. The ideal mechanical environment for medial fibrocartilage regeneration is provided by this particular moderate valgus [8]. Due to postoperative settling and bone resorption, reaching the 50% threshold (neutral alignment) causes unacceptably high varus collapse recurrence rates [9]. In order to protect the lateral compartment, some contemporary surgeons advocate for a goal closer to 55% or 60%, however in the case of medial osteoarthritis, it is still generally agreed that modest valgus is preferable to neutral [10].

3.2 The Miniaci Method

Geometry is needed to determine the precise wedge width [11]. For this objective, the Miniaci approach continues to be the most dependable clinical instrument [12]. A full-length, weight-bearing scanogram is necessary [13]. The planned lateral hinge point on the proximal tibia, the center of the talus, and the center of the femoral head are all identified by the surgeon [14]. Usually, the hinge point is about 80% of the tibial width away from the medial cortex [15]. A fracture could result from positioning the hinge too medially, while a neurovascular damage could result from positioning it too laterally [16]. The surgeon establishes the angle of correction by drawing lines connecting these spots [17]. How far the medial cortex must be diverted depends on this angle [18]. This procedure is automated by contemporary digital templating software, which enables surgeons to mimic the opening wedge and cut the bone realistically before actually creating an incision [19]. By addressing internal tibial torsion, which frequently coexists with varus deformity, these instruments also enable rotation correction [20]. But using software shouldn't take the place of knowing the fundamentals of trigonometry [21]. against avoid software errors resulting in surgical errors, the surgeon must compare the digital plan against manual calculations [22].

4. Controlling the Sagittal Plane: The Posterior Tibial Slope

Surgeons frequently completely disregard the sagittal plane while becoming fixated on the coronal plane (varus/valgus) [23]. The natural proximal tibia slopes posteriorly by roughly 7 to 10 degrees; it is not flat [24]. This slope is naturally altered by MOWHTO, and joint kinematics are destroyed if it is not managed [25]. In regular practice, this is arguably the most neglected part of the process [26].

4.1 The Geometry of the Slope Increase

The posterior slope nearly usually rises when a surgeon opens the medial tibia [27]. Why does this occur? [28]. The cross-section of the proximal tibia is triangular [29]. Compared to the posteromedial cortex, the anteromedial cortex is smaller [30]. The narrower anterior region of the osteotomy gaps more than the larger posterior portion if the surgeon opens it symmetrically or inserts a rectangular wedge [31]. The tibial plateau has a rearward tilt [32]. Further aggravating the slope rise is the possibility that the posterior fragment will be pulled into extension when the anterior gap widens due to the stress of the posterior capsule and posterior oblique ligament [33].

4.2 Biomechanical Consequences of Slope Alteration

When bearing weight, the femur must glide posteriorly due to an increased posterior tibial slope [1]. The anterior cruciate ligament (ACL) is severely and abnormally strained as a result of this translation [2]. This results in persistent knee pain and tightness in a patient with a healthy ACL [3]. The elevated slope will aggressively rip the remaining fibers if the patient already has a partial ACL tear [4]. On the other hand, lowering the slope may result in PCL strain and anterior translation problems [5]. Maintaining the natural slope within two degrees of the preoperative measurement is the aim [6]. The strain parameters of the cruciate ligaments during gait cycles might be considerably changed by even a 5-degree rise [7].

4.3 Surgical Mitigation Strategies

The osteotomy gap must be trapezoidal rather than rectangular in order to preserve the original slope [8]. It is necessary to expand the posterior gap about twice as wide as the anterior gap [9]. Moreover, slope behavior is mostly determined by the superficial medial collateral ligament (sMCL) [10]. The osteotomy's opening is precisely where the sMCL attaches [11]. The posterior cortex stays attached if the surgeon does not sufficiently release the distal fibers of the sMCL [12]. The posterior bone functions as a restrictive hinge, forcefully pushing up the posterior slope when the surgeon applies the spreader, causing the anterior bone to open [13]. To control sagittal alignment, it is absolutely necessary to release the distal sMCL completely and carefully behind the posteromedial corner [14]. To confirm the slope before to final fixation, intraoperative lateral radiographs are crucial [15]. In order to mechanically enforce the proper geometry, certain contemporary plate systems provide slope-neutralizing designs that compress the posterior portion of the osteotomy while the anterior aspect is opened [16].

5. Patellofemoral Dynamics and Joint Line Elevation

The bone is lengthened by opening the medial proximal tibia [17]. More significantly, it causes the tibial tuberosity to move farther away from the joint line [18]. An iatrogenic patella infera (patella baja) is the result of this geometric change pulling the patella downward [19]. This phenomenon has significant clinical implications and is more than just a radiological observation [20].

5.1 Measuring the Drop

The Blackburne-Peel and Caton-Deschamps indices regularly decline after MOWHTO, according to clinical investigations [21]. The size of the opening wedge directly correlates with the decrease in patellar height [22]. A clinically significant change is typically obtained with a 10-millimeter correction [23]. The patella may drop sufficiently in major corrections larger than 12 millimeters to engage the patella's inferior pole with the tibial insert during flexion, resulting in mechanical obstruction [24].

5.2 Clinical Implications of Patella Infera

The contact forces inside the trochlear groove are significantly changed by a lowered patella [25]. The femur is engaged at an incorrect angle by the thickest portion of the patellar cartilage [26]. This causes anterior knee pain, particularly when getting out of a chair or climbing stairs [27]. Inability to fully flex the knee or a sense of stiffness are common complaints from patients [28]. Additionally, patella infera makes subsequent complete knee replacements extremely difficult [29]. When the patella is tethered distally, it becomes very difficult to expose the joint after an arthroplasty; in order to flip the patella, vigorous soft tissue releases or even a tibial tubercle osteotomy are sometimes necessary [30]. This raises the possibility that the extensor mechanism will be disrupted during the conversion procedure that follows [31].

5.3 Avoiding Patellofemoral Complications

In order to save the patella, surgeons must change the trajectory of their cut [32]. Biplanar osteotomies are now the norm rather than retaining the osteotomy completely proximal to the tibial tuberosity [33]. An upward vertical cut leaves behind the patellar tendon imprint, while the horizontal cut passes behind the tuberosity [1]. The tibial tuberosity is still joined to the proximal portion as a result [2]. The tuberosity follows the joint line when the wedge opens [3]. Native patellofemoral mechanics are preserved because patellar height is completely unaltered [4]. To prevent breaking the tuberosity itself, caution must be used when making the vertical cut [5]. The patellar tendon insertion is protected by the use of oscillating saws with guarded blades [6]. In situations with patella alta, some surgeons recommend a minor distalization of the tuberosity as a therapeutic treatment, however this calls for careful planning [7].

6. Intraoperative Execution and Hinge Management

Perfect implementation is essential to the geometry planning's success [8]. The entire process revolves around the lateral hinge [9]. The construct's stability is jeopardized and the correction can be lost if the hinge breaks [10]. The precise placement of the hinge, which is typically slightly below the fibular head, should be determined during preoperative planning [11]. The surgeon must stop about 1 centimeter short of the lateral cortex during the osteotomy [12]. Instead of a whole break, a greenstick fracture of the lateral cortex is possible when the cut is completed with an osteotome [13].

Another thing to think about is bone grafting [14]. Hematomas may fill the gap in tiny wedges and heal on their own [15]. To avoid subsidence in bigger repairs, especially those larger than 10 millimeters, structural bone grafts or synthetic substitutes are required [16]. The graft maintains the plate against cyclic loading and acts as a scaffold for bone ingrowth [17]. Stability is improved by compression across the osteotomy site, which is made possible by the plate design [18]. Excessive compression, however, may cause the wedge to shut before to union [19]. Stability and compression must be carefully balanced [20]. Protection of the neurovascular system is crucial [21]. The anterior compartment is near the deep peroneal nerve [22]. Retraction needs to be forceful but delicate [23]. If the osteotomy extends too far posteriorly, there is a risk to the posterior neurovascular bundle [24]. Catastrophic harm is avoided during the cutting phase by maintaining constant awareness of the anatomical landmarks [25]. To verify the position of the guidewires and the depth of the cut, fluoroscopy should be used extensively [26].

7. Complications and Mitigation

Complications arise even with meticulous planning [27]. The most frequent intraoperative problem is hinge fractures [28]. The type of fracture determines the construct's stability in the event of a lateral hinge fracture [29]. With safe weight bearing, a basic nondisplaced fracture may recover [30]. Additional fixation or a different treatment may be necessary for a displaced fracture or one that extends into the plateau [31]. Another risk is non-union, especially in patients with low bone quality or smokers [32]. Preoperative smoking cessation is required [33]. Bone stimulation or revision grafting may be necessary in cases of delayed union [1].

Although infection rates are often low, they can have catastrophic consequences [2]. Antibiotics are used to treat superficial infections [3]. Hardware removal and debridement may be necessary for deep infections [4]. Because the medial tibia is located subcutaneously, hardware discomfort is prevalent [5]. following union is verified, usually a year following surgery, many patients need the hardware removed [6]. By being aware of these dangers, the surgeon can appropriately advise patients and be ready for any unforeseen circumstances [7].

8. Rehabilitation and Return to Sport

The quality of the bone and the stability of the fixation determine the postoperative regimen [8]. Although many surgeons recommend protected weight bearing for the first six weeks to allow for initial bone healing, stiff locked plating allows for immediate weight bearing [9]. To avoid stiffness, start range-of-motion exercises right away [10]. To complement the altered posture, strengthening concentrates on the hamstrings and quadriceps [11].

Resuming sports is a slow process [12]. Swimming and cycling are low-impact activities that can start as early as three months [13]. Depending on radiographic union, running and cutting sports are usually postponed until six months to a year [14]. Patients need to be aware that the altered load distribution requires time for the bone to restructure [15]. Returning to activities too quickly increases the risk of stress fractures or hinge failure [16]. In order to help the patient adjust to the new mechanical axis during gait retraining, physical treatment is essential [17].

9. Conclusion

The medial opening wedge high tibial osteotomy is an extremely harsh surgery [18]. Poor surgical geometry cannot be addressed by strong fixation plates and biological healing [19]. To meet the Fujisawa objective, the procedure requires rigorous adherence to preoperative digital templating [20]. Surgeons need to see beyond the coronal plane [21]. Aggressive treatment of the posterior tibial slope through asymmetric gap opening and full sMCL release is necessary to protect the ACL [22]. An upward biplanar incision is required to prevent patella infera while maintaining patellofemoral kinematics [23]. MOWHTO has a severe learning curve [24]. It necessitates a thorough grasp of radiological analysis and lower limb biomechanics [25]. Occasional knee surgeons should not perform this operation [26]. But when orthopedic surgeons become proficient in these multiplanar factors, MOWHTO becomes a highly predictable, definitive joint preservation method instead of a dangerous biomechanical gamble [27]. It provides an opportunity for the active patient to maintain a high degree of function, postpone arthroplasty, and keep their native joint [28]. Understanding osteotomy geometry is a commitment to biological preservation and long-term patient outcomes in a time when joint replacement is frequently the preferred course of action [29]. In the future of knee surgery, precise, geometry-driven intervention will be used to save joints rather than to replace them [30].

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