We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

BOOK CITATION INDEX INDEXED

CLARIVATE ANALYTICS

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Primary Total Knee Arthroplasty in Valgus Deformity

Nikolopoulos Dimitrios, Sagos George and
Michos Ioannis

Additional information is available at the end of the chapter

Abstract

Proper limb and component alignments as well as soft tissue balance are vital for the longevity and optimal long-term outcomes of total knee arthroplasty (TKA). The majority of orthopedic surgeons agree that the total arthroplasty procedure in valgus knees with a deformity of more than 10° is technically demanding and may prove challenging. At the time of operation, the bone and soft tissue abnormalities that should be corrected make accurate axis restoration, correct component positioning and joint stability attaining a difficult task. Specific pathologic anatomic changes associated with valgus knee should be understood preoperatively and estimated so as to select the proper surgical method, to enhance component position and to restore soft-tissue balancing. The purpose of this chapter is to consider all the valgus knee anatomical variations, to analyze the best pre-operative planning and to evaluate the type of implant, constrained or not. Lastly, it will also be underlying the current main approaches and techniques to be proposed in the literature for both bone cuts and soft tissue management of valgus knees and if minimally invasive techniques can be performed in severe deformed knees.

Keywords: valgus, knee, arthroplasty, lateral approach, medial approach

1. Introduction

Angular deformities around the knee joint necessitate special consideration to restore normal alignment during total knee arthroplasty (TKA). In the region of 10–15% of patients requiring a primary TKA present with a valgus deformity (VD), the accurate correction of which still poses a challenge [1]. Excessive preoperative malalignment predisposes to a greater risk of failure compared to well-aligned knees [2]. For this reason, the restoration of

the normal mechanical axis of the knee and the balance of the surrounding soft tissues have to be observed to be important for the final outcome of knee replacement operations [2–5]. Thus, the severely valgus deformed knees are associated with a worse outcome when compared with their varus counterparts [5].

The etiologic parameters of knee VD are different and multifactorial from congenital to secondary such as primary osteoarthritis. More specifically, inflammatory arthritis (rheumatic diseases), primary osteoarthritis, posttraumatic arthritis (as a result of a tibial malunion, physeal arrest, or tibial plateau fracture), or overcorrection from a high tibial osteotomy for a preexisting varus deformity are the main etiologies in adults with [2, 6]. However, a significant percentage of adults with lateral compartment arthritis and concomitant VD represents unresolved physiologic valgus deformed knees. Infrequently, persistence of genu valgus from childhood may exist secondary to metabolic disorders, such as rickets and renal osteodystrophy [7]. Overwhelmingly, the most common etiology of VD knees is primary osteoarthritis and secondly rheumatoid arthritis and posttraumatic arthritis, whereas other inflammatory disorders and osteonecrosis are scarce etiologies based on the main clinical series that utilized TKA in the last two decades [1–5, 8–16].

The valgus deformity is sustained by anatomical variations divided into bone remodeling and soft tissue contraction/elongation, and usually it is a combination of primary or secondary bone and soft-tissue abnormalities. These include contracted lateral capsular and ligamentous structures, lax medial structures, and acquired or preexisting bony anatomic deficiencies. This constellation of pathology makes attaining soft-tissue balance when the knee is returned to physiologic alignment extremely difficult [2, 4, 6]. More specifically, the contracted structures are the iliotibial band (ITB), the lateral collateral ligament (LCL), the popliteus tendon, and the posterolateral capsule (PLC). Rarely, the lateral head of the gastrocnemius and the long head of the biceps femoris are affected. Some authors also further described a posterior cruciate ligament (PCL) alteration in valgus knees, but in the literature its influence in maintaining the deformity is not universally accepted [2]. The stabilizing structures on the medial side of the knee are attenuated. Unlike its varus counterpart, bone tissue variations consist of lateral cartilage erosion, lateral condylar hypoplasia and metaphyseal femur remodeling, while the tibial plateau is usually less affected [2, 3, 8–10]. The described deformities can lead to a tibial external rotation and to a patellar lateral subluxation tendency [11].

In 2005, Ranawat described three grades of VD [1]. More specifically, in Grade-I (80%), the deformity is less than 10° and is passively correctable, whereas it is characterized by an intact medial collateral ligament (MCL). In Grade-II (15%), the axis deviation ranges between 10° and 20°, whereas the MCL is elongated but functional; and in Grade-III (5%), the axis deviation is more than 20°. All the medial stabilizing elements are typically not functional so a constrained implant usually is required [1, 10].

Understanding the specific pathologic anatomic changes associated with the valgus knee is a prerequisite so as to select the proper surgical method, to optimize component position and restore soft-tissue and gap balance [17]. Over the last 20 years, numerous approaches and soft-tissue procedures have been proposed to perform TKA in VD with the purpose to restore and maintain the limb's anatomical axis. In this chapter, we overview the most common approaches, we analyze the different techniques of succeeding anatomical axis restoration and soft tissue and gap balance, and lastly we present the literature up-to-date long-term results.

2. Clinical examination and preoperating planning

Total knee arthroplasty (TKA) with valgus release is indicated when both mechanical and pharmacological nonoperative treatment modalities for end-stage degenerative joint disease have failed to relieve pain. The major contraindication to TKA is infection, and relative contraindications include young age, high activity level, and obesity [18]. Clinical evaluation and radiological assessment are extremely important as part of the TKA preoperating planning.

2.1. Knee physical examination

Patients with end-stage degenerative joint disease and valgus knee deformity have significant pain, limitation of daily living activities, increasing angular deformity, and increasing instability. In mild to severe VD, there is important ROM limitation, and in many cases night pain awakes the patient.

During standard physical examination for end-stage degenerative knee disease, the orthopedic physician should assess the patient's overall alignment both in the supine and weight-bearing positions, and the gait should be observed, in order to identify other dynamic instabilities (**Figure 1**). Both sagittal deformity (as fixed flexion contracture or recurvatum) and rotational deformity must be attended. Furthermore, the knee range of motion should be measured; the

Figure 1. Valgus left knee in standing position.

extensor mechanism status and the patellofemoral joint should be evaluated and measured [2, 6, 11].

In addition, preoperative clinical examination plays a major role for the orthopedic surgeon to determine whether the deformity is fixed, correctable or unstable. The knee should be further evaluated for anteroposterior laxity, coronal and sagittal deformity, and mediolateral instability [3]. It is very crucial to assess if VD is fixed (Ranawat Grade III) or still reducible (Ranawate Grade II or I). In fixed deformity, the lateral structures are tight and in contrast the medial ligaments are partially continent. As a consequence, in these deformities, when the lateral soft tissue release is fulfilled, the remaining laxity requires the usage of constrained prosthesis. In contrast, in a reducible deformity, soft tissue release is less invasive, and a standard unconstrained prosthesis could be used. The orthopedic surgeon would lastly perform a neurovascular examination to differentiate a possible lumbosacral or vascular disease [2, 9–11].

2.2. Radiographic evaluation

After the clinical assessment, the mandatory preoperative planning radiographs of three classic views of the affected knee are: standing anteroposterior, lateral (profile), and sunrise (**Figure 2**). The limb axis deviation measurement with long film standing views or CT-scan with anterior

Figure 2. Anteroposterior X-ray in standing position for measuring valgus deviation.

orientation of the patella is very useful and important [3]. It has been mentioned that rotation up to 20° has little effect on the measurement of the femorotibial axis deviation [19].

Based on our experience, in cases of serious bone stock deficiency, a knee computer tomography will be helpful. Attention should be paid to lateral distal femoral hypoplasia, posterior femoral condyle erosion and metaphyseal remodeling both of the femur and tibia, which can lead to malalignment or malrotation of the femoral component and which could be better measured with CT. The patellofemoral joint may also be partially dislocated.

The anteroposterior and lateral X-ray views would further aid to evaluate the amount of osseous resection needed to correct deformities without leading to knee instability. A precise knee profile view is helpful for assessing the tibial slope, and the height of the patella (alta or baja) based on the Insall-Salvati ratio. In addition, the 30° flexion patellofemoral view will help to evaluate if patella is centered in troxilia (centered, subluxation, luxation) [2, 11, 20].

In order to measure the VD level and plan the amount of surgical correction (templating), a weight-bearing long leg X-ray view is fundamental so as to evaluate the lower limb alignment (mechanical and anatomical axis) (**Figure 3**). Stress radiographs or fluoroscopic examination may be used to determine the amount of medial instability [2]. A baseline electromyogram should be made for patients presenting with symptoms such as hypoesthesia, dysesthesia, and paresthesia that may be attributed to lumbosacral disease [2, 11].

2.3. Templating

In the radiographic weight-bearing anteroposterior view of the knee, a template of bone cuts should be performed in consideration with the prosthesis type and design that will be implanted in the candidate for TKA. Two lines are drawn: one line on the tibial anatomical axis and afterward a perpendicular one at the level of the lateral tibial plateau. In that way, the surgeon will have an indication for the tibial resection [2, 4]. Firstly, the femoral anatomical axis is drawn and secondly the line with the desired amount of remaining valgus (usually 3°) at the level of the intercondylar notch [4]. The orthopedic surgeon should also observe the
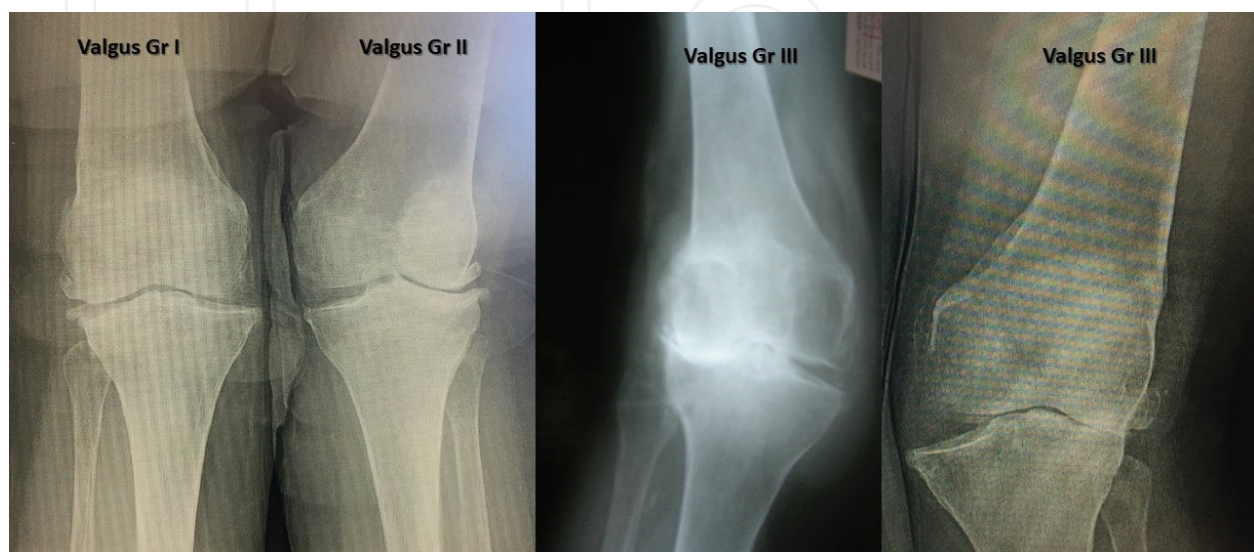

Figure 3. Anteroposterior X-rays in standing position of Valgus knees in different grades.

posterior capsule's presence of osteophytes, on the knee X-ray lateral view. Lastly, the lateral view can be further used for sizing the femoral component and for locating the entry point of the femoral canal [1, 11, 17].

2.4. Component selection

During preoperating planning, the orthopedic surgeon selects the implant. The selection should be carried out based on the clinical evaluation and the radiological measurements, but the final decision should be taken during the operation and after the knee bone cuts and soft-tissue balancing. That is why valgus knee surgeons always have plane A and plane B in the prosthesis selection (constrained component, VVC or classical), especially in severe deformed knees.

Preferably, in proper restored soft-tissue balancing, a minimally constrained component can be implanted. Nevertheless, if significant deformity necessitates posterior cruciate ligament (PCL) sacrifice for soft-tissue balancing, the majority of surgeons agree that a more constrained posteriorly stabilized (PS) component must be used [6]. PS knee components provide some degree of posterior stabilization as well as protection against posteromedial, posterolateral, straight medial, or straight lateral translation, but it will not protect against residual medial laxity, which is one of the major considerations in achieving proper balance in VD knees [9, 10, 18].

The debated issue between posterior-stabilized (PS) and cruciate-retaining (CR) implants in VD is that the PCL is often contracted and it may limit the deformity correction [10, 21]. It is true that in specific cases, the deformity correction with an intact PCL may be difficult to be obtained, as the PCL is a secondary stabilizer [22, 23]. Above and beyond, the PS design is more stable than a CR one due to the post-cam mechanism, and the PS design allows greater lateralization of the femoral and tibial components that improves the patella tracking and minimizes the necessity performing a lateral retinacula release [1, 2]. For these reasons, in VD knees, some orthopedic surgeons prefer a contracted PCL with a PS design as simplest as to stabilize it by using a CR implant [6].

McAuley et al. also presented that CR implants could be used in a wide range of VD osteoarthritic knees and that survival is improved when the LCL and/or the popliteus tendon are preserved. Release of both the PCL and popliteus is one of the two factors that made revision resulting from wear, osteolysis, or instability more likely, whereas, release of both the LCL and popliteus increased the likelihood of revision by 19.9 times due to more mediolateral laxity [24].

A debated issue is the amount of constraint needed to balance a VD knee. Favorito et al. proposed that the surgeons should resist the temptation, if possible, of a more highly constrained prosthesis. Although a highly constrained component may be necessary in difficult revision cases, they are infrequently necessary for primary arthroplasties [6]. In severe VD knees, the problem is that the PCL may be stretched or elongated, which means nonfunctional and these knees require either an ultra-congruent (VVC or hinged) or PC component.

Additionally, in extremely deficient lateral femoral condyle valgus knees, the usage of component augmentation blocks may be required. That is because the lateral femoral condyle may have had little or no distal femoral bone resected or, similarly, little to no bone resected from the chamfer and posterior cuts; then component augmentation blocks may be required

[4, 6]. Nevertheless, if press-fit femoral component is being performed, then as long as native bone is resting on the medial-posterior side of the chamfer cuts, then the remaining lateral defect can be filled with autograft bone taken from other cuts during the procedure [1, 6].

3. Surgical approach and technique

In order to understand and perform the valgus knee operative procedure, the orthopedic surgeons should consider that the lateral stabilizers are of two types: (1) the lateral collateral ligament (LCL) and the popliteal tendon who insert near the flexion-extension axis and act in both knee extension and flexion and (2) the fascia lata, the posterolateral articular capsule (PLC), the biceps and the external gastrocnemius muscles who insert remotely with respect to the axis and act only in extension [17, 25].

Many and various protocols of progressive step-wise release have been proposed during the last two decades, and as a consequence, the sequence of the lateral release remains controversial. In 2003, the SOO (*Societe d'Orthopedie de l'Ouest*—Western France Orthopedics) Society presented a classification system of four types of valgus knee, with increasing surgical difficulty to be distinguished from Type I to IV. More specifically, in Type I valgus knees, the deformity can be completely reduced, without medial laxity, and with no particular problems whereas a medial approach is possible. In case of course of patellar dislocation, a lateral approach is recommended. In Type II valgus knees, the deformity is totally or partially irreducible, nonetheless without medial laxity, and is the most frequent; and lateral release is required. In Type III, the deformity is reducible, but with medial distension laxity, and then the medial laxity should be managed. Lastly, in Type IV, the deformity is irreducible, with medial distension laxity, and a combination of Types II and III problems [25].

3.1. Anterolateral approach

Keblish [11] was the first, in 1991, to recommend a lateral capsular approach for TKA in the valgus knee, and the technique was refined by Buechel [25]. It has been proved unpopular because it is considered to be technically more demanding as elevation of the tibial tubercle was also recommended. On the other hand, Whiteside in 1993 [27] and Bulki et al. in 1999 showed the outcome in VD knees with lateral approach and tibial tubercle osteotomy (TTO) [28]. The disadvantage of this approach is the TTO, which is necessary for eversion of the patella. In 1998, Fiddian et al. presented a modified lateral capsular approach with repositioning of vastus lateralis in VD knee arthroplasties with very good results [29].

A longitudinal incision along the lateral border of the quadriceps muscle was described by Keblish [11], always taking care to leave 1 cm of the lateral retinaculum, from the junction between the vastus lateralis and the quadriceps tendon to the patella, through 50% of the tendon. In difficulty of the lateral closure, it was proposed two different tricks to be facilitated. On the one hand, approximation of the infrapatellar fat pad to the patellar ligament; and on the other hand, separation of the vastus lateralis from the rectus femoris, followed by suturing together the two tendons in a staggered position [11].

In the anterolateral approach, as described in detail by Nikolopoulos et al. [4, 17], a straight midline skin incision is followed by a lateral parapatellar capsulotomy. The ITB is next elevated from Gerdy's tubercle. Also, in order to medially displace the patella, TTO is performed laterally, leaving the soft tissues intact medially. The TTO length measures 5–6 cm, whereas proximally, at the upper part of the patellar tendon insertion, the transverse part of the osteotomy prevents proximal migration. The tibial tubercle is hinged medially, hence offering a wide exposure of the joint surface (**Figure 4**).

Tibial resection is done—directing the level of the cut perpendicular to its longitudinal axis. After removal of the osteophytes, especially in the lateral tibial plateau, a resection must always be performed from 6 to 8 mm in the medial compartment (**Figure 5**). In cases of severe bony deformity of the tibial plateau, no bone may be resected on the lateral side so as medial over-resection or malaligned cuts to be avoided [2].

The distal femoral cut is done in 3° of valgus in relation to the femoral axis. The distal femoral cut at 3° only, instead of 5–7° that applies in varus knees, protects against under-correction. A slightly more varus result has been proposed during TKA for VD to counteract any tendency for the knee to shift back into valgus [11]. In order to avoid elevation of the joint line, caution should be taken so as the lateral femoral condyle not to be over-resected [4]. In severe VD of the distal femur, Rossi et al. proposed [2] no lateral condyle distal femoral resection or minimal (1–2 mm) resection. Also the femoral resection in the medial condyle should be no more than 10 mm (usually 7–8 mm). The surgeon should also pay attention to the lateral condylar hypoplasia in VD that can determine a great intra-rotation of the components if a posterior reference is used [2]. Both the AP axis of Whiteside and the epicondyle axis are used to assess and confirm the orientation of the femoral cut [3, 4]. Arima et al., taking into consideration this aspect, utilized the usage of the anteroposterior axis so as to give the proper femoral rotation in valgus anatomy [30]. In cases of severe trochlear dysplasia, the Whiteside line is extremely difficult to be identified, so the epicondylar axis or parallel to the tibial cut technique must be used to assess a correct femoral rotation [2].

At this phase, especially for tight knees in flexion, the sub-periosteal POP and LCL elevation from the epicondyle is performed. In tight knees, PLC release could be performed in both flexion and extension. During closure, the tibial tuberosity is generally fixed to its original position or slightly more medially in cases that the patella tends to track laterally and dislocate.
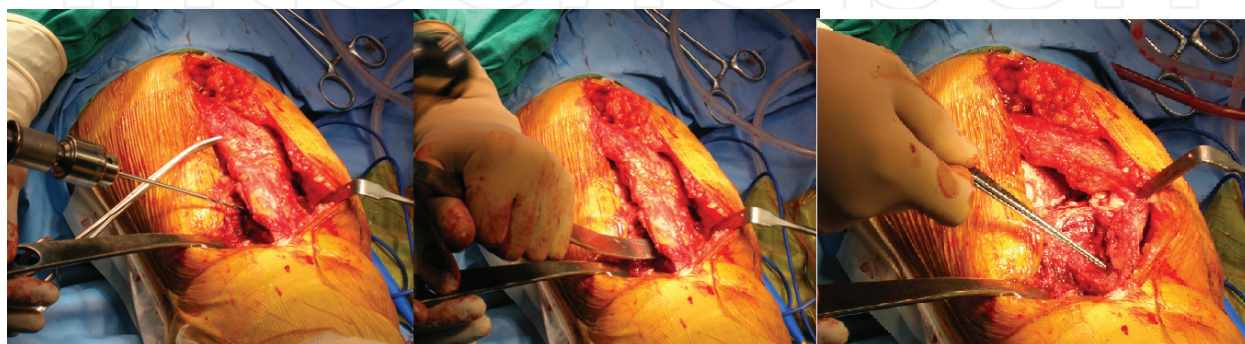

Figure 4. Surgical procedure of the tibial tubercle osteotomy stages (TTO).
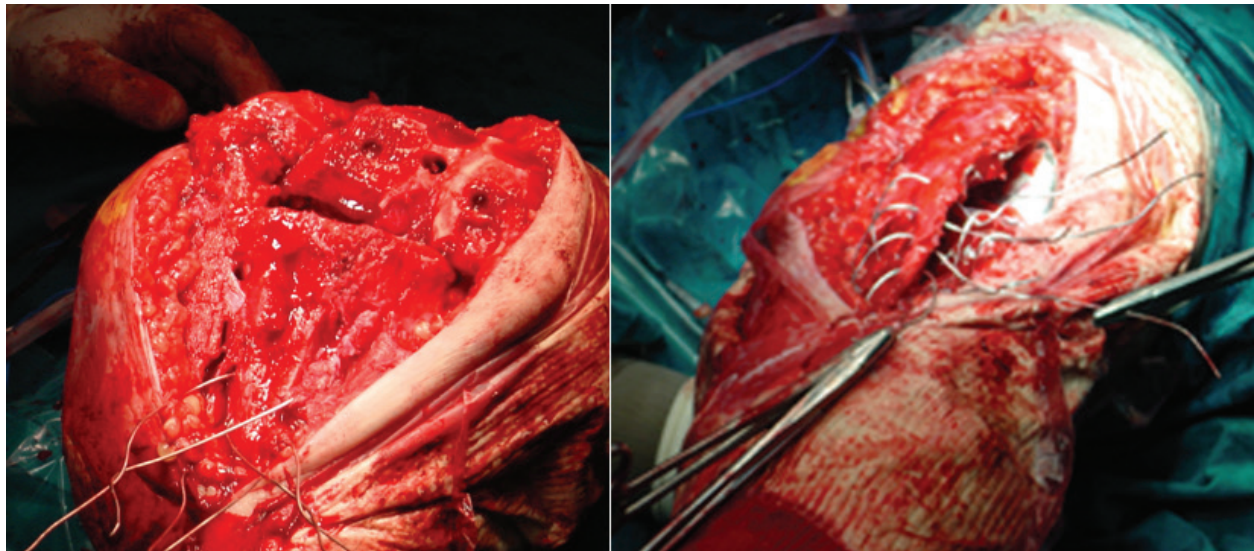
Figure 5. During operation, fixing the tibial tuberosity osteotomy with three loops.

Therefore, tibial tubercle transfer is necessary for satisfactory alignment. Tibial tubercle fixation can be performed even with two 4.5 mm cortical screws or with three wire loops (preferred). The oblique direction of the wire loops offers better resistance to proximal directed forces [4]. Patellar tracking was finally checked with the "no-thumb" test.

The main reasons and advantages considered of the group of orthopedic surgeons [1–4] preferring the anterolateral procedure are mainly three. Firstly the lateral release, as part of the approach, is usually necessary in VD knees and it does not seriously impair the extensor mechanism vascular supply as in medial arthrotomy. Secondly, the lateral approach facilitates the release of the lateral contracted elements, offering better surgical view and lastly the possibility to medicalize the tubercle if required improves the patella tracking [2, 4].

3.2. Anteromedial approach

The anteromedial is the standard approach being used commonly all these decades by the surgeons in the VD knees and with no contraindications [1–6]. A straight midline skin incision is performed, followed by a standard medial parapatellar arthrotomy. The tibial and femoral bone cuts followed the same technique as the one described in the anterolateral approach. In order to achieve optimal soft tissue balancing, as contracture of the ITB is noted with the knee in full extension, release is performed by elevation from Gerdy's tubercle or fractional lengthening with multiple stab wounds. An additional release includes the LCL from the distal part of the femur and popliteus [4]. In most cases with mild to severe VD, release of the posterolateral capsule is performed. The PLC is released either from the distal part of the femur, with the knee in flexion, using a curved osteotome; or with the knee in full extension, fractionally lengthening by means of multiple stabs punctures ("pie crust" technique) [1, 32]. Finally, lateral retinacular release is required to facilitate patellofemoral tracking. Tracking of the extensor mechanism is again evaluated with use of the appropriate lift-off test [3, 4].

The main disadvantage of the medial approach is that it is more difficult to reach the postero-lateral corner during the lateral soft tissue release. For this reason, sometimes a TTO is necessary. Additionally, in cases that a medial parapatellar approach is combined with a lateral release, patellar vascular damage has been described [26].

3.3. Soft tissue balancing

3.3.1. Lateral soft tissue

It is accepted worldwide that the lateral structure release is necessary in VD knees. Nevertheless, there is an open debate on the subject of the best sequence and the best technique to perform those releases. In the abovementioned part, our experience was presented [3, 4], in accordance with the main ideas of other researchers [11, 26–29, 31–34]. In that part, the literature different proposals for soft tissue balancing of the retracted lateral structures of VD knees would be analyzed. More specifically, the releases should be performed with the knee extended and by using lamina spreaders to check the tension of the medial and lateral compartments. After each release, evaluation of the alignment and the stability of the knee should be performed in order to achieve a symmetrical rectangular extension and flexion gaps with the spacer block in situ [2, 35].

First, Krackow et al. presented in type I valgus knees the release of the ITB and the LCL, followed by the PLC, POP and the lateral head of the gastrocnemius muscle (when necessary) [10]. In type II valgus deformities, a medial ligamentous reconstruction was also proposed, either proximal or distal advancement of the medial ligament mechanism according to the surgeon's preference. Buechel presented simultaneously a sequential three-step lateral release for correcting fixed VD knees during TKA, which included firstly elevation of the ITT from Gerdy's tubercle, secondly the LCL and PT, and lastly the entire periosteum of the fibular head. Ligament balancing was achieved when the knee was aligned in both the frontal and sagittal planes with a medial and lateral opening of 2–3 mm when forced valgus and varus stress were applied at 5° of flexion.

Ranawat et al. described a stepwise technique in which the first structure to be released was the PCL; and afterward, a PLC intra-articular release by using an electrocautery at the level of the tibial cut surface. The ITB is released when necessary with multiple "inside-out" stab incisions as well as the LCL. These multiple transverse stab incisions, the so-called "pie-crusting" technique, are performed a few centimeters proximal to the joint line of the ITB with a no. 15 surgical blade, lengthens as necessary the lateral side. On the contrary, the POP is normally preserved [1]. Clarke et al. [36] and Aglietti et al. [37] performed the pie-crust technique with excellent results. It is believed that the pie-crusting technique reliably corrects moderate to severe fixed valgus deformities with a low complication rate and reasonable mid-term results. The multiple punctures reduce the risk of posterolateral instability allowing gradual stretching of the lateral soft tissues and preserving the popliteus tendon [36]. Nevertheless, one of the disadvantages of this technique is the potential risk of peroneal nerve lesion [1, 36, 37]. In a cadaveric study, Bruzzone et al. observed that the nerve is at overall risk during the release of the PLC, in the triangle defined by the POP, the tibial cut surface and the most posterior fibers of the ITB ("danger zone"), but not during the pie-crusting of the ITB ("safe zone") [38].

As the LCL is the tightest more common structure, then it is the first structure to be released according to Favorito et al. The next sequential release follows is the POP (an important structure for rotational and valgus stability in flexion), the PLC, the femoral insertion of the LHG and, finally, the ITB [6].

Whiteside described a sequence of soft tissue release based on the anatomic function of ligaments in flexion and extension consistently. A ligament attached to the femur near the epicondyles, so near the axis through which the tibia rotates and the knee flexes and extends, has an important role in flexion stability. Conversely, a ligament attached far away from the epicondyle is more important for the extension knee stability. Thus, for knees that are tight in flexion and extension, the LCL and POP tendon are released. For those knees that remain tight only in extension, ITB release is needed. Posterior capsular release is performed only when necessary for persistent lateral ligament tightness [39].

In 1999, Krackow and Mihalko published a cadaveric study that assessed the amount of correction achieved in each step of release, comparing it in flexion and extension. The sequences on the one hand were ITB, POP, LCL, and LHG; and on the other hand LCL, POP, ITB, and LHG. They evaluated the amount of correction at 0°, 45°, and 90° of flexion. The results showed that the greatest varus rotation occurred once all structures were released, with the LHG origin last in both groups. The largest increase occurred after the LCL release. Then it is hypothesized that in severe VD, the LCL should be released first; and POP and ITB should be used afterward to grade the release [40].

Boyer et al. emphasized the purpose of the lateral approach in valgus knee arthroplasty, as it allows the automatic ITB division and elevation from the Gerdy's tubercle to be taken in continuity with the anterior compartment fascia and release of the attachments of the lateral part of the femur. More specifically in tight knees in extension, firstly the ITB was released. Afterwards, if additional releases are needed, a tight PLC was detached from the posterior condyles or transected at the level of the tibial cut from PCL insertion to the posterolateral corner. Release of the gastrocnemius and the biceps tendon should be considered in cases that the result was not sufficient. If the spacer introduced, then the ligament release stops to prevent varus laxity. [41].

In 2002, Brilhault et al. described an alternative technique for lateral structure release in association with a lateral parapatellar approach [42]. More specifically, a sliding osteotomy of the femoral LCL and POP insertions is done and the resulting bone block is mobilized and placed more distally. Bremer et al. presented in their study excellent result without any conversion to semi-constrained or constrained knee prosthesis [43]. Mullaji and Shetty described a more accurate repositioning of the epicondyle, after releasing the PLC and the ITB, with the use of a computer-navigated system [44]. Computer navigation while performing lateral femoral epicondylar osteotomy allows precise, controlled, quantitative lengthening of lateral structures, and restoration of optimum soft tissue balance and alignment [45].

3.3.2. Medial soft tissue

Krackow et al. analyzed that in Grade II VD knees, the MCL may not be completely functional and a residual medial laxity is poorly tolerated postoperatively. In these conditions, the authors suggested tightening the medial ligamentous structures, particularly if the PCL has been retained

[44]. A small bone plug with the attached insertion of the PCL, and the PLC is removed from the tibia and moved distally, securing it with transosseous sutures. In this technique, the MCL is tightened by moving a bone block distally with its tibial insertion [45].

The advancement of the MCL from the epicondyle or a division and imbrication in order to tighten it can be performed in conjunction with the use of constrained condylar prosthesis [6].

3.4. Clinical results

Accurately restoring the mechanical axis (MA) of the limb, aligning components, and properly balancing soft tissue—as already mentioned—are vital for the long-term success of TKA [1–6]. In the last three decades, a number of different surgical techniques have been described for TKA, in severe valgus deformed knees [1–6, 9–11, 18, 31–34]. The distal femoral cut at 3° only, instead of 5–7° that applies in varus knees, protects against under-correction. A slightly more varus result has been proposed during TKA for VD to counteract any tendency for the knee to shift back into valgus [31]. Miyasaka et al. in their 10- to 20-year follow-up study presented successful bony alignment in 75% of cases by having a postoperative valgus alignment between 2° and 7° [22].

Above and beyond, on the subject of ligament balancing, there is no consensus regarding the sequence in which the lateral elements should be released in valgus knees. Starting with Insall et al. [46], in 1979, who described a soft-tissue balancing technique in which the ITB was divided transversely above the joint line, while the lateral aspect of the capsule, the LCL and the POP tendon were detached from the lateral femoral condyle [9, 46]. The excellent or good results referred was 93%; with limited posterior subluxation (<3%) and 3.6% reoperation rate in 5 years [45] and 6.7% in 12 years [47].

Afterward, other researchers such as Keblish [11], Buechel [26] and Fiddian [27] recommended a lateral approach with or without TTO. Keblish preferred lateral approach in VD knees as it has a better view; it is direct, anatomical and more "physiological" technique according to his opinion that maintains soft-tissue integrity. In 79 cases, Keblish performed the "lateral release" as part of the approach and concluded that the patellofemoral tracking and alignment stability were optimized and medial blood supply preserved. Clinical experience also showed the approach to be more esthetic and the results objectively superior, that is why the lateral approach was recommended as the "approach of choice" for fixed VD in TKA. In that difficult group of patients, there were good to excellent scores in 94.3% of cases; whereas knee stability was enhanced with the use of nonconstrained prostheses [11].

Furthermore, Buechel recommended the lateral approach with TTO in order to regain neutral alignment in VD of up to 90° and then to correct the fixed external tibial rotation deformity [26]. Fiddian et al. performed the lateral approach with repositioning of vastus lateralis at closure, with good to excellent results in 25 cases. The knee ROM and VD restoration were achieved in all the 25 cases; apart from two cases that developed 10° and 15° of fixed flexion deformity. With the repositioning of vastus lateralis at the end, the normal patellofemoral tracking was also restored [29].

Whiteside proposed the sequential releases of the ITB, POP, LCL and the lateral head of gastrocnemius; and tibial tubercle transfer when the Q angle was >20° [27]. He referred mean

valgus angle at 7° after surgery; but with no alignment or varus-valgus stability deterioration during the 6-year follow-up period. Nevertheless, in greater than 25° VD, knees had a tendency for increased posterior laxity. Lastly, Whiteside presented patellar subluxation and dislocation in less than 1% in the study [27].

Conversely, Krackow [10, 40, 45] and Healy [48] recommended medial soft-tissue advancement or reconstruction combined with lateral release. To be more specific, Krackow and Mihalko [40] studied in cadavers the flexion-extension joint gap changes after lateral structure release for VD correction in TKA and concluded that in severe valgus deformities, the LCL should be considered first for release and the POP and ITB be used to grade the release. In their series of 99 TKA, the Grade I VD knees (based on Ranawat classification) were treated with lateral release versus the Grade II VD knees which were treated with ligament reconstruction procedures on the medial side. The 72% of the patients referred excellent results whereas 18% good, 7% fair, and 2% poor [45]. Healy et al. presented, in Grade II VD knees, lateral ITB release in combination with proximal MCL advancement with bone plug recession, with fully stable and functional ROM at 4–9 years follow-up [48].

Apart from Krackow cadaveric study, extremely interesting results published in 2001 by Peters et al. who studied the flexion-extension gap symmetry during sequenced release of the lateral structures in VD knees. It is concluded that complete release of the ITB at the joint line had a more profound effect on the extension than the flexion gap. On the contrary, complete release of the LCL/POP from the femur more profoundly affected the flexion than the extension gap; both of these release steps produced gap increases that were significant (7–12 mm). Selective fractional lengthening of the ITB, the PLC, and the POP tendon alone produced smaller magnitudes of correction, which more symmetrically affected flexion-extension gaps [49].

Above and beyond, in 2004, Politi and Scott referred, good-to-excellent results in TKAs with VD >15°, and achieved soft tissue balance, with a lateral cruciform retinacular release, and without LCL and POP release in 32 out of 35 cases [50]. In the remaining three cases, the extension gap balancing was achieved by adding, apart from the lateral cruciform retinacular release, the LCL and POP partial release. No further prosthetic constraint was necessary following these releases, and these knees have remained clinically stable at their latest mean 3.4-year follow-up despite the partial release of the LCL and its contribution to flexion gap stability [50].

Stern et al. accomplished ligamentous balancing in TKAs with VD >10°, with sequential releases from the lateral side of the femur and without MCL reconstruction, achieving 91% of good-to-excellent results. The postoperative axis alignment was 5–9° valgus [31]. Likewise, Laurencin et al. reviewed TKAs with 25° VD, where lateral retinacular release was accompanied by sequential lateral release achieving postoperative anatomic alignment between 0° and 10° valgus, in 96% patients [51].

In 2014, Chalidis et al. presented the results of 57 Grade II VD knees that underwent a primary TKA via lateral parapatellar approach with a global step-cut "coffin" type TTO over a 10-year period. Postoperatively, there was a significant improvement in knee extension, flexion, Knee Society Pain and Function Scores and WOMAC Osteoarthritis Index. Congruent

patellar tracking was observed in all cases. So, the researchers concluded that lateral approach in combination with TTO is an effective technique for noncorrectable valgus deformed knee in TKA [52].

Brilhault et al. also proposed in 2002 an interesting balancing way for VD knees by treating 13 patients with fixed VD of the knee with a semi-constrained TKA combined with advancement of the LCL by means of a lateral femoral condylar sliding osteotomy [42]. At follow-up of mean 4.6 years, the mean Knee Society Score improved from 32 to 88 and the functional score from 45 to 73 conversely. The mean tibiofemoral angle was corrected from 191° to 180°. There was no postoperative tibiofemoral or patellar instability and, in most knees, distal transposition of the lateral femoral condyle achieved satisfactory stable alignment [42].

Hadjicostas et al. used computer navigation in severe VD (>20°) knees in combination with an osteotomy of the lateral femoral condyle. The correct mediolateral balancing of the extension gap was confirmed by the navigation system during the operation time and before the final fixation of the lateral femoral condyle. The 15 knees were corrected to a mean of 0.5° of valgus (0–2°), with excellent mid-term results referred by the authors. Lastly, flexion of the knee statistical significantly also improved to a mean of 105° (90–130°) postoperatively, and the mean Knee Society score improved from 37 (30–44) to 90 points (86–94) [53].

As a consequence, the "outside-in" or the "inside-out" technique has been proposed by different surgeons with similar results, such as Keblish, Murray, Stern, Buechel [4, 8, 9, 11, 26, 29, 31]. Likewise, the "pie crust" technique has also been proposed by Ranawat as an alternative way of knee balance, plus Clarke through the taut PLC or ITB with the knee fully extended [36, 37, 54]. If the lateral release cannot sufficiently stabilize flexion and extension gaps, then the medial side of the joint should be addressed, in an effort to limit the degree of lateral soft-tissue release [4, 6]. Several techniques have been similarly described for successfully and safely "tightening" the incompetent MCL [10, 40, 48].

Taking into consideration firstly that many surgeons find it difficult to correct a VD by using a conventional alignment guiding system without also using a constrained implant; and secondly that a marked coronal femoral bowing deformity is easily missed [55, 56]. Huang et al. proposed, in 2016, that the use of a computer-assisted surgery (CAS) for an intra-articular bone resection is effective for increasing the accuracy and reproducibility of limb and component alignment with fewer outliers [55]. Both intra-articular bone resection and CAS are beneficial in Ranawat arthritic type-II VD knees with marked coronal femoral bowing deformity as with a rather high prevalence has been reported in Japan, China, Korea, India, Taiwan, Singapore, and Turkey. The marked coronal bowing deformity alters the relationship between the MA and anatomical axis (AA) of the femur, thereby affecting the postoperative MA and the placement of the femoral component [55, 56]. The most important Huang's et al. study finding was that CAS was more efficacious than intra-articular resection for facilitating a properly reconstructed MA, femoral component placement, and restoration of the joint-line in TKA on patients with marked coronal femoral bowing deformity. Nevertheless, CAS did not yield a better clinical outcome at a mean follow-up of 60.2 months [55].

3.5. The advantages of the anterolateral approach and the lateral balancing versus hazards of anteromedial approach

The medial parapatellar release arthrotomy though suggested as a standard procedure in a varus knee does not represent the optimal approach in a severe and technically demanding VD knee [4]. That is because the release of lateral patellar retinaculae is necessitated in most VD cases in order to prevent patellar instability. The latter as accompanied with medial capsulotomy results in significant impairment of the knee extensor mechanism's blood supply [57]. Though if the knee joint is approached via a lateral parapatellar arthrotomy, release of the lateral retinaculae is integrated in the approach and patella vascularity is preserved as the medial side stays undisturbed [4, 10, 57]. Laurencin reported 12% of patella avascular necrosis in medial parapatellar approach for TKA in combination with extensive lateral retinacular release [51]. Miyasaka also reported only one case out of 108, in which a patella fracture occurred 3 years after surgery which was believed to be secondary due to avascular necrosis [31]. In Nikolopoulos et al. series, no patella fracture or avascular necrosis was observed [3, 4].

Very important also in the knee extensor mechanism is the scar tissue due to previous knee's surgical operations. More specifically, scar tissue from previous tibial osteotomy makes patella's eversion problematic, and there is always a hazard for patellar ligament avulsion by forceful intraoperative retraction. Therefore, in order to protect the knee extensor mechanism, additional surgical techniques are needed either proximally (V-Y quadricepsplasty or "quadriceps snip") [58, 59] or distally to the patella with TTO [4, 6, 28, 34, 60–63]. We believe that the eversion of the patella is easily performed when a TTO is added to the lateral approach in primary TKA with severe valgus deformity, offering excellent view [4].

Likewise, in a lateral capsulotomy, the extensor mechanism is displaced medially, and as the tibia rotates internally, offers an excellent exposure of the contracted lateral structures, thus facilitates their adjustment. This encourages more conservative releases and significantly, discourages unnecessary steps that may create instability [4, 11]. In contrast in the medial approach, the lateral displacement of the extensor mechanism increases the external tibial rotation, pushing the contracted PLC away from the operative field and consequently technical difficulties in balancing the valgus knee [11]. Analyzing the literature on the subject of TTO, it has been valuated as a highly beneficial and safe procedure in achieving gentle eversion of the patella [4, 6, 28, 35, 60–63]. Besides, it prevents tibia internal rotation during patellar eversion, which may simplify proper positioning of the tibial component in severe valgus knees [4, 10, 63].

Furthermore, in a medial approach, the patella tracking is less than optimum and postoperative patellar problems are more common [10, 11, 27]. In opposition, the patellar tracking in a lateral approach is assured with the self-centering movement of the quadriceps-patellar tendon mechanism [11, 27]. In cases where a TTO is added, alignment of the extensor mechanism can be improved or adjusted when required, as osteotomy fixation at the end of the operation allows medial transfer of the patellar tendon insertion, eliminating in that way the postoperative patellar maltracking [4, 11]. In Nikolopoulos et al. series [3, 4], no patellar instability
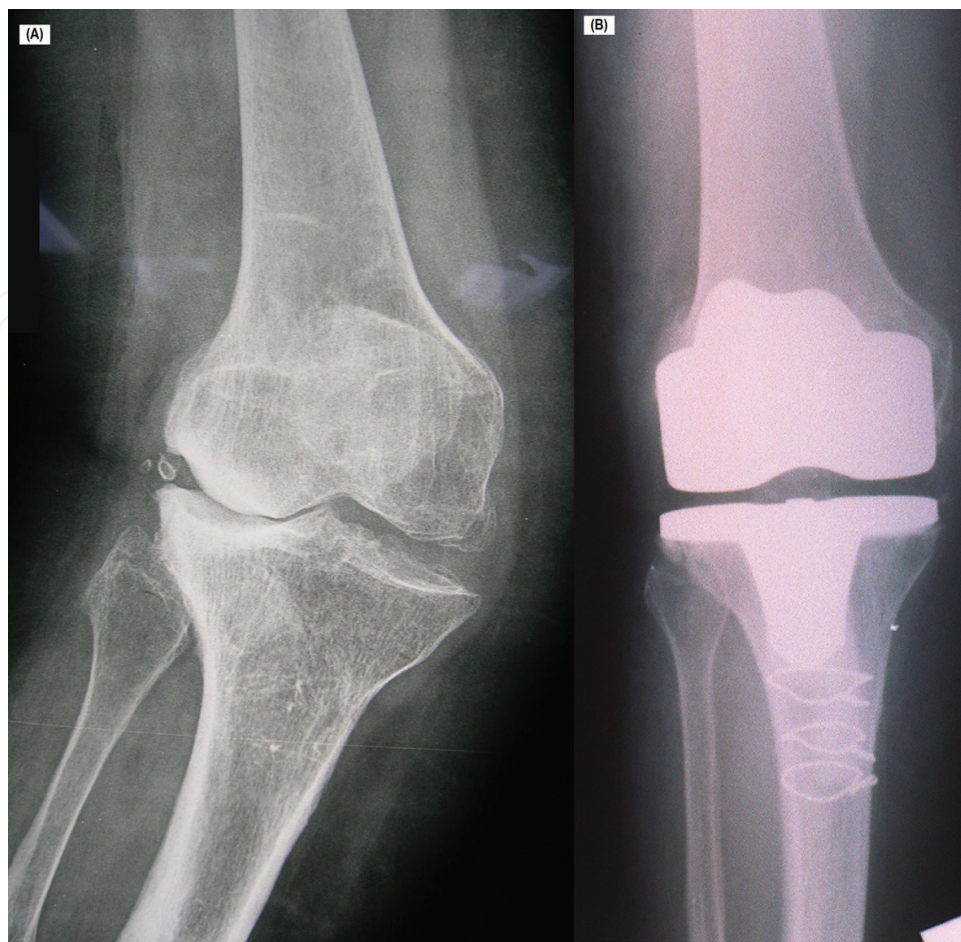
Figure 6. Severe valgus deformity (A). Full correction after the operation (B).

was observed postoperatively in the group of lateral parapatellar arthrotomy combined with TTO, as we had the chance to release the soft tissues easily and to transfer the tuberosity medially in two cases, succeeding the optimal quadriceps-patella tendon balance [4].

Burki et al. observed good results in 88% of their cases by applying TTO as part of lateral approach in revision valgus TKAs. No complications were reported from the osteotomy side, apart from one case complicated with anterior tibial compartment syndrome [28]. We also presented one case in our series [3]. Burki et al. hypothesized that TTO may traumatize the anterior tibial compartment; that is why it was recommended as a standard procedure the release of the anterior tibial fascia with several longitudinal incisions [28]. The length of the osteotomized tubercle in our series were 5 cm [3, 4] versus 7 cm in Burki series [28]. That was with the purpose of avoiding tibial fractures. Piedade had 8.7% of TTO fractures and tibial plateau fissures [63]. Consequently, consideration needs to be given to the size of the bony fragment and the quality of the fixation with respect to achieving sound consolidation of the osteotomy [4].

The results in valgus knees arthroplasties with medial parapatellar capsulotomy have been inferior to those of varus knees with significant deformity [5]. Karachalios et al. mentioned the residual VD in these knees with arthroplasty did not result in early component failure,

but was associated with a worse clinical outcome [5]. The literature on the other hand refers 70–78% of full restoration of the anatomical axis in valgus knees [2, 5, 6, 9]. Incomplete axis restoration has been linked with impaired clinical outcome [4, 5]. Conversely, the authors using lateral parapatellar capsulotomy have reported better results in terms of anatomical axis correction and also in terms of clinical performance [11, 26, 64]. Besides, in cases with moderate or severe VD, an excellent decision with very good results is the use of a PCL-sparing prosthesis as Krackow et al. [10] showed.

Last of all, it is very important to resume the results of the open debate: "which approach leads to better outcome?" The recent studies which compare standard medial parapatellar approach versus lateral parapatellar with TTO showed the following:

(a) Nikolopoulos et al. [4] reported no statistically significant differences in terms of clinical results, on the groups of lateral approach combined with TTO vs. a standard medial approach (**Figures 6** and **7**). Nevertheless, in the lateral approach group, a valgus deviation occurred in 9% of the patients compared to 32% in the medial one [4].
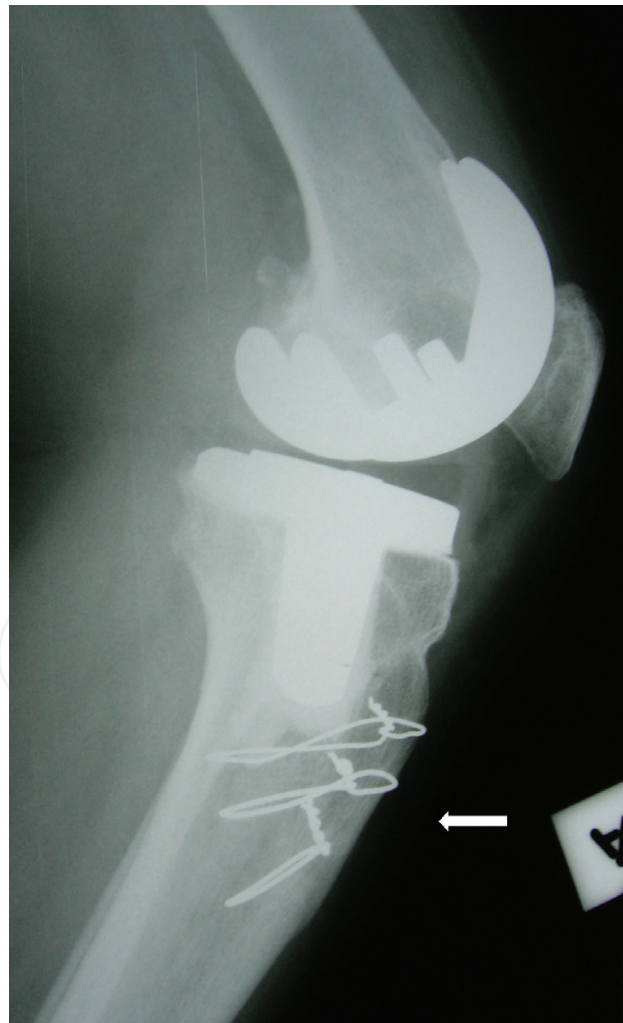

Figure 7. Profile standing position knee X-ray. Oblique direction of the wire loops for resistance to upwards pulling forces and step at the upper part of osteotomy, preventing the proximal migration.

(b) Hirschmann et al. showed that the lateral parapatellar approach with TTO leads to at least comparable functional results and less pain after TKA at 2 years follow-up. The burning question for the researchers, however, remained if this can outweigh the higher risk of early complications and revisions [36].

(c) Sekiya et al. [35] reported the clinical and radiological results in two randomized groups of patients (medial vs. lateral without TTO) after performing a TKA in valgus knees. They found no significant differences in ROM between the groups, but better postoperative flexion was mentioned in the lateral group.

Hay et al. had randomly divided 32 patients into two groups, the one in which the lateral subvastus approach combined with a TTO was performed and the other with the medial parapatellar approach. No significant differences were found between the groups in the parameters of clinical outcome, as the ROM, the VAS score, the Western Ontario McMasters University Osteoarthritis index, and the KSS at 2-year follow-up. It was found significant better patellar tracking in the group of lateral subvastus approach combined with TTO. Due to complications related with TTO and longer surgical time (10–15 min) in the lateral approach, the researchers did not support its routine use of the except for the patients in whom problems with patellar tracking were anticipated [65].

4. Complications

Several complications have been reported in valgus knee arthroplasties. More specifically, Favorito et al. [6] presented in a review article the main complications referred in the literature. The most commonly reported complications are tibiofemoral instability (2–70%), recurrent valgus deformity (4–38%), postoperative motion deficits which requires manipulation under anesthesia (1–20%), wound problems (superficial or deep infection) (4–13%), patellar stress fracture or osteonecrosis (1–12%), patellar tracking problems (2–10%), and peroneal nerve palsy (1–4%) [1, 2, 4, 8, 10]. Nikolopoulos et al. also referred one case of a 5 mm proximal migration of the osteotomized fragment occurred which was stabilized with screws only, without the use of wire loops. However, this did not affect the final outcome, despite breakage of one screw (**Figure 8**) [3].

One more very important complication after TKA for VD that has been cited is the peroneal nerve palsy. Due to the femorotibial axis deformation and the elongation of the lateral side, the nerve is stretched and is placed at risk for indirect injury via traction or induced ischemia [4, 6, 23]. Other indirect mechanisms of injury may include compression or crushing from tight dressings [66]. Also, the "pie crust" technique as part of the lateral release when is used puts the peroneal nerve in hazard, so greater deal of safety concern should be accomplished [28, 36, 38]. According to the literature, Idusuyi and Morrey [67] reported 32 postoperative peroneal nerve palsies in more than 10,000 consecutive TKAs. Ten out of the 32 palsies had 12° or more of preoperative VD. The lengthening of the lateral aspect during lateral stabilizer release and subsequent traction to the peroneal nerve presumably caused the palsy. That is

Figure 8. Profile Knee X-ray. Fixation with screws only: Six weeks post-op, slight proximal migration of tubercle, with one screw broken.

why our recommendation is generally patients' careful evaluation for palsy symptoms post-operatively. If peroneal nerve palsy type symptoms are discovered, the knee should be flexed to relax the tension that is effectively being placed on the nerve. There are no objective guidelines or data to support the efficacy of any immediate surgical intervention [67].

5. Conclusion

TKA is a well-established procedure and has proven to be durable and effective for the treatment of advanced arthritis of the knee joints; however, the long-term follow-up in VD arthritic knees was relatively inferior to those of varus counterparts. The main reason for poor prognosis is the difficulty to achieve good soft-tissue balance during the operation, and this is the challenge for every orthopedic surgeon in knee arthroplasties. In this chapter, we analyzed in detail the valgus knee philosophy, the approaches and surgical techniques proposed both for bone cuts and soft tissue management analyzing in detail the pros and cons of each proposed technique. The surgeon in valgus knee should more confidently achieve soft tissue balancing, resulting in better load distribution and enhancing component stability and longevity.

Conflict of interest

None.

Notes/thanks/other declarations

None.

Author details

Nikolopoulos Dimitrios[1]*, Sagos George[1] and Michos Ioannis[2]

*Address all correspondence to: drdnikol@hotmail.com

1 Orthopaedic Department, Central Clinic of Athens, Greece

2 D Orthopaedic Department, Asklepion Voulas General Hospital, Voula, Greece

References

[1] Ranawat AS, Ranawat CS, Elkus M, Rasquinha VJ, Rossi R, Babhulkar S. Total knee arthroplasty for severe valgus deformity. The Journal of Bone and Joint Surgery. American Volume. 2005;**87**:271-284

[2] Rossi R, Rosso F, Cottino U, Dettoni F, Bonasia DE, Bruzzone M. Total knee arthroplasty in the valgus knee. International Orthopaedics. 2014;**38**(2):273-283

[3] Apostolopoulos AP, Nikolopoulos DD, Polyzois I, Nakos A, Liarokapis S, Stefanakis G, et al. Total knee arthroplasty in severe valgus deformity: Interest of combining a lateral approach with a tibial tubercle osteotomy. Orthopaedics & Traumatology, Surgery & Research. 2010;**96**(7):777-784

[4] Nikolopoulos DD, Polyzois I, Apostolopoulos AP, Rossas C, Moutsios-Rentzos A, Michos IV. Total knee arthroplasty in severe valgus knee deformity: Comparison of a standard medial parapatellar approach combined with tibial tubercle osteotomy. Knee Surgery, Sports Traumatology, Arthroscopy. 2011;**19**(11):1834-1842

[5] Karachalios T, Sarangi PP, Newman JH. Severe varus and valgus deformities treated by total knee arthroplasty. Journal of Bone and Joint Surgery (British). 1994;**76**:938-942

[6] Favorito PJ, Mihalko WM, Krackow KA. Total knee arthroplasty in the valgus knee. The Journal of the American Academy of Orthopaedic Surgeons. 2002;**10**:16-24

[7]   White GR, Mencio GA. Genu valgum in children: Diagnostic and therapeutic alternatives. The Journal of the American Academy of Orthopaedic Surgeons. 1995;**3**:275-283

[8]   Murray PB, Rand JA. Symptomatic valgus knee: The surgical options. The Journal of the American Academy of Orthopaedic Surgeons. 1993;**1**:1-9

[9]   Elkus M, Ranawat CS, Rasquinha VJ, Babhulkar S, Rossi R, Ranawat AS. Total knee arthroplasty for severe valgus deformity: Five to fourteen-year follow-up. The Journal of Bone and Joint Surgery. American Volume. 2004;**86**:2671-2676

[10] Krackow KA, Jones MM, Teeny SM, Hungerford DS. Primary total knee arthroplasty on patients with fixed valgus deformity. Clinical Orthopaedics. 1991;(273):9-18

[11] Keblish AP. The lateral approach to the valgus knee. Surgical Technique and analysis of 53 cases with over two year follow-up evaluation. Clinical Orthopaedics and Related Research. 1991;**271**:52-62

[12] Satish BR, Ganesan JC, Chandran P, Basanagoudar PL, Balachandar D. Efficacy and mid-term results of lateral parapatellar approach without tibial tubercle osteotomy for primary total knee arthroplasty in fixed valgus knees. The Journal of Arthroplasty. 2013;**28**(10):1751-1756

[13] Rajgopal A, Dahiya V, Vasdev A, Kochhar H, Tyagi V. Long-term results of total knee arthroplasty for valgus knees: Soft-tissue release technique and implant selection. Journal of Orthopaedic Surgery (Hong Kong). 2011;**19**(1):60-63

[14] Radulescu R, Badila A, Japie I, Ciobanu T, Manolescu R. Primary total knee arthroplasty in severe valgus knee. Journal of Medicine and Life. 2013;**6**(4):395-398

[15] Girard J, Amzallag M, Pasquier G, Mulliez A, Brosset T, Gougeon F, Duhamel A, Migaud H. Total knee arthroplasty in valgus knees: Predictive preoperative parameters influencing a constrained design selection. Orthopaedics & Traumatology, Surgery & Research. 2009;**95**(4):260-266

[16] Ang CL, Fook S, Chia SL, Chin PL, Lo NN, Yeo SJ. Unconstrained arthroplasty in type II valgus knees: Posterior stabilized or cruciate retaining? Knee Surgery, Sports Traumatology, Arthroscopy. 2014;**22**(3):666-673

[17] Nikolopoulos D, Michos I, Safos G, Safos P. Current surgical strategies for total arthroplasty in valgus knee. World Journal of Orthopedics. 2015;**6**(6):469-482

[18] Lombardi AV Jr, Dodds KL, Berend KR, Mallory TH, Adams JB. An algorithmic approach to total knee arthroplasty in the valgus knee. The Journal of Bone and Joint Surgery. American Volume. 2004;**86-A**(Suppl 2):62-71

[19] Swanson KE, Stocks GW, Warren PD, Hazel MR, Janssen HF. Does axial limb rotation affect the alignment measured in deformed limbs? Clinical Orthopaedics. 2000;**371**:246-252

[20] Robbins GM, Masri BA, Garbuz DS, Duncan CP. Preoperative planning to prevent instability in total knee arthroplasty. The Orthopedic Clinics of North America. 2001; **32**(4):611-626

[21] Mihalko WM, Miller C, Krackow KA. Total knee arthroplasty ligament balancing and gap kinematics with posterior cruciate ligament retention and sacrifice. American Journal of Orthopedics (Belle Mead NJ). 2000;**29**(8):610-616

[22] Matsuda Y, Ishii Y, Noguchi H, Ishii R. Varus-valgus balance and range of movement after total knee arthroplasty. Journal of Bone and Joint Surgery. British Volume (London). 2005;**87**:804-808

[23] Mihalko WM, Krackow KA. Anatomic and biomechanical aspects of pie crusting posterolateral structures for valgus deformity correction in total knee arthroplasty: A cadaveric study. The Journal of Arthroplasty. 2000;**15**:347-353

[24] McAuley JP, Collier MB, Hamilton WG, Tabaraee E, Engh GA. Posterior cruciate-retaining total knee arthroplasty for valgus osteoarthritis. Clinical Orthopaedics and Related Research. 2008;**466**(11):2644-2649

[25] Williot A, Rosset P, Favard L, Brilhault J, Burdin P. Total knee arthroplasty in valgus knee. Orthopaedics & Traumatology, Surgery & Research. 2010;**96S**:S37-S42

[26] Buechel FF. A sequential three-step lateral release for correcting fixed valgus knee deformities during total knee arthroplasty. Clinical Orthopaedics. 1991;**260**:170-175

[27] Whiteside LA. Correction of ligament and bone defects in total arthroplasty of the severely valgus knee. Clinical Orthopaedics. 1993;(288):234-245

[28] Burki H, Knoch M, Heiss C, Drobny T, Munzinger U. Lateral approach with osteotomy of the tibial tubercle in primary TKA. Clinical Orthopaedics. 1999;**362**:156-161

[29] Fiddian NJ, Blakeway C, Kumar A. Replacement arthroplasty of the valgus knee. A modified lateral capsular approach with repositioning of vastus lateralis. The Journal of Bone and Joint Surgery. American Volume. 1998;**80**(5):859-861

[30] Arima J, Whiteside LA, McCarthy DS, White SE. Femoral rotational alignment, based on the anteroposterior axis, in total knee arthroplasty in a valgus knee. A technical note. The Journal of Bone and Joint Surgery. American Volume. 1995;**77**(9):1331-1334

[31] Stern SH, Moeckel BH, Insall JN. Total knee arthroplasty in valgus knee. Clinical Orthopaedics. 1991;(273):5-8

[32] Miyasaka KC, Ranawat CS, Mullaji A. 10- to 20-year follow-up of total knee arthroplasty for valgus deformities. Clinical Orthopaedics and Related Research. 1997;**345**:29-37

[33] Sekiya H, Takatoku K, Takada H, Sugimoto N, Hoshino Y. Lateral approach is advantageous in total knee arthroplasty for valgus deformed knee. European Journal of Orthopaedic Surgery and Traumatology. 2014;**24**(1):111-115

[34] Hirschmann MT, Hoffmann M, Krause R, Jenabzadeh RA, Arnold MP, Friederich NF. Anterolateral approach with tibial tubercle osteotomy versus standard medial approach for primary total knee arthroplasty: Does it matter? BMC Musculoskeletal Disorders. 2010;**11**:167

[35] Matsueda M, Gengerke TR, Murphy M, Lew WD, Gustilo RB. Soft tissue release in total knee arthroplasty. Cadaver study using knees without deformities. Clinical Orthopaedics and Related Research. 1999;**366**:264-273

[36] Clarke HD, Fuchs R, Scuderi GR, Scott WN, Insall JN. Clinical results in valgus total knee arthroplasty with the "pie crust" technique of lateral soft tissue releases. The Journal of Arthroplasty. 2005;**20**(8):1010-1014

[37] Aglietti P, Lup D, Cuomo P, Baldini A, De Luca L. Total knee arthroplasty using a pie-crusting technique for valgus deformity. Clinical Orthopaedics and Related Research. 2007;**464**:73-77

[38] Bruzzone M, Ranawat A, Castoldi F, Dettoni F, Rossi P, Rossi R. The risk of direct peroneal nerve injury using the Ranawat "inside-out" lateral release technique in valgus total knee arthroplasty. The Journal of Arthroplasty. 2010;**25**(1):161-165

[39] Whiteside LA. Selective ligament release in total knee arthroplasty of the knee in valgus. Clinical Orthopaedics and Related Research. 1999;**367**:130-140

[40] Krackow KA, Mihalko WM. Flexion-extension joint gap changes after lateral structure release for valgus deformity correction in total knee arthroplasty: A cadaveric study. The Journal of Arthroplasty. 1999;**14**(8):994-1004

[41] Boyer P, Boublil D, Magrino B, Massin P, Huten D, Guepar Group. Total knee replacement in the fixed valgus deformity using a lateral approach: Role of the automatic iliotibial band release for a successful balancing. International Orthopaedics. 2009;**33**(6):1577-1583

[42] Brilhault J, Lautman S, Favard L, Burdin P. Lateral femoral sliding osteotomy lateral release in total knee arthroplasty for a fixed valgus deformity. Journal of Bone and Joint Surgery. British Volume (London). 2002;**84**(8):1131-1137

[43] Bremer D, Orth BC, Fitzek JG, Knutsen A. Briard's sagittal sliding osteotomy of the lateral condyle in total knee arthroplasty of the severe valgus knee. Operative Orthopädie und Traumatologie. 2012;**24**(2):95-108

[44] Mullaji AB, Shetty GM. Lateral epicondylar osteotomy using computer navigation in total knee arthroplasty for rigid valgus deformities. The Journal of Arthroplasty. 2010;**25**(1):166-169

[45] Krackow KA, Holtgrewe JL. Experience with a new technique for managing severely overcorrected valgus high tibial osteotomy at total knee arthroplasty. Clinical Orthopaedics and Related Research. 1990;(258):213-224

[46] Insall JN, Scott WN, Ranawat CS. The total condylar knee prosthesis. A report of two hundred and twenty cases. The Journal of Bone and Joint Surgery. American Volume. 1979; **61**(2):173-180

[47] Vince KG, Insall JN, Kelly MA. The total condylar prosthesis. 10- to 12-year results of a cemented knee replacement. Journal of Bone and Joint Surgery. British Volume (London). 1989;**71**(5):793-797

[48] Healy WL, Iorio R, Lemos DW. Medial reconstruction during total knee arthroplasty for severe valgus deformity. Clinical Orthopaedics. 1998;**356**:161-169

[49] Peters CL, Mohr RA, Bachus KN. Primary total knee arthroplasty in the valgus knee: Creating a balanced soft tissue envelope. The Journal of Arthroplasty. 2001;**16**(6):721-729

[50] Politi J, Scott R. Balancing severe valgus deformity in total knee arthroplasty using a lateral cruciform retinacular release. The Journal of Arthroplasty. 2004;**19**(5):553-557

[51] Laurencin CT, Scott RD, Volatile TB, Gebhardt EM. Total knee replacement in severe valgus deformity. The American Journal of Knee Surgery. 1992;**5**:135-139

[52] Chalidis BE, Ye K, Sachinis NP, Hawdon G, McMahon S. Lateral parapatellar approach with tibial tubercle osteotomy for the treatment of non-correctable valgus knee osteoarthritis: A retrospective clinical study. The Knee. 2014;**21**(1):204-208

[53] Hadjicostas PT, Soucacos PN, Thielemann FW. Computer-assisted osteotomy of the lateral femoral condyle with non-constrained total knee replacement in severe valgus knees. Journal of Bone and Joint Surgery. British Volume (London). 2008;**90**(11):1441-1445

[54] McNabb DC, Kim RH, Springer BD. Instability after total knee arthroplasty. The Journal of Knee Surgery. 2015;**28**(2):97-104

[55] Huang TW, Chuang PY, Lee CY, Lin SJ, Huang KC, Shen SH, Tsai YH, Lee MS, Hsu RW. Total knee arthroplasty in patients with Ranawat type-II valgus arthritic knee with a marked coronal femoral bowing deformity: Comparison between computer-assisted surgery and intra-articular resection. Journal of Orthopaedic Surgery and Research. 2016;**11**(1):88

[56] Huang TW, Hsu WH, Peng KT, Hsu RW, Weng YJ, Shen WJ. Total knee arthroplasty with use of computer-assisted navigation compared with conventional guiding systems in the same patient: Radiographic results in Asian patients. The Journal of Bone and Joint Surgery. American Volume. 2011;**93**:1197-1202

[57] Wetzner SM, Bezrch JS, Scott RD, Bierbaum BE, Newberg AH. Bone scanning in the assessment of patellar viability following knee replacement. Clinical Orthopaedics. 1985; (199):215-219

[58] Coonse K, Adams JD. A new operative approach to the knee joint. Surgery, Gynecology & Obstetrics. 1943;**77**:344-347

[59] Garvin KL, Scuderi G, Insall JN. Evolution of the quadriceps snip. Clinical Orthopaedics and Related Research. 1995;**231**:131-137

[60] Dolin MG. Osteotomy of tibial tubercle in total knee replacement. A technical note. The Journal of Bone and Joint Surgery. American Volume. 1983;**65**:704-706

[61] Whiteside LA, Ohl MD. Tibial tubercle osteotomy for exposure of the difficult total knee arthroplasty. Clinical Orthopaedics and Related Research. 1990;(260):6-9

[62] Wolff AM, Hungerford DS, Krackow KA, Jacobs MA. Osteotomy of the tibial tubercle during total knee replacement. The Journal of Bone and Joint Surgery. American Volume. 1989;**71**:848-852

[63] Piedade SR, Pinaroli A, Servien E, Neyret P. Tibial tubercle osteotomy in primary total knee arthroplasty: A safe procedure or not? The Knee. 2008;**15**:439-446

[64] Insall JN, Easley ME. Surgical techniques and instrumentation in total knee arthroplasty. In: Insall JN, Scott WN, editors. Surgery of the Knee. 3rd ed. New York NY: Churchill Livingstone; 2001. pp. 1717-1738

[65] Hay GC, Kampshoff J, Kuster MS. Lateral subvastus approach with osteotomy of the tibial tubercle for total knee replacement: A 2 year prospective, randomised, blinded controlled trial. Journal of Bone and Joint Surgery. 2010;**92B**:862-866

[66] Rose HA, Hood RW, Otis JC, Ranawat CS, Insall JN. Peroneal-nerve palsy following total knee arthroplasty: A review of The Hospital for Special Surgery experience. The Journal of Bone and Joint Surgery. American Volume. 1982;**64**:347-351

[67] Idusuyi OB, Morrey BF. Peroneal nerve palsy after total knee arthroplasty: Assessment of predisposing and prognostic factors. The Journal of Bone and Joint Surgery. American Volume. 1996;**78**:177-184