ARTHRITIS AND ARTHROPLASTY: THE KNEE

Principles of Correction for Monocompartmental Arthritis of the Knee

Dror Paley, MD

Introduction

Osteotomy for monocompartmental osteoarthritis of the knee is one of the most common indications for deformity correction surgery. Because arthrosis is already present, the goal of treatment is to preserve the knee joint and delay the need for total knee replacement (TKR) as long as possible. Although many patients who undergo osteotomy never require TKR, the osteotomy must be performed with the assumption that each patient must remain an optimal TKR candidate.

Biomechanics

Static malalignment is readily documented on long standing radiographs by measuring the mechanical axis deviation (MAD) in the frontal plane. Measurement of joint orientation angles and joint line convergence identifies the origin of the MAD (femur, tibia, joint line convergence). These objective parameters are not always a reliable means of predicting outcome after corrective osteotomy[1–3]. Theoretically, the moment arm created by the medial location of the ground reaction force vector is a better objective parameter to determine medial compartment loading. Unfortunately, this vector cannot be readily determined except in a gait laboratory. Gait studies of the knee have shown that the predicted load on the medial compartment is related to alignment. Hsu et al.[4] reported that the load on the medial compartment in a normally aligned knee is approximately 70%, compared with 30% on the lateral compartment (Figure 1). Furthermore, they showed that with an increasing varus tibiofemoral angle, the load on the medial compartment increased to 100% when the knee was in 6° of mechanical varus. Based on their model, “valgusizing” the knee to 4° changes the loading pattern to 50/50. If the load on the knee were 70% in the normal situation, everyone would likely have medial compartment osteoarthritis. However, the model presented by Hsu et al.[4] does not factor in joint reaction forces from the surrounding muscles and ligaments. Maquet[5] proposed that the tensor fascia lata (TFL) and gluteus maximus equalized the forces around the knee through their pull on the iliotibial band, neutralizing the adductor moment arm (Figure 2A).

Using cadaver and magnetic resonance imaging measurements, investigators at the Oxford Orthopaedic Engineering Center[6,7] developed an anatomy-based mathematical model to predict loads transmitted across the knee. This model incorporated the lines of action and moment arms of the major force-bearing structures crossing the human knee joint, including both muscles and ligaments. Theoretical values derived from this model replicate the previously published experimental measurements presented by Herzog and Read[8], validating the model. Including contributions from muscles and ligaments, both experimentally measured and theoretically calculated forces across the knee are more evenly distributed than published results have suggested. The difference between the static single limb standing simulations[4] and those that factor in the surrounding muscle forces is mostly attributable to the pull on the iliotibial band by the TFL and the gluteus maximus muscles. In a well-conditioned person, these muscles counter the adduction moment arm on the knee, unloading the overloaded medial side and transferring that load to the lateral side. As one gets older (older than 35 years) and naturally loses muscle mass and strength, the protection afforded the medial compartment by these muscles is diminished and lost (Figure 2, B and C). The loss of protein can precipitate the progressive deterioration of the medial compartment that most commonly occurs in people older than 40 years, which has led us to prescribe gluteus maximus and TFL strengthening exercises to treat early medial compartment osteoarthritis (e.g., 45° oblique straight limb-raising exercises).

Therefore, in persons older than 40 years, the static model presented by Hsu et al.[4] becomes representative of the clinical situation.

The dynamic loads that occur during walking and other weight-bearing activities of daily living have been difficult to accurately determine. Important issues regarding the dynamics of knee malalignment have been reviewed in detail by Andriacchi[1]. The normal forces that act on the lower extremity during gait produce moments tending to flex, extend, abduct, and adduct the knee. These are the primary factors influencing the distribution of medial and lateral loads across the knee. The ground reaction force acting at the foot during the stance phase of gait passes medial to the center of the knee. The perpendicular distance from the line of action of this force to the center of the knee is the length of the lever arm for this force. The product of the magnitude of the force and the length of the lever arm results in an adduction moment acting on the knee. This adduction moment during gait is an external load tending to thrust the knee into varus; it is also known as a lateral thrust[2,3].

The external forces and moments acting on the lower extremity can be measured directly in a gait laboratory. The internal forces acting through muscles, through ligaments, and on joint surfaces are of greater interest but can only be estimated based on the external forces and moments measured[1,9,10]. Mechanical equilibrium mandates that external forces acting on the limb must be balanced by internal forces generated by muscles and ligaments. Prediction of internal forces is extremely complicated because of the many combinations of muscle and soft tissue forces that can balance the external forces and moments acting on the limb. Solving this problem requires several simplifying assumptions, the most basic of which is to group internal structures together. Analysis of the relationship between external loads and internal forces under these assumptions allows estimation of the magnitude of the joint reaction force acting across either the medial or lateral compartment independently. The distribution of the medial and lateral joint reaction forces shows that the adduction moment is the primary factor producing the higher medial joint reaction force during normal function. For a group of normal participants, the maximum joint reaction force across the knee is approximately 3.2 times the body weight, with 70% of the load passing through the medial compartment. The average maximum magnitude of the adduction moment during normal gait for this population has been calculated as approximately 3.3% of the product of body weight and height[1]. This adduction moment is greater than the moments calculated for either flexion or extension of the knee in the same study group.

Some patients modify their gait, effectively reducing the load on the medial compartment of the knee. The adaptive mechanism used reduces the adduction moment and has been related to a shorter stride length and an increase in external rotation of the foot (toe-out position) during stance phase[1–3]. The toe-out position places the hindfoot closer to the midline, beneath the center of gravity. This simply moves the ground reaction vector toward the center of the knee, effectively reducing the lever arm of the external ground reaction force and therefore the resulting adduction moment. Patients are considered to have high adduction moments if the calculated moment exceeds 4% of the product of body weight and height when walking at speeds of approximately 1 meter per second.

The clinical outcome after treatment of patients with varus gonarthrosis by valgus high tibial realignment osteotomy has been closely related to the magnitude of the adduction moment measured during preoperative gait analysis[1–3]. Patients who had low preoperative adduction moments had better clinical results initially, and the results were sustained during a mean follow-up period of 6 years. The valgus correction was maintained with follow-up in 79% of the low adduction moment group compared with only 20% of the high adduction moment group.

Load transmission across the knee can effectively be altered by adjusting the location of the center of gravity. This dynamic compensation involves either the use of external support or gait modification. Shifting the upper body center of mass to a position directly over the involved limb can decrease the medial compartment force by 50% compared with its value when the center of gravity is positioned in the midline[4]. Clinical evidence has already established the importance of gait alteration and its relationship to results after corrective high tibial osteotomy (HTO). Patients with the best clinical outcomes are able to modify their gait, externally rotating the limb and developing a lower adduction moment at the knee.

Joint laxity is a further confounding variable to consider when determining the risk of developing osteoarthritis secondary to malalignment (Figure 2C). Sharma et al.[11] reported that ligament laxity can precede the development of osteoarthritis. Ligament laxity can result in dynamic malalignment during gait, with associated changes in loading patterns across the knee. Collateral ligament laxity can increase the risk of gonarthrosis and cyclically contribute to progression of the disease. Lateral collateral ligament (LCL) laxity typically is associated with varus malalignment and, when superimposed, might have a synergistic effect. The TFL can protect the knee from overload caused by LCL laxity. Again, this protection is gradually lost or overwhelmed with increasing age, deconditioning, and deformity.

Deformities Associated with Monocompartmental Osteoarthritis

The deformities associated with monocompartmental osteoarthritis can be subdivided into bone deformities and joint (soft tissue) deformities.

Bone Deformities of Femur and/or Tibia

- Varus
- Valgus
- Recurvatum
- Procurvatum
- Torsion
- Limb length discrepancy

Joint Deformities

- LCL laxity
- Medial collateral ligament (MCL) laxity
- Plateau depression
- Lateral subluxation
- Patellar maltracking
- Flexion contracture

Historical Background

The concept of using HTO to treat monocompartmental osteoarthritis is credited to Jackson and Waugh[12], who presented a report of eight procedures in 1961. The authors performed an osteotomy distal to the tibial tuberosity; both closing wedge and concave distal dome osteotomies were described. Difficulties with bone healing in the subtuberosity region led Coventry[13], in 1965, to present a report about closing wedge osteotomy proximal to the tuberosity through cancellous bone. Maquet[5] presented a report of a concave distal dome osteotomy. The Maquet osteotomy was designed to take advantage of the rapid metaphyseal bone healing of the region above the tuberosity and to add an element of adjustability.

The common goal for all the HTO procedures was to shift the mechanical axis from the medial compartment to the lateral compartment. Although it is impractical to completely unload the medial compartment, the goal of HTO is to reduce the load on the medial compartment. In the normally aligned knee (2° of tibiofemoral mechanical varus), the medial compartment has been estimated to take 75% of the load during single limb stance. When the mechanical axis passes through the center of the knee, the medial compartment bears 70% of the load. When the mechanical axis is moved into 4° of valgus, the load is 50% medial and 50% lateral. When the mechanical axis is moved into 6° of valgus, the load is 40% medial and 60% lateral (Figure 1). Most authors recommend that for treatment of monocompartmental osteoarthritis, the mechanical alignment of the lower limb should be moved into 2° to 6° of mechanical valgus[13–16]. Hernigou et al.[15] showed that the best results were with 3° to 6° of mechanical valgus and that results deteriorated when the mechanical valgus was more than 6°. Fujisawa et al.[14] recommended that the mechanical axis pass between 30% and 40% lateral to the center of the tibial spines. This distance has been termed the *Fujisawa point* (Figure 3). Jacobi and Jakob[16] modified the overcorrection recommendation made by Fujisawa et al.[14] based on the amount of cartilage space remaining on the medial side.

The Coventry procedure has become the “knee-jerk” response to monocompartmental osteoarthritis. Conversions of previous Coventry osteotomies to TKR have been associated with poor results[17–19]. Numerous factors contribute to greater technical difficulty and possibly poorer results of TKR after Coventry osteotomy. Because bone is resected proximal to the tibial tuberosity, the tuberosity moves closer to the knee joint line. After the osteotomy, the patella might ride proximally, creating a pseudo-patella alta. It is a “pseudo-alta” because in cases of true patella alta, the patellar tendon is abnormally long whereas in this case, it is of normal length. Alternatively, the patella might not be able to ride proximally because of the tethering retinaculum. The patellar tendon scars down and contracts, especially if the knee is splinted in extension after the osteotomy. This leads to a pseudo-patella baja according to the Insall ratio[20]. Again, this is a “pseudo-baja” because the tibial tuberosity to patellar distance decreases, although the level of the patella to the femur remains the same. After TKR in the case of patella alta, the thickness of the tibial prosthesis restores the level of the tibial tuberosity and thereby pulls the patella down to the normal level by means of the contracted shortened patellar tendon. Eversion of the patella for exposure is more difficult with pseudo-patella baja. Bone resection with the wedge based laterally leads to truncation of the proximal tibia. This leaves the lateral and posterior tibial plateau thin and unsupported. This scenario can make seating a large central or a peripheral tibial component peg problematic.

The valgus deformity resulting from the overcorrection created during osteotomy can also make TKR more difficult and might require greater bone resection. Soft tissue considerations, such as previous incision, previous peroneal nerve palsy, ligamentous laxity secondary to the osteotomy, and flexion deformity of the knee, all make TKR more difficult and complication-prone after previous Coventry HTO.

There are numerous relative contraindications for the Coventry osteotomy, including LCL instability, lateral subluxation, medial plateau depression, knee flexion less than 90°, knee flexion contracture greater than 10°, lateral compartment arthrosis, advanced age, and obesity[20]. These limitations might apply to the Coventry HTO but not to HTO in general. A customized approach to HTO can address many of these circumstances.

Customized HTO

Rather than one osteotomy for all cases of monocompartmental osteoarthritis, an “á la carte” approach is recommended[21], treating each case in a customized fashion according to the deformities that need to be addressed.

Various Types of Deformities and Suggested Treatment Methods

Varus Deformity Only: Type of Osteotomy and Fixation

The level of osteotomy for the proximal tibia can be proximal or distal to the tuberosity. When performing the osteotomy, the level of the center of rotation of angulation (CORA) should be considered. The CORA is almost always at the level of the joint or just distal to the joint. Therefore, if the osteotomy is made proximal to the tuberosity, it requires only angulation. If the osteotomy is made distal to the tuberosity, it requires angulation and translation[22]. Proximal to the tuberosity, a closing wedge osteotomy narrows the distance between the joint line and the tibial tuberosity, making future TKR more difficult. To preserve the distance from the tuberosity to the joint while still performing a closing wedge osteotomy at the Coventry level, the osteotomy can include the tuberosity with the proximal segment[23]. Opening wedge osteotomy proximal to the tuberosity tightens the MCL, which often has pseudolaxity from loss of medial joint space cartilage. An opening wedge osteotomy requires either bone graft for acute corrections or gradual distraction by an external fixator for bone regeneration. Hernigou et al.[15] published a very large series with a transverse medial opening wedge osteotomy. Franco et al.[24] modified this osteotomy, starting more distal on the medial side and ending just proximal to the head of the fibula, leaving the lateral cortex intact. Their opening wedge step plate supported the base of the osteotomy only as long as the lateral cortex remained intact. Staubli et al.[25] modified the osteotomy of Franco et al.[24] and developed a medial opening wedge locking plate for fixation. Jacobi and Jakob[16] also reported on the technique of Staubli et al[25]. Franco et al.[24] recommends bone grafting the defect if the base of the wedge is more than 10 mm, whereas Staubli et al.[25] almost never graft the defect. With a locking plate, one need be less concerned regarding maintaining the integrity of the lateral cortex because of the fixed angle relationship of the screws to the plate (Figure 4). Osteotomies distal to the tuberosity need to be performed in combination with lateral translation because they are far from the CORA (Figures 5 and 6). This applies equally to both opening and closing wedge osteotomies. Because of the poorer healing potential of this region, it is essential to preserve the periosteum and preferably perform the osteotomy with a minimally invasive approach. Bony contact at the osteotomy site is greater than for an opening wedge osteotomy because translation inserts the corner of the proximal segment into the medullary canal of the distal segment. Dome osteotomy is also an angulation-translation correction. The Maquet dome osteotomy consisted of concave distal rotation around an axis in the center of the circular cut distal to the CORA. The Maquet dome therefore creates a medial translation deformity. Paley et al.[21] and Paley[22] described the focal dome osteotomy (Figure 7) with which the center of the circular cut is “focused” on the CORA. This concave distal dome osteotomy translates in the same direction as the straight angulation-translation osteotomy and is distal to the tuberosity.

Varus Deformity plus Fixed Flexion Deformity (FFD)

The most common complaint with medial compartment osteoarthritis (MCOA) is not medial pain but rather anterior knee pain, which is caused by anterior impingement and FFD of the knee.

FFD is much more common than is realized and might be the primary cause of failure of realignment surgery. The definition of FFD is radiological and not clinical. Small degrees of FFD can be missed clinically but are easily quantified radiographically. The key is the lateral view radiograph of the knee in maximum extension. Normally, the anterior cortical line of the distal femur and proximal tibia are collinear with each other during full extension of the knee. Normally, they might be in up to 5° of hyperextension to each other but might not be in any flexion. Therefore, 5° of FFD measured radiographically is significant. Various factors contribute to FFD. The posterior distal femoral angle (PDFA) and the posterior proximal tibial angle (PPTA) should be measured to determine the presence of any sagittal malorientation of the knee joint from the distal femur or proximal tibia, respectively. Anterior tibial and femoral osteophytes can block full extension. A cyclops lesion from the stump of an anterior cruciate ligament (ACL) or osteophytes of the tibial spines and femoral notch also can limit extension. FFD is an indication for arthroscopy combined with the osteotomy. Notchplasty and osteophyte assessment and resection are helpful. Extension of the proximal tibial plateau to a maximum PDFA of 90° should be considered to treat the FFD (Figure 8). Greater degrees of flexion can be corrected by a distal femoral extension osteotomy. Varus associated with procurvatum deformity treated by opening wedge osteotomy can be treated proximal or distal to the tuberosity; when treated by closing wedge osteotomy, it should be treated distal to the tuberosity to avoid narrowing the distance between the patellar tendon insertion and the joint line.

Varus Deformity plus MCL Pseudolaxity

The MCL can be lax or contracted from loss of cartilage or bone on the medial side. Valgus stress radiographs differentiate between lax and contracted MCL. In the case of a contracted

MCL, it is important that the osteotomy does not further stretch the MCL because that would apply pressure to the medial side of the joint. In the case of a lax MCL, the osteotomy can be used to retension the MCL. If the MCL is not retensioned, residual knee instability can remain and the patient might complain of a “wobbly feeling” in the knee, which produces lack of confidence in the knee even in the absence of pain. Several methods to retension the MCL were discussed above and are illustrated. An alternative is to perform a hemiplateau elevation to tighten the ligamentous laxity, considering the laxity is caused by cartilage and bone substance loss on the medial side (Figure 6).

Varus Deformity plus LCL Laxity

LCL laxity commonly is associated with medial compartmental osteoarthritis and varus deformity. LCL laxity likely occurs secondary to chronic stretch in a varus knee. LCL laxity is not corrected by valgus realignment of the tibia or femur unless the realignment is excessive. LCL tightening can be performed independent of the type of tibial osteotomy. Gradual transport of the proximal fibula distally with an oblique osteotomy will retension the LCL.[21,22,26] Retensioning the LCL can be performed acutely by taking down the proximal tibiofibular joint and advancing and fixing the head of the fibula distally (Figure 9).[23] Coventry recognized the importance of this procedure and performed advancement of the LCL with the hamstring tendon routinely along with his closing wedge osteotomy[27].

LCL laxity can result from an HTO, even if it was not present preoperatively, if the proximal tibiofibular joint is released or resected in combination with any type of valgusizing osteotomy. This is especially true when combined with a Coventry closing wedge osteotomy[28].

Symptomatic cases that have been treated this way can be salvaged by retensioning the LCL by "distalizing" the head of the fibula (Figure 9).

Varus Deformity plus ACL Deficiency

The normal plateau of the tibia has a 10° posterior tilt (PPTA = 80°). During single limb stance, maximum loading of the knee is in 20° of flexion when the plateau is parallel to the ground and when the quadriceps joint reaction force is greatest. The latter produces an anterior drawer on the tibia, subluxing it forward with each step. If the plateau of the tibia were in recurvatum when the knee is maximally loaded, the femur would tend to move forward on the tibia, countering any ACL insufficiency. In veterinary medicine, the treatment of ACL insufficiency in a dog is an extension osteotomy[29]. In the treatment of MCOA in combination with ACL insufficiency, the proximal tibia should be extended to eliminate the posterior tilt (PPTA = 90°) in combination with the valgusizing osteotomy. Although this can be achieved with a medial opening wedge osteotomy above the tuberosity, it is more difficult at that level to angle the osteotomy in the sagittal plane because of the intact lateral bony hinge. It is easier and more reliable, controlled, and accurate to alter sagittal alignment below the tuberosity (Figure 10).

Varus Deformity plus Lateral Subluxation and Medial Plateau Depression

Lateral subluxation in the absence of severe bone loss of the medial tibial plateau can be treated by retensioning the MCL and LCL together with realignment[23,26]. If no plateau depression is present, the preferable method of treatment of the lateral subluxation is varus osteotomy of the femur in combination with valgus osteotomy of the tibia[5].

The varus of the femur will lead to reduction of the lateral subluxation. When lateral subluxation is present together with medial plateau depression, the knee often is very unstable. The tibia reduces with valgus stress, indicating that it would reduce if the medial joint space were filled by elevation of the plateau (Figures 11 and 12). Elevation of the medial plateau is performed from a medial incision and fixed with cannulated large-diameter screws from the lateral side. The opening wedge space is filled with autograft, allograft, or bone graft substitute. The best way to diagnose the medial plateau depression is to draw a line across the medial plateau toward the lateral plateau. If the lateral plateau is on the same line, the medial plateau is not depressed. If the medial plateau line passes superior to the lateral plateau, it is depressed. Elevation leads to immediate stabilization of the joint and can be combined with retensioning of the LCL.

Varus Deformity plus Rotational Deformity

Rotational deformity correction can be performed simultaneously with the varus realignment. Rotation of osteotomies proximal to the tuberosity will lead to displacement of the patellar tendon insertion, medially with internal rotation and laterally with external rotation (Figure 13). If no patellar maltracking is present, the osteotomy should be performed distal to the tuberosity. To correct internal tibial torsion together with varus, if the osteotomy were performed proximal to the tuberosity, the tibial tuberosity would displace laterally, producing patellar maltracking. External tibial torsion often is associated with a laterally located patellar tendon insertion and patellofemoral maltracking. To correct external torsion with varus and patellar maltracking, the osteotomy should be performed proximal to the tuberosity so that the internal rotation correction medializes the patellar tendon insertion. Paley[22] described an L-shaped osteotomy to facilitate patellofemoral realignment together with rotation, frontal plane correction, and sagittal plane correction (Figures 14 and 15). In addition to rotation and angulation, this osteotomy can be translated in the sagittal and/or frontal planes. Translation anteriorly in the sagittal plane unloads the patellofemoral joint without producing a bump, as is produced with the Maquet procedure. This is because the tuberosity remains in the same line as the anterior cortex of the tibia. Therefore, patients can kneel without pain.

Conclusions

Osteotomy surgery for medial compartment osteoarthritis has become less common as unicondylar knee arthroplasty and TKR are performed in patients of younger ages and for milder cases of arthritis. Osteotomy surgery lost its popularity after it was shown that conversion to a total knee yielded worse results after previous Conventry osteotomy. The Conventry closing wedge osteotomy is only one of many types of HTO. It addresses only the varus deformity and is contraindicated in the presence of flexion, subluxation, and bone loss of the medial side. The à la carte approach allows treatment of all the elements of deformity. It follows the principles of knee replacement surgery, of balancing the soft tissues and realigning the bones. Based on my experience, this approach reliably prolongs the life of the knee for 10 to 20 years. With such good results achieved with this osteotomy, as reported by me and others, it is unclear why it is not used more often.

One of the biggest reasons is economic. Knee replacement surgery is economically driven by both industry and the surgeon's own practice. TKR requires less follow-up, and most surgeons are well trained and skilled in performing arthroplasty. As fewer surgeons perform osteotomies, fewer residents are trained and proficient in their use. Considering that we tend to practice what we have learned, this becomes a self-fulfilling prophecy. Keep in mind that joint replacement is akin to joint amputation. The joint is removed and replaced by a prosthesis. When this goes well, it is one of the wonders of surgery. When it fails or when infection occurs, it often is a disaster. Osteotomy surgery does not burn bridges, but joint replacement does. It is my opinion that osteotomy should be considered more often than it currently is, especially for patients younger than 60 years.

In summary, osteotomies for monocompartmental osteoarthritis have to be performed with careful attention to both soft tissue and bone deformities. This discussion has described an overview of some of the most common scenarios. I think that osteotomies can be used for almost all patients with monocompartmental osteoarthritis as a first-line procedure before unicondylar knee arthroplasty or TKR. Osteotomy surgery burns no bridges and, if properly performed, can even make future arthroplasty simpler.

Acknowledgment

The author thanks Dori Kelly, MA, for an excellent job of manuscript editing.

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Figure Legends

Figure 1. The medial plateau force is 70% in single limb stance when the mechanical axis passes through the center of the knee in a normally aligned knee. It is 95%, with only 6° of mechanical tibiofemoral varus and is reduced to 50% with 4° of valgus and 40% with 6° of valgus (*From*, Hsu et al.[4]).

Figure 2. *A*, Static analysis predicts 70% of the load will pass through the medial compartment in a normally aligned knee. Dynamic analysis factors in the pull of a strong TFL and predicts equal balance of the load through the medial and lateral compartments. *GRV*, ground reaction vector. (Reprinted with permission from the American Academy of Orthopaedic Surgeons (Mont MA, Stuchin SA, Paley D, Sharkey PF, Parvisi J, Tria AJ Jr, Bonutti PM, Etienne G. Different surgical options for monocompartmental osteoarthritis of the knee: high tibial osteotomy versus unicompartmental knee arthroplasty versus total knee arthroplasty: indications, techniques, results, and controversies. Instr Course Lect. 2004;53:265-83. Review.)) *B*, When genu varum is present, the load on the medial side is predicted to be 90%, but if TFL dynamic pull is present, it is reduced to 50/50. *GRV*, ground reaction vector. Copyright 2007 Rubin Institute for Advanced Orthopedics. *C*, When LCL laxity is present, a medial thrust results, especially if the TFL is weak. If a strong TFL is present, it can reduce the medial compartment forces.

Figure 3. Fujisawa et al.[14] divided the medial and lateral plateaus by the percentage of distance from the center of the knee. The medial and lateral edges of the medial and lateral plateaus were considered to be 100%, and the center of the knee was considered to be 0%. The best results

from HTO were obtained when the mechanical axis line of the limb passed through the 30% to 40% lateral plateau region. We call this the *Fujisawa point*. (*From*, Paley[22].)

Figure 4. *A*, Genu varum with no loss of cartilage. No deformity is present in the sagittal plane. *B*, Intraoperative image intensifier views of the ankle, hip, and knee before the osteotomy. Using a grid, the MAD can be determined intraoperatively. *C*, The Puddu type of osteotomy[24] is performed and wedged open with a Puddu wedge until MAD = 0. *D*, The osteotomy can be stably fixed with a medial locking plate. *E*, Final radiographs after healing of bilateral medial opening wedge osteotomies. *LDFA*, lateral distal femoral angle; *LDTA*, lateral distal tibial angle.

Figure 5. Angulation-translation osteotomy below the tuberosity. The translation is a result of rotation around the CORA, which is at a more proximal level. (*From*, Paley[22].)

Figure 6. *A*, Varus with one-third cartilage loss and monocompartmental osteoarthritis. MAD = 40 mm and medial proximal tibial angle (*MPTA*) = 80°. *B*, Treated with angulation-translation osteotomy below the tuberosity and a circular external fixator. Corrected to one-third the way to the Fujisawa point. (*From*, Paley[22].)

Figure 7. *A*, The Maquet dome osteotomy leads to medial translation of the tibial shaft. *B*, Focal dome osteotomy performs the correction at the deformity, keeping the tibial shaft in line with the center of the knee. (*From*, Paley[22].)

Figure 8. *A*, Genu varum with MCOA and 10° of FFD of the knee. The anterior cortical lines of the femur and tibia are flexed. *B*, The preoperative PPTA was 75°. The knee was arthroscoped, anterior osteophytes resected, and notchplasty performed. The osteotomy was extended to PPTA = 90°. The anterior cortical lines are collinear after osteotomy. *C*, The knee is compared before and after osteotomy on the anteroposterior view radiograph. Note the medial osteophytes, which were resected through a separate incision.

Figure 9. *Left*, LCL laxity as a sequela of Coventry osteotomy fixed with a lateral plate. The proximal tibiofibular joint was resected according to Insall, and the fibular head migrated proximally and fused to the tibia. *Right*, The arthrodesed proximal tibiofibular joint was osteotomized, and the fibula was transported distally acutely and fixed with a screw. (*From*, Paley[22].)

Figure 10. *A*, MCOA with varus and ACL deficiency. The tibia is permanently subluxed anteriorly on the femur. *B*, The deformity was corrected below the tuberosity with an external fixator (Taylor spatial frame) in a gradual manner. The correction included extension to PPTA = 90° to compensate for the ACL deficiency. *C* and *D*, The limb was corrected to the Fujisawa point. The valgus lateral translation and extension are evident. *E*, Final clinical appearance.

Figure 11. *A*, Severed MCOA with varus, ACL deficiency, and lateral knee subluxation. LCL laxity and medial plateau depression. *B*, Varus stress emphasizes the complete loss of medial joint space and the lateral subluxation in varus. *C*, Valgus stress reduces the knee and shows the medial pseudolaxity. A line drawn across the lateral plateau does not intersect the medial plateau,

indicating loss of bone substance or depression of the medial side. *D*, Intraoperative radiographs show the medial hemiplateau osteotomy and elevation with fixation with 7.0-mm cannulated screws from the lateral side. The medial plateau is elevated to the level of the lateral plateau. *E*, To overcorrect the varus, it is necessary to perform a second osteotomy below the tuberosity. This osteotomy is used also to extend the knee to PPTA = 90° and anteriorly translate the tibia for the ACL deficiency. This is accomplished with the TSF external fixator. To retension the LCL, the tibia was lengthened and the fibular head transported distally. *F*, The final clinical result is shown with excellent knee range of motion.

Figure 12. *A*, Genu varum with medial collateral pseudolaxity and lateral subluxation. The medial and lateral plateau lines are not collinear. *B*, Medial hemiplateau elevation with screw fixation combined with acute medial opening wedge osteotomy fixed with a medial locking plate. *C*, Final union.

Figure 13. *A*, Effect of osteotomy for internal tibial torsion with osteotomy proximal or distal to the tibial tuberosity. If the osteotomy is proximal, the tuberosity will be moved laterally, creating maltracking of the patella. *B*, External rotation deformity with patellofemoral maltracking. If the osteotomy is made proximal to the tuberosity, the patellar tendon will displace medially, realigning the patellofemoral mechanism. (*From*, Paley[22].)

Figure 14. L-shaped HTO for cases of varus MCOA with external torsion and patellofemoral maltracking. *A*, The incision allows a lateral release to be performed. *B*, A saw is used to cut in the frontal plane behind the tibial tuberosity. *C*, A Gigli saw is used to complete the L-shaped

osteotomy below the tuberosity. *D*, The tibia is rotated internally, and the tuberosity displaces medially and anteriorly. *E*, Fixation with a locking plate. The tibia can be displaced anteriorly, as with a Maquet osteotomy, without a resulting anterior bump.

Figure 15. *A*, Genu varum with external tibial torsion and patellar maltracking. *B*, Radiographs of L-shaped osteotomy with internal fixation in place.