International Orthopaedics (SICOT) (2010) 34:191–199
DOI 10.1007/s00264-009-0875-1

ORIGINAL PAPER

Opening wedge tibial osteotomy for large varus deformity with Ceraver™ resorbable beta tricalcium phosphate wedges

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Received: 10 August 2009 / Revised: 2 September 2009 / Accepted: 3 September 2009 / Published online: 1 October 2009

Abstract The results in 53 knees that had been treated by proximal tibial opening-wedge osteotomy for large varus deformity and osteoarthritis of the medial compartment were evaluated after a mean length of follow-up of ten years (range, 8–12 years). We used a porous beta-tricalcium phosphate (β-TCP) wedge because it is resorbable and osteoinductive. All osteotomies were completely consolidated and complete osseointegration of the remnant of the β-TCP wedge took place. However, after a mean maximum follow-up of ten years none of the cases showed complete resorption. After ten years, 40 (81%) of the 53 knees had an excellent or good result, and in 13 knees there was recurrent pain for which six had an arthroplasty. Although the results deteriorated with time, time was not the only determinant of the result. Alignment, measured as the hip-knee-ankle angle on radiographs of the whole limb that were made with the patient bearing weight, was also a determinant of long-term results. The best results were obtained in the knees that had a hip-knee-ankle angle of 183–186 degrees. In these knees, there was no pain and no progression of the arthrosis in either the medial or the lateral tibiofemoral compartment. Of the three knees that had an angle of more than 186 degrees, all five had progressive degenerative changes in the lateral compartment. In the undercorrected knees (an angle of less than 183 degrees), the results were less satisfactory, and there was a tendency toward recurrence of the varus deformity and progression of the arthritis of the medial compartment. However, when the correction was insufficient the deterioration was slow. Therefore, proximal tibial osteotomy is a very suitable operation even for patients who have gonarthrosis of the medial compartment and a large varus deformity. Although, a rigidly standardised and precise operative technique is required as well as accurate radiographic measurements of the mechanical axis of the limb because exact postoperative alignment is the prerequisite for the longest possible period of relief of symptoms after osteotomy, and this exact alignment is difficult to obtain for patients with large varus deformity.

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Introduction

It has been well documented that the early results after proximal tibial osteotomy for gonarthrosis are favourable [1–4]. Osteoarthritis of the knee is often associated with varus malalignment of the affected extremity. Such malalignment may predispose patients to accelerating the degenerative joint disease. Osteotomy has long been recognised as the treatment for knee osteoarthritis in young patients. The effect of the procedure is to redistribute body weight away from the diseased tibiofemoral compartment and onto the adjacent compartment. While osteotomy was for many years the surgical treatment of choice for unicompartmental tibiofemoral arthritis, it is increasingly giving way to unicompartmental and total knee arthroplasty as such techniques have become more widespread and surgeons more confident in their results following arthroplasty [4]. Nevertheless, osteotomy is still appropriate in young, active patients for its potential to allow improved activity. In some cases, osteotomy may be considered as a bridge to eventual arthroplasty. Although the opening wedge osteotomy has been described for many years [5], the advantages of the opening wedge as compared to a closing wedge technique have only been recently discussed, particularly in the English language literature. Until now, opening wedge tibial osteotomy has been criticised because of the difficulty of the technique in patients with large varus deformity and because of the risk of the inconvenience related to the use of cortico-cancellous grafts [6] used to fill the gap. However, for large varus deformity the closed wedge osteotomy decreases the bone stock. The aim of this paper is to report our experience with the open wedge osteotomy in patients with a severe varus deformity when using resorbable tricalcium phosphate wedges.

Materials and methods

This report concerns the period from 1997 to 2001, during which 303 tibial osteotomies were performed in the Centre Hospitalo-Universitaire Henri Mondor. Of these 303 knees, 53 knees that had been treated by proximal tibial opening-wedge osteotomy for a large varus deformity, i.e. a varus deformity of more than 15 degrees of varus, with resorbable tricalcium phosphate wedges.

The indications for these osteotomies were a varus deformity combined with osteoarthritis. Twelve patients had a bilateral osteotomy; the two procedures were done two weeks apart. The ages of the 26 women and 15 men ranged from 43 to 67 years (average, 60 years) at the time of operation.

Operative technique

A longitudinal skin incision was made starting from a level inferior to the knee joint, between the medial part of the patellar tendon and the posterior border of the tibia, to expose the medial part of proximal tibia; the incision was 6–10 cm in length. A 10-cm longitudinal incision was made from the medial border of the patellar ligament distally along the medial aspect of the tibia. The insertions of the sartorius, gracilis, and semitendinosus muscles were divided, and the tendons were separated from bone. The pes anserinus was incised longitudinally 0.5 cm medial to its attachment to the tibia; if only moderate valgus is required the incision in it can be incomplete. The distal portion of the superficial medial collateral ligament was exposed and separated from bone proximally as far as the level of the osteotomy, which should begin at least 3.5 cm distal to the medial joint-line and directed laterally and proximally toward the tip of the fibula. The posterior compartment was opened at the level of the osteotomy and the posterior surface was rugined; the rugine being directed towards the upper end of the fibula.

After exposure of the proximal tibia, the osteotomy line, starting from 3–4 cm distal of the medial joint line, passes above the insertion of the patellar tendon to the tibial tubercle. The level and direction were checked under fluoroscopy (C-arm of the image intensifier) control. If appropriate, one K-wire is inserted to reflect the posterior slope. In the routine internal oblique radiographs taken preoperatively for the evaluation of proximal tibio fibular joint (PTFJ), the K-wire is inserted to reflect the posterior slope and the PTFJ position. For inpatients with a large varus deformity, we did not direct the osteotomy line toward the tip of the fibular head but more distally (to the level of the PTFJ). A pin was inserted by a drill at this point and directed towards the lateral border of the tibia just at the level of the proximal tibio fibular joint. Its position was checked radiologically. The osteotomy was made with an osteotome. The line of the osteotomy was made with a chisel on the distal side of the pin. It is slightly oblique from below upwards. If the line of the osteotomy passes through the tibial tubercle, the upper part of the tuberosity is separated from the upper tibia by a horizontal cut. With a 2.6-mm drill, the posterior tibial cortex was perforated by multiple holes by putting the drill through the osteotomy to avoid splintering the cortex when the osteotome is inserted. The posterior cortex was first divided with a narrow osteotome; the remainder was divided with a wide osteotome whose posterior part was placed in the bone division already made. The fibula and tibiofibular joint need not be disturbed. Maximum attention was given to keep the lateral cortex intact to benefit from its hinge feature. The cut was made with osteotomes, leaving the lateral part of the cortex of the lateral tibial condyle intact. The bone at the site of the osteotomy was forced open. The leg below the osteotomy was then pushed into valgus while the large osteotome maintained the upper end of the tibia in place. The surgeon put his hand under the Achilles tendon to avoid flexion at the site of the osteotomy. The opening must be greater at the posterior part than at the anterior part of the osteotomy.

Determination of the size of the wedges

Two methods were used in these series of patients: a graphic method and a table method.

1. The graphic method. The preoperative radiographs of the whole limb that were made with the patient bearing weight were used to determine the size of the wedges of bone that were needed to produce the desired correction. First, the lines that determined the preoperative hip-knee-ankle angle were drawn. Then a line representing the site of the tibial osteotomy was drawn, as well as a new tibial line that would produce the desired hip-knee-ankle angle and mechanical axis of the limb. Next, a tracing of the portion of the tibia that lies distal to the site of the osteotomy was made

and superimposed on the radiograph so that the axis of this tracing lies exactly on the previously drawn new tibial line on the radiograph. With the tibial tracing so placed, the size of the wedge was shown and the height of its base could be measured in millimetres.

2. The table method has been described in several papers [7–9] and allows the surgeon to transform the angle of correction in the size of the wedge.

Introduction of the wedge at the osteotomy site

During the operation, the wedge must have a base that is exactly the height that is needed; it is inserted in the opened osteotomy site posteriorly. This is done to avoid relative shortening of the patellar ligament as well as an increase of the posterior slope of the tibia.

We used a porous beta-tricalcium phosphate (β-TCP) wedge because it is resorbable and osteoinductive [10–12]. The wedge (Ceraver implant; Ceraver™, France) was held in place by the compressive force in the opened osteotomy. β-TCP is resorbed in vivo by osteoclasts and replaced by new bone [13]. The structure and porosity of the material define its mechanical as well as its bioconductive and resorptive characteristics. The advantage of low porosity β-TCP is that it has a high initial strength and immediate postoperative weight-bearing is possible. We postulated that complete resorption of the 30% macroporosity rigid β-TCP wedges would take at least several years. However, the resorption rate and the ultimate fate of the low porosity wedges have never been established.

A buttress plate was then applied to the anterior part of the medial aspect of the tibia to hold the upper end of the tibia and the shaft. The desired correction is the difference in degrees between the anteroposterior alignment on preoperative radiographs made on a long cassette and the desired postoperative result. After the osteotomy gap was distracted under image intensifier control, single wedges that were designed by the author and served as a jack were placed to the front and back of the angle-scale distractor to keep the area open. This correction can be checked during surgery by calculating the angle between the anatomical axis of the tibia and a line perpendicular to the tibial plateau. The same measure can be done on the lateral radiograph to be sure that flexion has not been introduced in the osteotomy site. Then the jack is changed for the rigid β-TCP wedge. Cancellous bone taken from the upper and lower surfaces of the osteotomy is packed into the posterior part of the opening. The wound was closed by repairing the divided tendons and superficial medial collateral ligament and then approximating the subcutaneous tissue and skin.

Plate and screws

A buttress plate was then applied to the anterior part of the medial aspect of the tibia to hold the upper end of the tibia and the shaft. The plates, which were manufactured according to the anatomical inclination of the proximal tibia, are made of steel and can be curved if necessary. In steel plates, 5-mm steel screws are used. We used cortical screws for both proximal and distal holes. We think that cancellous bone screws have a diameter that is too large; this is an inconvenience when they are removed at the time of a total knee arthroplasty. The direction of the proximal screws should avoid the anterior tibial artery. It passes from posterior to anterior through the upper part of the interosseous membrane, slightly under the inferior level of the PTFJ. This narrow region is approximately at the level of the tibial tubercle.

Postoperative care

The knee was not immobilised postoperatively. A suction drain was used for three days after operation. Prophylactic antibiotics were given orally for five days, starting just after surgery, and anticoagulants were administered for two months. Quadriceps-setting and straight-leg-raising exercises began the day after operation. Passive flexion of the knee was also begun immediately. After 15 days, patients usually had more than 90 degrees of flexion of the knee. Filling of the osteotomy line progresses from lateral to medial. Full weight-bearing was allowed at 45 days at a time when bone filling was not complete. The bone filling was complete after a mean of three months following the osteotomy.

Preoperative and postoperative assessments

Before operation and at the most recent follow-up, the severity of the patients' pain was assessed by asking them to grade it according to the following criteria. No pain indicated no symptoms and no limitation of activities because of the knee; slight pain was related to changes in the weather or after walking more than 1 km; moderate pain was indicated after walking a distance of less than 1 km but not when they first stood up and began weight-bearing, and only occasional use of analgesics was needed; and severe pain was indicated if felt as soon as they started weight-bearing or at rest, or regular use of analgesics was needed. The patients were also asked to indicate the maximum distance that they could walk without stopping. Finally, the range of motion and stability of the knees were determined by clinical examination.

Posteroanterior radiographs made while the patient was bearing weight, radiographs made with the application of varus and valgus stress, lateral radiographs, and patellofemoral radiographs were made preoperatively, during follow-up visits, and at the most recent follow-up examination (after ten years or more; Fig. 1). For assessment of the lateral compartment, the radiograph that was made with valgus stress was used. For assessment of the arthritis of the medial compartment, we used either the posteroanterior radiographs made during weight-bearing or the radiograph that was made with the application of varus stress (selecting the one that showed the most joint-space narrowing in each instance). Arthrosis of the medial tibiofemoral compartment was classified into five stages according to the radiographic method of Ahlback [14]. These stages range from simple narrowing of the joint space to severe attrition of bone that is visible on the posteroanterior radiograph.

Lateral subluxation of the tibia was recorded as the horizontal distance between two vertical lines: one drawn through the centre of the intercondylar notch of the femur and the other through a point midway between the tibial spines. Using this measurement of subluxation on the posteroanterior radiographs that had been made with the patient bearing weight before osteotomy, the overall average distance was 4 mm (range, 2–10 mm). Of the 53 knees, 15 were considered to show no subluxation because the distance was less than 5 mm and 38 were found to have subluxation of 5 mm or more.

The lateral radiograph was used to assess the amount of loss of tibial bone and the location of the loss in the medial plateau (anterior third, middle third, or posterior third). The patellofemoral radiograph was made in 30 degrees of flexion.

Fig. 1 View of the wedge after ten years

The preoperative varus deformity was measured on weight-bearing radiographs of the whole limb. The varus–valgus angulation of the tibiofemoral articulation was measured as the angle that was formed by lines drawn from the mid-point between the tibial spines to the centre of the femoral head proximally and to the centre of the talocrural joint distally. Therefore, this angle, which was called the hip-knee-ankle angle, was formed by the mechanical axis of the femur and the mechanical axis of the tibia. Normally these axes form a straight line (180 degrees). Therefore, in the presence of a varus deformity the angle is less than 180 degrees and when there is a valgus deformity it is more than 180 degrees. The preoperative hip-knee-ankle angles for these 53 knees ranged from 158 to 165 degrees (average, 162 degrees).

To verify the correction that had been achieved, we measured the hip-knee-ankle angle ten days after the osteotomy on radiographs of the whole limb that were made without weight-bearing. Radiographs of the whole limb while the patient was bearing weight were made one year after the osteotomy and at the most recent follow-up.

All radiographs were used for the evaluation of bone remodelling and resorption of the β-TCP wedges. The radiographs were classified in random order according to the radiological classification system described by Van Hemert et al. [15]. The classification system by Van Hemert comprises five phases. In phase 1 the boundary between the β-TCP wedge and bone is clearly visible. Complete resorption of the β-TCP wedge was defined as having reached phase 4 or 5. In phase 5 there is no sign of the osteotomy, and complete remodelling has taken place. For analysis, the follow-up time was divided into time intervals of different length. Since the follow-up periods varied between patients, the number of evaluated patients differed between intervals. If more than one radiograph of the same knee was made within one time interval, the median of these scores represents the phase of resorption in that time interval. Inverted Kaplan–Meier survival analyses were used to determine the transition from phase 1 to phase 2 and from phase 2 to phase 3 over time. The median number of months it took before transition to the next phase was calculated.

Results

Relief of pain

Of the 53 knees that had had no additional treatment and had been followed up for an average of ten years, 40 had no pain during walking and 13 were painful during walking and weight-bearing. The patients with the 40 painless knees could walk an unlimited distance or at least 1 km. Of the other 13 knees, the pain was slight in two, was great enough (moderate or severe) to restrict activity and require occasional analgesics in five and severe enough to require revision in six.

Motion of the knee

Before osteotomy, the average flexion of the knees was 115 degrees (range, 60 to 140 degrees). Postoperatively, the average was 110 degrees (range, 60 to 140 degrees). Of the knees that had had 100 degrees of flexion or more before operation, none had lost motion at the time of the last follow-up examination, while of the 13 that had had less than 100 degrees (range, 60 to 90 degrees) of flexion before operation, three had lost from 10–20 degrees of flexion. At the last follow-up examination, there was no correlation between the amount of flexion and the presence or absence of pain.

The average flexion contracture both before operation and at the last follow-up examination was 5 degrees (maximum, 20 degrees). Of the sixteen knees in which there was a preoperative flexion contracture of more than 10 degrees, only four showed a decrease in the contracture at the last follow-up examination. Despite the persistence of a flexion contracture of more than 10 degrees in the other 12 knees, eight of the 12 were pain-free when the patients were last seen. Sixteen other knees, that had not had a flexion contracture preoperatively, had a contracture of more than 10 degrees at the last follow-up examination, and 13 of the 16 were painful at that time.

Stability

Laxity was determined clinically by passive varus–valgus testing. The criteria that were used to establish instability were total varus–valgus excursion of 5 degrees or more when the knee was in maximum extension and excursion of at least 10 degrees when the knee was in 20 degrees of flexion. Before operation, 22 knees were judged to be unstable. At the time of the last follow-up examination, only seven knees were unstable, and only two of the 22 knees that had been unstable preoperatively showed increased instability. At the last follow-up examination, all pain-free knees were stable and all unstable knees were painful.

Hip-knee-ankle angle

The average hip-knee-ankle angle was 162 degrees (range, 158–165 degrees) preoperatively and 184 degrees (range, 180–188 degrees) ten days after osteotomy. In five knees, an insufficient correction (a hip-knee-ankle angle ranging from 180 to 182 degrees) was found immediately after the osteotomy. The causes of these undercorrections included errors in the determination of the size of the wedges in two knees, fracture of the lateral part of the cortex of the tibia with immediate displacement in one knee, and fracture of the wedge in two knees. One β-TCP wedge fractured during introduction of the wedge in the osteotomy gap. The other fracture was noticed at two months.

At one year, the average hip-knee-ankle angle was 183 degrees (range, 176–188 degrees) and in four of these knees there was a varus deformity (hip-knee-ankle angles ranging from 176 to 180 degrees). Therefore, between ten days and one year after operation, a recurrent varus deformity developed. No displacement of the surfaces of the osteotomy and no collapse of the wedge had occurred, but it appeared that there had been insufficient opening at the site of the osteotomy to compensate for the laxity of the lateral structures.

Ten to twelve years after osteotomy, the average hip-knee-ankle angle in the knees that could be followed up for that period was 180 degrees (minimum, 173 degrees; maximum, 190 degrees), and only 40 of the 53 knees still showed valgus angulation (hip-knee-ankle angles ranging from 181 to 190 degrees). Therefore, between one year and the last follow-up examination at ten to 12 years, changes in alignment continued to occur in most of the knees that were followed up for that length of time. These changes were almost always in a varus direction. The exceptions were among the three knees in which the hip-knee-ankle angle at one year was more than 186 degrees. For the other knees, the change in the hip-knee-ankle angle was 2 degrees varus or less in 16 knees and more than 2 degrees varus in the others.

Before revision, the hip-knee-ankle angle of the six knees that required revision was less than 178 degrees.

Radiographic changes in osteoarthritis and alignment

To assess the radiographic changes, we used the posteroanterior radiographs that were made with the patient bearing weight as well as radiographs made with the application of varus–valgus stress, a lateral radiograph, and a patellofemoral radiograph. The weight-bearing and varus–valgus stress radiographs were used to assess changes in the medial and lateral compartments.

In the medial compartment, the preoperative posteroanterior radiographs showed narrowing of the joint space and subchondral sclerosis. Ten to 15 years after osteotomy, the radiographs of the same knees showed that the arthrosis of the medial compartment had progressed in 20, remained essentially unchanged in 18, and improved in 15. In the knees in which the arthrosis progressed, the follow-up radiographs showed increased narrowing of the joint space.

In the lateral compartment, the preoperative posteroanterior view showed no narrowing of the joint space (it was 4 mm wide or more), no osteophytes, and no subchondral sclerosis in 47; narrowing of the joint space to 3 mm in one (secondary to infectious arthritis in childhood); and impingement of the lateral femoral condyle against the intercondylar eminence of the tibia without associated narrowing of the lateral joint space in five. Ten to 12 years after osteotomy, 45 of the knees that had showed no joint-space narrowing and no subchondral sclerosis in the lateral compartment before operation still showed no changes; the six that had had slight preoperative changes in the lateral compartment had not changed; and the remaining two knees, which had had a normal lateral compartment preoperatively, showed severe lateral arthrosis, attrition of bone, subchondral sclerosis, and osteophytes. The severe changes that were observed in these two knees were explained by the excessive valgus alignment (a hip-knee-ankle angle of more than 186 degrees) that was noted at the last follow-up examination.

Lateral coronal subluxation did not develop after osteotomy in any knee that had not had preoperative subluxation, and in the knees that had been subluxated preoperatively there was no increase after osteotomy.

The radiographs of the patellofemoral joint were analysed for evidence of joint-space narrowing (50% or more) and of subluxation of the patella. At the time of operation, the patello-femoral joint was not normal in 15 knees. In these knees, there was no clear correlation between the radiographic location of the degeneration in the patellofemoral compartments and the clinical result. Indeed in 20 of these 35 knees the apparent patellar symptoms improved after the osteotomy. No patient required a patellectomy or other procedure for patellofemoral symptoms after the osteotomy, and no failure after osteotomy could be explained by the presence of coexisting patellofemoral arthrosis.

Resorbability of wedge

After a mean maximum follow-up of ten years (range, 8–12 years), none of the cases showed complete resorption. All the cases were scored as having reached phase 3 at maximum follow-up. However, all osteotomies were completely consolidated and complete osseointegration of the remnant of the β-TCP wedge took place. Inverted Kaplan–Meier survival analysis showed that transition from phase 1 to phase 2 took place after a median of four months (95% CI 2–6 months). The transition from phase 2 to phase 3 took place after a median of 22 months (95% CI 16–28 months). Transition to phase 4 did not occur.

Revision

In two patients the fixation system was removed because of local complaints after a mean duration of 29 months (range, 16–42 months). In six knees a conversion to a knee arthroplasty was performed after a mean duration of 56 months (range, 37–82), including five total knee arthroplasties and one medial unicompartmental arthroplasty. The implanted β-TCP wedge did not interfere with placement of the knee arthroplasties. The β-TCP wedge was still visible after the arthroplasties, and was not removed during surgery. The osteotomy did not appear to have jeopardized the result of the arthroplasty.

Discussion

Although it is currently believed that tibial osteotomy is unlikely to give a satisfactory results in patients who have severe preoperative varus deformity [1, 4, 16, 17], in our series this was not found to be true. Most of the knees had a good result at the ten year follow-up examination. When deterioration with time occurred after osteotomy, it became evident at an average of seven years (minimum, five years; maximum, ten years). Deterioration was always associated with recurrence of pain in the knee. The passage of time seemed to influence the result only in knees that were undercorrected or overcorrected as observed at the most recent follow-up examination. In knees that had ideal correction (hip-knee-ankle angles ranging from 183 to 186 degrees), there was no progression of the disease. The increased load on the lateral compartment of these knees did not seem to damage the articular cartilage; in addition, the patellofemoral joint remained unchanged. Therefore, proximal tibial osteotomy with ideal correction did interrupt the natural evolution of gonarthrosis for as long as an average of ten years in patients with severe varus deformity.

Many authors have reported that the results of tibial osteotomy are better when the preoperative radiographs do not show advanced changes of osteoarthritis in the medial compartment such as loss of bone, instability due to erosion of bone, laxity of the lateral structures, or subluxation of the tibia. In our series, the result was good in five of the 13 knees in which there had been preoperative attrition of bone, in six of the 25 knees that had had preoperative subluxation of between 5 and 10 mm, and in six of the 26 knees that had had preoperative laxity. At the last follow-up examination of the 17 knees that had a good result, all were free of pain; those that had had preoperative subluxation showed less displacement, and the knees that had been unstable preoperatively due to loss of bone or laxity of the lateral structures were stable as determined by both clinical testing and valgus–varus stress radiographs. Therefore, preoperative subluxation, loss of bone, and ligamentous laxity do not seem to contraindicate valgus osteotomy, but they may make the preoperative determination of the amount of correction that is required more difficult.

The severe varus knee is a triple varus knee that refers to varus alignment owing to the additive affects of three causes. The first is bone related with a physical component that appears early in childhood and in its most severe form produces an arrest of the medial growth plate; in some cases it is related to a diaphyseal component which may be post-traumatic. The second deformity of severe tibia vara is articular, consisting of a depressed medial tibial plateau and manifested by a false laxity of the medial collateral ligament on valgus stress radiographs. The third cause is lateral laxity. The plain radiographs revealed all our knees had (a) severe sloping of the medial tibial plateau and arrest of the medial tibial physis resulting in a tibiofemoral osseous alignment, (b) narrowing of the joint space with severe attrition of bone that is visible on the posteroanterior radiograph and (c) separation of the lateral compartment and lateral ligamentous insufficiency (true varus lateral laxity).

The pathological changes that were responsible for the preoperative deformity were primarily in the tibia, as determined from the so-called internal tibial and internal femoral angles. The internal tibial angle is the medial angle formed by the mechanical axis of the tibia and the plane of the subchondral plates of the tibial plateaus, while the internal femoral angle is the lateral angle formed by the mechanical axis of the femur and the plane of the subchondral plates of the femoral condyles. The pre-operative hip-knee-ankle angles for these 53 knees ranged from 158 to 165 degrees (average, 162 degrees). The average internal tibial angle was 86 degrees (minimum, 76 degrees; maximum, 83 degrees) and the average internal femoral angle was 89.7 degrees (minimum, 85 degrees; maximum, 95 degrees). Since the origin of the deformity was predominantly in the tibia, proximal tibial osteotomy seemed to be a logical procedure, even though over-correction with some obliquity of the plane of the tibial plateaus with respect to the vertical was produced. The maximum postoperative obliquity in this series was 10 degrees, and six knees showed this amount of deformity. At the last follow-up examination, there was no medial subluxation of the tibia in these six knees despite the obliquity, and the clinical results were consistent with the findings by biomechanical analysis. This suggests that some obliquity of the joint line after valgus osteotomy does not significantly modify the distribution of compressive stresses on the articular surfaces.

In an attempt to analyse the influence of the severe varus deformity on the results in this series, we identified two components of the preoperative deformity: the articular component and the osseous component. The articular component was the varus angulation secondary to the arthrosis and was assumed to be due to loss of articular cartilage and bone or laxity of the lateral structures, or both. This component was determined by drawing tangents to the subchondral bone-plates of the femur and of the tibia on the weight-bearing radiograph and measuring the angle that they formed. In the absence of any arthrosis, it was assumed that there was no articular component. This was because normally the tangents are nearly parallel to one another but not quite, since the articular cartilage in the medial tibiofemoral compartment is thicker than that on the lateral side. However, for the purpose of this analysis these tangents were assumed to be parallel, and therefore the articular-component angle was considered to have been zero degrees before the development of arthrosis in all knees. In this series, the articular-component angle ranged from 0 to 10 degrees (average, 5 degrees) before the operation. Ten years after osteotomy, the articular-component angle ranged from 0 to 9 degrees (average, 4 degrees). In none of the knees, even those that had been overcorrected (a hip-knee-ankle angle of more than 186 degrees), was there any increase of the medial laxity. In addition, at the last follow-up examination no valgus articular-component angles had developed, no increase in the laxity of the lateral structures was evident, and no varus articular-component angles had increased even when the correction was insufficient.

With regard to the use of bone graft, autogenous iliac crest has been the gold standard because of its structural characteristics, osteoconductive and osteoinductive potential, as well its high rate of union. Problems with it relate to the morbidity and potential complications associated with its harvest. The use of a bone substitute wedge eliminates these problems yet provides only osteoconductive benefit. There are not many reports in the literature to date regarding its use in this procedure particularly in knees with large varus deformity. We postulated that when bone union is evaluated, this substitute would be a satisfactory choice and would provide healing of the osteotomy in a timely fashion of two months or less and that the wedge construction would not collapse. One could argue that this substitute choice lacks the osteoinductive properties of autogenous iliac crest and therefore requires a longer time to union. The time to complete clinical and radiographic union of the osteotomy ranged from five to nine weeks, with a mean of seven weeks. The two cases with collapse of the wedge at the osteotomy site were used in calculating the average time to union, counting the time to union as nine weeks (the point at which union was diagnosed). It is not surprising to note that time to bone union increases as a greater amount of correction (wedge opening) is obtained. The difference in mean healing times between each osteotomy size was not statistically significant however. The porous portion of this substitute acts as an ideal osteoconductive substitute in this situation. The well-established bone-healing process of creeping substitution can proceed across the resorbable part. This characteristic is lacking in some other substitutes that have been used in the past and reported in the literature such as coral, hydroxy-apatite, acrylic bone cement. In combination with the 30% macroporosity β-TCP wedge, full weight-bearing is possible immediately after operation if pain allows. Thereby, the disadvantages and complications due to immobility are prevented. This is an advantage over other techniques, for which full load bearing is possible only after six weeks or longer. The postoperative rehabilitation protocol for the 70% macroporosity β-TCP in combination with an angle-stable locking plate consists of 10–15 kg weight-bearing for six weeks [18–20]. The osteotomies completely consolidated in all our cases and no serious complications occurred. In 16 out of 21 cases the fixation system was removed because of local complaints related to its subcutaneous position over the superficial pes anserinus. In six cases a conversion to a knee arthroplasty was performed. The implanted β-TCP wedge did not interfere with placement of the knee arthroplasties.

We assessed the resorbability of rigid β-TCP wedges. Complete resorption of the β-TCP wedges was not seen in any of the cases up to 12 years postoperatively. In all knees remnants of the β-TCP wedge remained visible. Consequently, the maximum score according to the van Hemert classification [15] was phase 3. Nevertheless, within phase 3 substantial differences could be observed in the amount of resorption of the β-TCP wedge over time. Yet, after consolidation of the OWHTO, resorption and remodelling of the β-TCP wedge progressed. However, within the average follow-up time of ten years, this never led to complete resorption of the β-TCP wedge. The van Hemert's classification system does not show this slow resorption process, since it focuses on the interface between the bone and the β-TCP wedge and not on the absolute amount of β-TCP resorbed. Our results are in line with previous reports using 30% macroporosity β-TCP in OWHTO [18, 19]. Dehoux et al. [18] followed their patients over a mean of 18 months (range, 6–60 months). At maximum follow-up 75% of the β-TCP was still present in the majority of the patients, and more than 50% resorption did not occur. Bonnevialle et al. [19] described that in 18 out of 22 cases, the β-TCP was barely visible after five years, but traces of the implant remained visible.

Finally, the surgeon must be aware of the importance of maintaining the integrity of the lateral hinge at the osteotomy site when performing osteotomies with large corrections. The significance of this in aiding union is born out in other papers [20, 21] and by our own experience. Strict attention to technical details during the operation will serve to minimise this eventuality. Frequent use of the image intensifier in multiple views during the procedure and a high index of suspicion will assist in making the diagnosis of lateral hinge fracture. Care must be taken to identify this intraoperative complication when it occurs and to act accordingly with the application of supplemental lateral fixation.

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