The knee is a complex and dynamic joint that is subjected to many forces during normal activities. Increased forces through a compartment of the knee may be partially responsible for the development of degeneration of that same compartment, leading to conditions such as malalignment of the lower extremity. One also could make the argument that abnormal forces might cause supporting structures to fail which, in turn, result in malalignment. Whether increased forces lead to degeneration, followed by malalignment, or lead to structural failure and then malalignment, possibly both—it follows that efforts to realign the lower extremity would reduce existing, problematic destructive forces on the affected compartment.

To this end, many operative and nonoperative measures have been applied in an attempt to realign the lower extremity and reduce excessive forces impacting the knee, with different levels of success. All approaches have the common theme of endeavoring to shift the weightbearing axis away from the affected compartment.

Alignment
The normal alignment of the lower extremity has been critically examined and defined. A line drawn from the center of the femoral head to the center of the ankle should pass through the center of the knee (Fig. 1). As defined in deformity analysis, a line that falls towards the lateral side of the knee indicates that the lower extremity is in valgus. Similarly, a line that falls onto the medial side of the knee indicates that the lower extremity is in varus. As the weightbearing axis of the lower extremity follows this line, a varus alignment would tend to increase the load in the medial compartment of the knee, and a valgus alignment would tend to increase the load in the lateral compartment. The knee joint, itself, is not perpendicular to the mechanical axis of the lower extremity. Rather, according to Paley and Tetsworth, the joint is internally rotated 3° relative to the mechanical axis of the lower extremity.

Both Hsu and colleagues and Moreland and coworkers have critically looked at the alignment of the lower extremity in an effort to define what is normal. Hsu and associates used a radiographic analysis of 120 normal subjects to define normal alignment of the lower extremity. The study found that the normal tibiofemoral mechanical axis averaged 1.2° varus, and the normal relationship between the femoral mechanical and anatomic axes was 4.2° (4.9° when full-length films were analyzed). During a single-leg stance, it was determined that 75% of body weight passed through the medial compartment. Knee joint obliquity was more varus in males (1.0° ± 1.5° varus) than in females, who tended to have a more valgus obliquity (0.1° ± 1.7° valgus). Similarly, Moreland and colleagues found the tibiofemoral mechanical axis to be 1.3° varus in 25 normal male volunteers. In this study, the joint line obliquity averaged 2.6° to 3.0° varus.

Biomechanics
An understanding of the basic biomechanics of the normal knee is a prerequisite to understanding the diseased knee and the progression of pathology within the deranged knee. The knee can be thought of as functioning in different capacities within the gait cycle. In the swing phase,
the knee provides the necessary forces and moments to overcome and control the inertial effects of the leg. In the stance phase, the knee is subjected to compressive forces, and one of its major roles is to resist loads imposed by the foot (ground reaction forces). Variables on the knee during the stance phase include the magnitude of the force on the knee and the direction of the force relative to the articular surfaces and axis of the lower extremity. The magnitude of the forces through the knee joint have been evaluated by several investigators, who have shown that during normal activity the knee is subjected to forces of 1.3 to 2 times body weight.4-6

The direction of the ground reaction force (GRF) is the second variable force across the knee joint. This force is directed upward and posterior to the knee during heel strike, but at midstance the force is directed upward and anterior to the knee. Because the knee is able to flex and extend, the effect of these forces is to cause a flexion (heel strike) or extension (midstance) moment on the knee. These moments must be controlled by the antagonist muscle group (quadriceps at heel strike, hamstrings at midstance) to provide stability to the knee. The combination of GRF plus the antagonist muscle force (AMF) on the knee is what causes the joint reaction force (JRF), or the compressive force within the knee: GRF + AMF = JRF.

The moment arm of the antagonist muscle is considerably smaller than the moment arm of the GRF or almost any externally applied force; therefore, the force exerted by the antagonist muscle group is considerably greater than that of the GRF. The length of the antagonist muscle groups is relatively fixed by the point of insertion of the muscle group. However, the length of the moment arm of the GRF, or externally applied force, can be very long, such as when one performs a straight leg raise with ankle weights. In most activities, the externally applied load has the mechanical advantage of being up to six times greater than that of the antagonist muscle. This causes very high forces through the knee during normal activities. Thus, a person who weighs 70 kg (generating a force of approximately 700 N) can easily generate forces through the knee in the range of 3500 N during normal activities.7

**Coronal Plane Biomechanics**
The GRF not only has an effect in the sagittal plane, but it also exerts an effect in the coronal plane, where it wields varus and valgus forces on the knee. During normal ambulation, there is a medially directed portion of the GRF that imparts a varus moment on the knee. Using the example of a 70 kg individual, the varus force is approximately 50 N in the normal knee. The moment arm generated from a 50 N force about the knee must be equaled by an opposite moment within the knee.

The knee has available three possible means of creating internal moments to neutralize the varus or valgus moments created by external forces. The mechanisms are: 1) redistribution of the joint contact force between medial and lateral compartments, 2) redistribution of the joint contact force that is augmented by additional forces from antagonist muscle contraction, and 3) production of ligamentous loads by stretching the collateral ligaments.

It is evident that during normal activities the knee is subjected to extreme loads. In the sagittal plane this can be explained by the relatively short lever arm of the quadriceps and hamstrings, as compared to the long moment arms of GRFs. Because of the short lever arms, the knee is subjected to forces that can be up to several times greater than body weight during normal activities. In the coronal plane, the normal medially directed force on the
foot causes the JRF to be redistributed between the medial and lateral compartments to maintain a stable joint. When the ability of the JRF to be redistributed is exceeded, this force has to be augmented by either coordinated co-contraction of the quadriceps and hamstrings or by loading of the collateral ligaments. The load experienced by the knee increases dramatically in both of these cases, with clinical manifestations.

**Biomechanics of the Varus and Valgus Knee**

It is well known that the alignment of the lower extremity affects how the extremity is loaded. A lower extremity that is in varus will have its mechanical axis positioned medial to the midline of the knee. Conversely, the mechanical axis will fall lateral to the midline of a knee in a valgus lower extremity. Because the weightbearing axis of the lower extremity follows the mechanical axis, a varus knee will experience a shift in the joint compressive pressures towards the medial compartment, and the valgus knee will, similarly, experience a shift of the joint compressive pressures toward the lateral compartment.

In a knee with varus angulation, the mechanical axis falls medial to the midline of the knee. During normal gait, there is, typically, a medially directed force causing a varus moment on the knee. This medially directed component of the GRF acts arithmetically with the mechanical axis to increase the varus moment on the knee and consequently increase the pressure in the medial compartment and decrease the force on the lateral compartment of the knee.

With increased amounts of varus deformity, forces increase in the medial compartment and proportionally decrease in the lateral compartment. At a critical level, the pressure on the lateral compartment reaches zero and the lateral compartment begins to separate unless the quadriceps and hamstrings produce augmented compressive forces or the LCL is tensioned. Co-contraction of the quadriceps and hamstrings is able to neutralize the external varus force, but it does so at the expense of increased joint contact forces in the medial compartment. If the lateral compartment is allowed to separate, the LCL is tensioned. The LCL is then able to resist the external varus moment; however, the force on the medial compartment is similarly increased. In addition, the increased load on the LCL can lead to its attenuation and ultimate failure.

In a lower extremity with valgus angulation, the mechanical axis falls laterally to the midline of the knee. As the weightbearing axis of the lower extremity follows the mechanical axis, the compressive forces across the knee joint will shift toward the lateral compartment, with increasing levels of valgus angulation. Because the mechanical axis falls laterally to the midline of the knee, it tends to create a varus moment around the knee. However, there is still a medially directed component of the GRF from normal gait, and this force creates a varus moment around the knee. The varus moment tends to offset the valgus moment from the laterally directed mechanical axis and minimizes, therefore, the effects of the valgus deformity. In a valgus knee, the force on the lateral compartment increases, and the force on the medial compartment decreases but proportionally less than for same angulation in the varus knee.

Changes in the varus/valgus angle of the lower extremity affect the distribution of load across the medial and lateral compartments of the knee. At neutral varus/valgus angulation, there is almost twice the compressive force across the medial joint as across the lateral joint. This is a result of the medially directed component of the GRF. As the knee moves into varus, the compressive force increases in the medial compartment and decreases proportionately in the lateral compartment. Similarly, as the knee moves into valgus, the compressive forces increase in the lateral compartment and decrease in the medial compartment. The correction of varus or valgus malalignment will reduce pressure in the affected compartment (Fig. 2); however, this comes at the expense of increasing pressure in the opposite compartment. Therefore, for cases of varus or valgus malalignment, the common goal of all intervention, whether operative or nonoperative, is to move the mechanical axis away from the affected compartment toward the opposite compartment.

**Relationship between Static and Dynamic Loading**

Two different methods exist for analyzing forces across the knee, static and dynamic. The static model, as popularized by Maquet, uses full-length radiographs of the lower extremity to assess where the mechanical axis passes in relation to the knee joint. If the axis passes medial to the knee joint, then a varus deformity exists, and the medial compartment will be over loaded. Similarly, if it passes lateral to the midline of the knee, then a valgus deformity exists, and the lateral compartment will be over loaded. In static models, the location of the mechanical axis is an indicator of load-bearing across the knee joint.

Static models have been criticized for not taking into consideration the influence of forces outside of the model or on the motion of the models. Therefore, these models may not accurately represent the true biomechanical relationship and interplay of forces and moments on the moving knee. Harrington, however, stated that under static loads these models will accurately predict the correlation between the tibiofemoral angle and load across the knee. However, under dynamic testing, Harrington also showed that loads are transmitted further medially than static analysis would predict. He further demonstrated that there is no correlation between the tibiofemoral angle, magnitude of the load, and the location of the load across the knee joint. Harrington showed that patients with knee deformities modify the force profile of their gait cycle. Specifically, he found that there is a blunting and absence of peak forces as compared to normally aligned knees. Harrington concluded that patients with knee deformities modify force transmission at the joint.
by altering their gait pattern velocity during ambulation.

Using gait analysis and force plates to perform dynamic analysis of the forces across the knee joint, Johnson and coworkers\(^\text{11}\) found that for knees with varus deformity the load on the medial compartment rapidly approached 100% of the total joint load. However, for valgus deformities, the investigators found that the load remained medial in 20 out of 28 cases. They concluded that the difference between the measurements of static and dynamic analysis of load across the knee joint is the influence of the medially directed component of the GRF and its effect of medializing the forces and moments through the knee joint. This medially directed force has been well described by several investigators\(^\text{6,12}\) and, as was seen in the above examples, has a significant influence on the distribution of forces through the knee.

**Influence of Alignment**

**Incidence of Osteoarthritis**

As shown above, the varus or valgus malalignment has a tremendous influence on the loading of the articular surfaces of the knee. However, what needs to be demonstrated is whether or not this malalignment or increased loading of the articular surfaces results in an increased incidence or increased rate of progression of osteoarthritis (OA) in the knee. To date, there are no studies that have defined the relationship between knee alignment and the incidence of OA of the knee. In spite of this, several animal models have been able to demonstrate a causal relationship of deformity on degenerative changes within the knee joint.

Okata and colleagues\(^\text{13}\) were able to produce unicomparte-

mental OA by applying a varus stress to moving rabbit knee joints. In this study, the degenerative changes were limited to the medial compartment of the knee. They found that the duration of application of the varus stress had a greater impact on the degree of degenerative changes found in the knee than did the magnitude of the varus stress applied. While they found significant changes in the articular cartilage consistent with degenerative changes, they did not find subchondral trabecular hypertrophy.

Wu and coworkers\(^\text{14}\) created 30° varus or valgus proximal tibial osteotomies in rabbits in order to determine whether or not subchondral bone changes are an important step in the development of OA of the knee. At 34 weeks post-osteotomy, there were significant articular cartilage changes, including fibrillation, derangement of cell columns, cloning, and osteophyte formation in the overloaded compartment of the knee. Increased subchondral bone density was also discovered in the overloaded compartment. The investigators concluded that OA is a final common pathway for mechanically induced joint failure and that such joint failure is heralded by progressive changes in the articular cartilage and increased subchondral bone density.

While a direct causal relationship between malalignment and OA has not been demonstrated in humans, there is substantial evidence in the literature on the influence of alignment to support a causal hypothesis.\(^\text{15}\) Prospective clinical studies will need to be performed to definitively demonstrate this relationship for clinical benefit.

**Progression of Osteoarthritis**

There is no definitive proof that varus or valgus alignment causes OA in humans; however, two recent studies have been able to demonstrate a causal relationship between alignment and the progression of OA in a human population. Sharma and associates\(^\text{16}\) examined whether varus or valgus alignment increased the rate of progression of OA in the medial or lateral compartments of the knee in a human population. For 18 months, 237 volunteers with clinical and radiographic evidence of OA were followed clinically and radiographically. Patients with a varus deformity had 4.09 times the risk of progression of medial disease versus patients without a varus deformity at 18 months. Similarly, the investigators found that patients with a valgus deformity had a 4.89 times the risk of progression of lateral disease versus patients without a valgus deformity. In addition, the study showed that a greater loss of medial joint space was correlated with a greater initial degree of varus alignment, and that a greater loss of lateral joint space was associated with a greater initial valgus alignment. The investigators concluded that varus and valgus alignment causes increased rates of progression of medial and lateral OA, and the rate of progression of joint space loss is directly proportional to the initial amount of varus or valgus alignment.

Cerejo and colleagues\(^\text{17}\) examined whether the influence of alignment on subsequent progression of knee OA differs according to the baseline stage of disease. They followed 230 subjects (370 knees) in whom the alignment of the lower extremity and grade of OA were noted at baseline. In patients with an initial varus alignment and with grade 2 disease, the odds ratio of having increased medial joint space narrowing was 4.12. For patients with grade 2 disease, initially, but who had a valgus deformity, the odds ratio of progressing was 2.46. For patients with an initial grade of 3, the odds ratio for risk of progression was 10-fold for both varus and valgus knees. The investigators concluded by stating that the impact of malalignment relative to the probability of the progression of OA is greater in the presence of more advanced stages of OA at baseline. This is theorized to be due to greater joint vulnerability as a result of the loss of protective surfaces such as cartilage and menisci.

**Treatment Options**

From the studies mentioned above, it may be concluded that 1) correcting malalignment may decrease the rate of progression of OA, and 2) earlier intervention may be more efficacious than late intervention, in terms of preventing further destruction of the articular surfaces of the knee. Thus, employing interventions that are aimed at reducing malalignment may decrease the incidence and rate of progression of OA. As well, applying interventions early in the disease course may provide...
an increased level of protection relative to later in the disease course. Treatment modalities that can be utilized include both operative and nonoperative interventions. Nonoperative interventions that have been evaluated for the treatment of varus OA of the knee include heel wedge orthotics and unloader braces. Operative treatment is limited to osteotomies about the knee.

Nonoperative Management

Heel Wedge Orthotics

Heel wedges are orthotics designed to fit into the heel of a shoe. They are built up on either their medial or lateral side and are used to mechanically realign the lower extremity to unload the affected knee compartment. A heel wedge that is built up on the lateral side is used to decrease loads across the medial compartment, while a heel wedge that is built up on the medial side is used to decrease loads across the lateral compartment.

Yasuda and Sasaki18 showed that a laterally based heel wedge shifts the subtalar joint in valgus, which causes the mechanical axis to shift laterally. In a varus lower extremity, they demonstrated that this intervention would cause the mechanical axis to move in a lateral direction towards the knee. The relative lateralization of the mechanical axis would decrease the varus moment on the knee and decrease compressive forces on the medial compartment.

Kerrigan and coworkers19 showed that a laterally based heel wedge significantly reduced the knee varus torque during ambulation. They demonstrated that a 5° orthotic reduced the peak knee varus torque by 6°, while a 10° wedge reduced the peak torque by 8°. However, a 10° orthotic was associated with varying degrees of discomfort; therefore, the 6° orthotic was recommended for the management of medial compartment OA.

In a 6-month randomized, prospective controlled study, investigating the effect of a laterally based heel orthotic, Maillefer and associates20 failed to demonstrate a statistical difference in pain or functional scores compared to the control group. However, there was an increased rate of compliance and a decreased usage of nonsteroidal anti-inflammatory drugs (NSAIDs) in the heel wedge group.

The above mentioned studies indicate there may be a role for heel wedge orthotics in the management of medial unicompartmental OA. However, it should be noted that the role for medially based heel orthotics in the treatment of lateral compartment disease is less clear and, to date, no studies have looked at the efficacy of such wedges for the treatment of lateral compartment disease.

Unloader Brace

An unloader brace is a type of knee brace that places a three-point bend on the knee in the coronal plane. With this positioning, the brace is able to exert a valgus or varus moment on the knee in an effort to reduce medial or lateral compartment compressive forces. The use and efficacy of these braces has been studied by several investigators. Lindenfeld and colleagues21 evaluated the effect of the unloader brace in patients with medial compartment OA, specifically related to the adduction moment at the knee. They found that with employment of the brace, the adduction moment decreased to levels found in the normal knees of the control group. The results demonstrated that pain, function, and biomechanical knee loading can be altered by an unloader brace.

Kirkley and coworkers22 followed 110 patients with varus gonarthritis for 6 months who were randomized to one of three groups: medical management, neoprene sleeve, or unloader brace. At 6 months, both the neoprene sleeve and the unloader brace provided significantly greater improvements in disease specific quality of life and functional scores than did medical management. In addition, the unloader brace provided significantly better functional scores and almost significantly better disease specific quality of life scores [WOMAC™ (Western Ontario MacMaster osteoarthritis index)] than did the neoprene sleeve. The study concluded that patients with medial gonarthritis may benefit from the use of an unloader brace in combination with medical management.

Komistek and associates23 were able to demonstrate using fluoroscopy how the unloader brace performs. They asked 15 patients with medial compartment OA to walk on a treadmill, first without and then with an unloader brace. Fluoroscopic images were taken of the subjects’ knees during heel strikes. Twelve of the 15 patients reported pain relief with the use of the unloader brace. Radiographic evaluation of the knees of these patients showed there was separation of the femur from the tibia in the affected (medial) compartment during heel strikes. Three of the subjects were obese and could not maintain an appropriate fit of the brace. These three patients failed to gain much pain relief and radiographic evaluation indicated that they did not achieve compartment separation with the brace. The investigators concluded that medial compartment separation in a degenerative knee can be achieved with the employment of unloading braces and can provide relief of knee pain.

Using an adjustable unloader brace on 11 patients with medial compartment gonarthritis, Pollo and colleagues24 showed that pain and activity level were improved in all of their subjects. During gait, the unloader brace reduced the net varus moment by 13% (710 N/cm) and similarly reduced the medial compartment load by 11% (114 N/cm). The investigators concluded that an adjustable unloader brace effectively reduces medial compartment loads and, therefore, is able to decrease pain and increase function in patients with medial compartment OA of the knee.

From the studies mentioned above, the unloader brace may be viewed as effective in unloading the affected compartment, reducing pain, and improving function. A disadvantage is that unloader braces are often large and uncomfortable for a patient to wear. Thus, compliance can be a problem, especially with the elderly population. In ad-
dition, to our knowledge, there are no studies looking at the efficacy of unloader braces for the valgus knee.

**Operative Management**

**Osteotomy**

The treatment concept behind employing an osteotomy is to realign the mechanical axis from the arthritic compartment of the knee to the less affected compartment. The goals of osteotomy include pain relief and improvement in functional status. Because patients retain their native articular surfaces, a secondary goal of osteotomy is to allow patients to continue with a higher demand lifestyle than would be allowed using a prosthetic replacement. The success of osteotomies lies in appropriate patient selection, careful preoperative planning, and execution of exacting surgical technique.

The indications for osteotomies about the knee for the correction of a varus or valgus malalignment are not absolute; however, characteristics of the ideal patient can be generalized. Corrective osteotomies provide the best results for patients with OA, posttraumatic arthritis, or prophylaxis against the development of OA in patients with varus or valgus deformities. Inflammatory arthritides are generally considered a contraindication to performing an osteotomy. While tri-compartmental disease is usually considered a contraindication, neither mild disease in the less affected compartment nor mild patellofemoral compartment disease is considered an absolute contraindication to surgical treatment. The ideal candidate is also of a younger age, generally less than 65 years of age. One of the reasons is that younger patients have an easier time with the necessary postoperative rehabilitation after an osteotomy, including 6 to 8 weeks of non-weightbearing or partial weightbearing. Secondly, patients over the age of 65 years generally do well with total knee arthroplasty and can reasonably expect the surgical benefits to last their lifetime. Normally, osteotomy candidates should not be obese. Coventry showed that patients of normal weight, over all, had a better result than obese patients. Patients should have a good preoperative range of motion with at least a 90° arc of motion and less than 15° of flexion contracture. In addition, the knee should not be unstable to varus or valgus stresses.

Various types of osteotomies have been developed for malalignment of the knee and include osteotomies through the proximal tibia, through the distal femur, or both. Generally, these can be performed through either a closing wedge or opening wedge technique. Closing-wedge osteotomies, as described by Coventry, have the advantage of being simple to perform and have a high rate of healing, due to the large surface area of cancellous bone. They have the disadvantage of shortening the leg and ipsilateral collateral ligaments, infrapatellar scarring, patella baja, and the creation of offset between the proximal tibial segment and the tibial shaft. Opening wedge osteotomies have the advantage of tightening the ipsilateral collateral ligaments and lengthening the leg. They have the disadvantage of patellar displacement, possible nonunion, and graft site morbidity. Osteotomies that are performed closer to the articular surface have the advantage of being able to provide a larger correction, have a greater surface area for healing, and cause less offset. Disadvantages include the risk of nonunion and the risk of creating an intra-articular fracture.

**Result of Osteotomies for Medial Compartment Disease**

The results of osteotomies are mixed in the literature, with a trend towards a decrease in success over time. For the treatment of medial compartment OA, several long-term studies have shown that, in general, results of high tibial osteotomies have been very good in the first several years following surgery. However, the results seem to decrease approximately 10 years postoperatively. Five-year excellent results have been shown by Cass and Bryan (87%), Healy and Riley (88%), Hernigou and coworkers (90%), and Ritter and Fechtman (80%). However, at 10 years postoperatively, these excellent results decrease to results of 69%, 80%, 45%, and 58%, respectively (Table 1).

A critical review of the literature indicates that not all osteotomies have a functional lifespan of 10 years. Rather, it appears that superior results are dependant upon appropriate patient selection and good surgical technique. Patient characteristics associated with better outcome include an age of less than 60 years, angular deformity less than 12°, pure unicompartmental disease, preoperative range of motion of greater than 90°, flexion contracture less than 15°, and ligamentous stability. The study by Berman and associates included 10 patients that should not have received a high tibial osteotomy according to the above criteria. Had these patients presented when indications were better clarified, they likely would have been excluded. That being said, among the 10 poor results in this series of patients, preoperative diagnoses included diffuse degenerative OA (4), inflammatory OA (2), prior septic arthritis (1), and posttraumatic arthritis with significant bone loss (1). If these patients are excluded from the results, then the good to excellent outcome at 12 years improves to 79%. Thus, the success of an osteotomy can be seen to be clearly dictated by appropriate patient selection. Patients who fall outside of the above mentioned criteria should be steered toward other modes of treatment or, if indicated for a high tibial osteotomy, should be informed that the procedure has limited goals that can be achieved.

Just as appropriate patient selection is paramount in the

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success of high tibial osteotomies, so is execution of exacting surgical technique. Chillag and Nichols reported on a series of patients in which rigid patient selection was followed. Of 30 high tibial osteotomies followed for 51 months, 43 were judged good and 57 poor. There were no technical errors and alignment was appropriately corrected in all of those patients with good outcomes. However, in the 17 patients with poor outcomes, there were 10 technical errors, three of which were under correction of alignment (5), over correction of alignment (3), and fracture into the articular surface (2).

Odenbring and colleagues reported on a series of 314 patients, followed for 10 to 19 years postoperatively. Over half (170) of these patients were reported to have had an under correction of their deformity. Of these, 54 went on to require additional surgery. In contrast, only eight of the 144 patients who were determined to have had their alignment either appropriately corrected or over corrected required revision surgery. It can be concluded from this series that, in addition to appropriate patient selection, exacting surgical technique has a direct impact on the outcome following a high tibial osteotomy. However, there is no consensus as to what constitutes appropriate correction of alignment. Hermigou and coworkers recommended 3° to 6° of valgus correction. Cass and Bryan recommended 10° to 12° of valgus correction, and Rudan and Simurda recommended 6° to 14° of valgus correction.

Osteotomies for the Valgus Knee

Similar to osteotomies to correct varus deformities, good outcomes for osteotomies to correct valgus deformities are dependent on appropriate patient selection, proper surgical technique, and adequate correction of the deformity. Good candidates are those under 65 years of age who are diagnosed with OA or posttraumatic arthritis, with isolated degenerative changes in the lateral compartment, minimal ligamentous laxity, a preoperative range of motion of at least 90°, and less than 15° to 20° of flexion contracture.

The outcome for osteotomies for correction of the valgus knee is not as predictable as for the varus knee. This is because the natural anatomic valgus of the femur makes it difficult to move the mechanical axis to the medial compartment. In general, the two most common types of osteotomies performed for the valgus knee include the high tibial osteotomy and the distal femoral osteotomy.

Coventry performed a varus closing wedge osteotomy in 31 patients for painful lateral compartment OA in valgus knees. The average postoperative correction was a tibiofemoral angle of 0.03° of valgus. Following a 2- to 17-year follow-up, 24 of the 31 patients (77%) had either mild or no pain. Six of the patients required revision to total knee arthroplasty at an average of 9.8 years after the tibial osteotomy. There were no reported nonunions or infections in this series. The patients with the best results were those with a preoperative deformity of less than 12° valgus and a postoperative medial joint line obliquity of less than 10°. Coventry found knees that were corrected to 8° or more of postoperative valgus had a survival rate of 94% at 10-year follow-up. However, for knees that were under corrected to less than 5° of postoperative valgus, the survival rate was only 63% at 10-year follow-up. He concluded that correction to an anatomic tibiofemoral angle of 0° is most appropriate to prevent recurrence of the valgus deformity and to decrease the lateral compartment load. For patients with preoperative valgus angles of greater than 12° or for cases where the predicted postoperative medial joint line obliquity would be greater than 10°, Coventry recommended that a distal femoral osteotomy be performed. The results of distal femoral osteotomies pattern those of high tibial osteotomies in that the successful results decrease over time. Miniaci and associates reported 86% successful results in 35 distal femoral osteotomies, 5.4 years postoperatively, but Finklestein and associates showed only 64% successful results after 11 years postoperatively.

Patient selection is very important for distal femoral osteotomies. Healy and coworkers reported a series of 23 patients that underwent a distal femoral osteotomy for the correction of valgus deformity. Overall, 86% of the patients were satisfied with the procedure 4 years postoperatively. Fourteen of 15 patients with osteotomies had good or excellent results. Of the four knees that were determined to be failures, three were in patients with rheumatoid arthritis. The investigators concluded that the distal femoral osteotomy is a valid treatment for valgus deformity in patients with OA or posttraumatic arthritis but is not appropriate for patients with inflammatory arthritis.

McDermott and associates reported a series of 24 patients with lateral degenerative arthritis associated with a valgus deformity and in which the patients received a distal femoral osteotomy. At 4 years postoperatively, they reported success in 22 patients (92%). The investigators’ goal for correction was a neutral and anatomical angle between the femur and tibia in order to ensure that the mechanical axis passed through the medial compartment of the knee. A 0° anatomic tibiofemoral angle has been the surgical goal of other investigators.

For severe cases of lateral compartment degenerative arthritis with significant degrees of valgus angulation, combined distal femoral and high tibial osteotomies may be indicated. Such a combined procedure is recommended when a single osteotomy would result in excessive bone resection or excessive joint obliquity. In general, the same indications for surgery apply as described above. The surgical technique generally involves performing the distal femoral osteotomy first and then intraoperatively reassessing the mechanical axis to determine the degree of correction needed in the proximal tibia.

Babis and colleagues reported on 24 patients with an average deformity of 13.9° valgus, who underwent 29 double-level osteotomies. Postoperatively, the average
mechanical axis was 3° of valgus and the average joint line obliquity was 0.66° medial obliquity. These patients were followed for an average of 82.7 months and showed significant improvement in clinical and functional scores. The cumulative rate of survival was projected to be 96% at 100 months postoperatively. The investigators concluded that double-level osteotomy is indicated for patients with a large valgus deformity that cannot be addressed with a single-level osteotomy without resecting excess bone or creating an oblique joint line.

**Conclusion**

The treatment of degenerative arthritis of the knee is an evolving and complex topic. A thorough understanding of the biomechanical forces affecting the knee is essential for the proper treatment of these conditions. Malalignment of the knee, whether occurring as a consequence of abnormal forces acting on the knee or being a cause of them, often results in knee pathology. Frequently, malalignment and resulting pathology occur in younger, active patients for whom joint replacement is not a viable option. Due to this challenge, surgeons are increasingly looking towards correction of malalignment as an alternative to joint arthroplasty. Often, in the properly selected patient, alignment correction, achieved with or without surgery, is a successful and gratifying procedure.

**References**

5. Efftman H. [The force exerted by the ground in walking.] Arbeitsphysiologies. 1939 May;10(5):485-491. [German]


