OSTEOTOMY, WHAT'S NEW?

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INTRODUCTION

For many athletes, high and repetitive joint loading may lead to knee joint degeneration either by acute trauma or repetitive overload. Traumatic knee injury causing ligamentous, meniscal, or cartilage damage can lead to focal degeneration. Excessive, repetitive joint loading may lead to osteoarthritis in the long term. A combination of both, as well as congenital or acquired limb malalignment may even exacerbate the problem of knee joint degeneration. If athletes become symptomatic and develop knee pain or posttraumatic instability or both, many non-surgical treatment options are available[1–3]. However, these options often fail to provide a sustainable solution, in which case surgical options should be considered. For recreational athletes, joint replacement surgery may be an option, mostly in non-pivoting sports. However, high- and elite-level competition in impact sports is not compatible with good long-term outcomes following joint replacement surgery. The use of joint-preserving surgical treatments like proximal tibial osteotomy (PTO) can be a suitable option for active patients and even allow for a high level sports practice in some selected cases. PTO is most frequently used to correct lower limb malalignment in the frontal plane in order to treat overload in either the medial or the lateral tibiofemoral compartment[4,5]. In more rare cases of specific knee instability, sagittal-plane PTO may be considered to compensate either for anterior (ACL) or posterior cruciate ligament (PCL) insufficiency.

Many athletes present with a varus morphotype, leading to an excessive loading of the medial part of the joint. In case of non-treated ACL or PCL injuries and associated intraarticular damage, biomechanical changes do often even increase varus loading, thereby exacerbating the degenerative process of the medial tibiofemoral compartment. In patients with symptomatic medial compartment overload or osteoarthritis, a bony realignment procedure in the frontal plane may therefore be indicated to decrease varus loading. In most cases, the varus deformity is located at the proximal tibia, which is the reason why PTO is a good surgical option for these patients. The rare cases of varus knees in which the deformity is located at the distal femur should be ruled out. If a PTO is performed in these patients, a lateral inclination of the joint line may occur, thus increasing the risk of an unsuccessful outcome. In these patients, as well as in most patients presenting with the much rarer lateral tibiofemoral overload or osteoarthritis, deformity correction may require a distal femoral osteotomy (DFO).

The aim of sagittal plane corrections is to modify the tibial slope, either by increasing or decreasing the inclination of the tibial plateau. Slope-changing PTO is a powerful tool to balance the knee in the sagittal plane by altering the position of the tibia underneath the femur. In ACL deficient knees, a decrease of the tibial slope can decrease anterior tibial translation (ATT)[6,7], because an excessive tibial slope is an established risk factor for ACL injuries and recurrences[8,9]. This procedure may be required in some cases of repeat ACL revision surgeries. Likewise, an increase of the slope increases Anterior Tibial Translation and is therefore a valid alternative for chronic PCL-deficient knees[10]. In exceptionally rare and very challenging cases, corrections in both the frontal and sagittal plane can be combined.

In the past, the most preferred PTO was a lateral closing wedge osteotomy (LCWO), but over the last 2 decades,

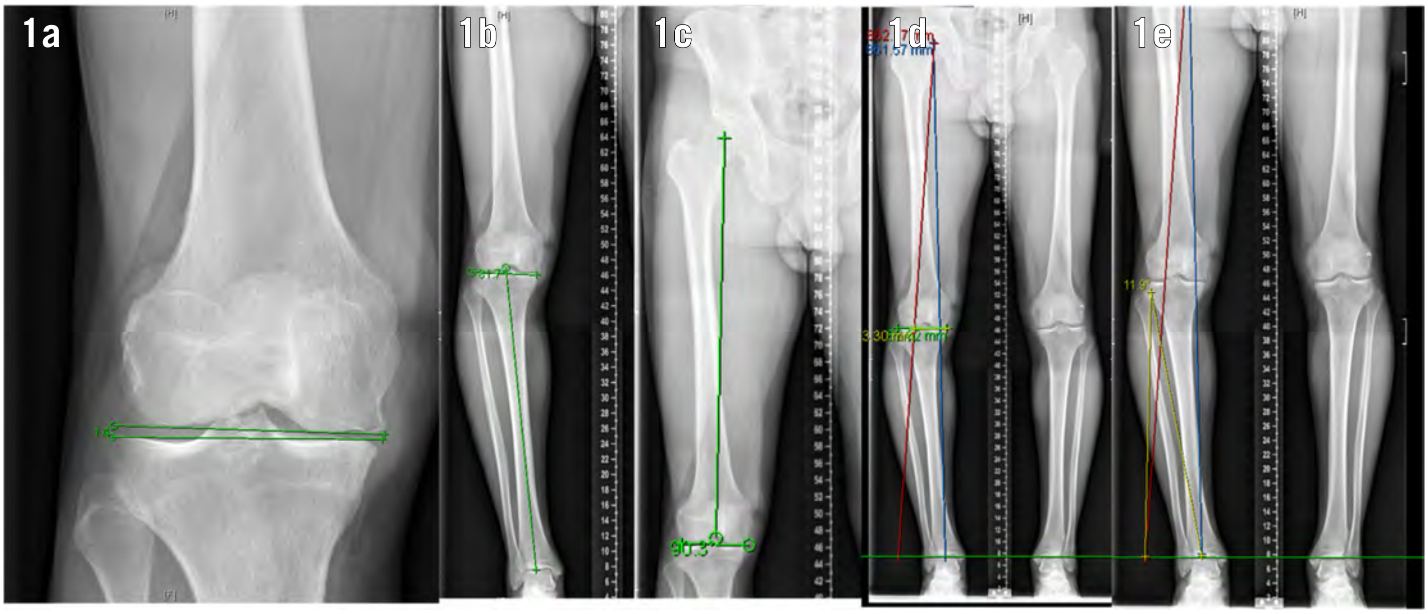


Figure 1: Measurement of angles. (a and b) Medial Proximal Tibia Angle (MPTA) and Joint Line Congruency Angle (JLCA). (c) Lateral Distal Femoral Angle (LDFA). (d and e) Calculation of the needed correction using the Miniaci Method: we first draw the lower limb weight bearing line (blue): line passing from the center of the hip to the center of the ankle. A second line (red) connecting the hip center, passing through the selected "Fujisawa" point and crossing a line parallel to the ground and passing through the center of the ankle is drawn as well. A line (yellow) connecting the future tibial hinge point and the center of the ankle joint is given is drawn. Similarly, another line (yellow), connecting the future tibial hinge point and the intersection of the red line with a line parallel to the ground passing through the center of the ankle joint is drawn. The angle formed those lines going from the native ankle position and the future (after correction) ankle position, crossing at the hinge level represents the predicted correction angle (angle α).

medial opening-wedge PTO (MOWO) has undergone a rapid evolution[11] and gained in worldwide popularity. The reasons for this are a decreased intra- and perioperative morbidity, which is mainly due to the development of powerful internal fixator plates displaying a high primary stability. In comparison to LCWO, MOWO techniques do also induce lesser anatomical changes of the proximal tibia and avoid the need of an associated fibular osteotomy, a frequent cause of intraoperative morbidity and persisting postoperative pain. A growing number of studies have reported good post-operative outcomes of MOWO with very low (< 5%) complication rates[5]. The aim of this publication is to summarize the indications and principles of multiplanar PTO, including the 3D pre-operative planning for MOWO and to present the post-operative outcome of active patients.

SURGICAL PLANNING

a) MOW-PTO

Thorough and precise surgical planning is required in order to achieve best possible surgical accuracy. This is especially mandatory in complex cases with combined problems associating OA and pathologic ligament laxities. It has been shown that an accurate correction in all three spatial planes is a pivotal factor to obtain good clinical outcomes[12]. To achieve ideal correction, various planning methods and surgical techniques have been developed. Conventional radiographic measurement methods, various intraoperative techniques to assess lower-limb alignment, computer-assisted surgery (CAS)[13,14] and recently the use of patient-specific cutting guides (PSCG)[15–17] are all useful to help the surgeon achieve the best possible accuracy.

In the vast majority of cases frontal plane PTO aims to correct an extra-articular deformity by shifting the mechanical axis from the affected tibiofemoral compartment to the other in order to unload cartilage and subchondral bone[18]. In those cases, natural evolution of knee arthritis might be slowed down by correcting a pre-existing tibial or femoral metaphyseal abnormality.

Planning should be performed on bilateral long-leg weight bearing X-rays, ideally with the patella centered in the middle of the knee and a forward orientation of the feet[19]. On these radiographs, the Hip-Knee-Ankle (HKA) angle is used to estimate the overall alignment of the lower limb. This angle is the result of three components, which are the bony alignment of the femur, the bony alignment of the tibia and the intra-articular deformity resulting of articular surface wear and soft-tissue laxity. Two additional angles are mandatory to establish the bony alignment of the distal femur and the proximal tibia: (a) The lateral distal femoral angle (LDFA), which is defined by the angle between the femoral mechanical axis and the articular surface of the distal femur and (b) The medial proximal tibial angle (MPTA), which is defined as the angle between the mechanical axis of the tibia and the articular surface of the proximal tibia. Finally, it is also recommended to measure the Joint Line Congruency Angle (JLCA) which best reflects cartilage wear, meniscus loss and soft-tissue laxity. (Figure 1 a,b, and c).

When dealing with a malaligned lower limb, the next step is to establish the desired postoperative alignment and therefore to plan the desired correction. Early studies of valgus PTO's led to the concept that the postoperative, ideal weight-bearing line should be within 62% and 65% of the lateral tibial plateau (with the medial side set at 0% and the outermost lateral aspect at 100%)[20] However, this did often result in severe overcorrections in the frontal plane as well as negative, laterally inclined joint line angles. Therefore, more recent studies[21] recommended to adapt the degree of correction to the degree of OA, thereby resulting in a lesser degree of frontal overcorrection. (Figures 1 d and e). Once the desired correction point has been determined, the amount of needed correction can be calculated according to well-established planning methods. The most popular one has been described by Miniaci and Jakob[22] (Figures 1 d and e).

b) Slope-changing PTO

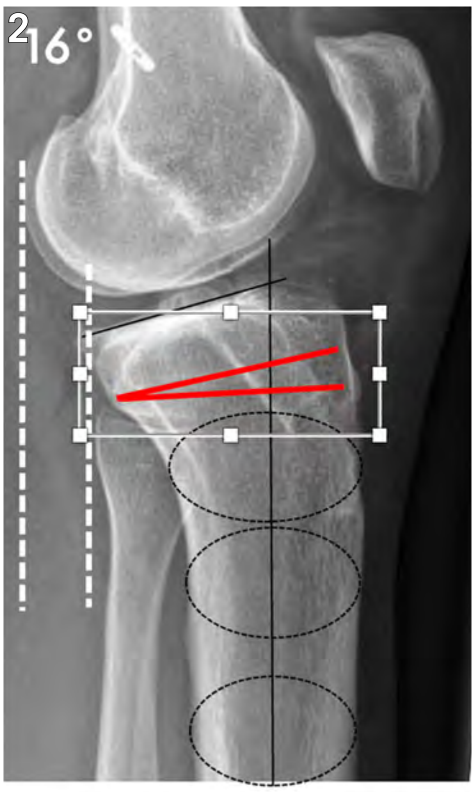
In patients where slope corrections need to be performed, a different planning strategy is needed (Figure 2). In the routine clinical setting, the measurement method popularized by Dejour on short lateral views is recommended to evaluate the slope of the concave, medial tibial plateau. In a Caucasian population, a value of 12° is the threshold above which the tibial slope is considered being a risk factor for primary and recurrent ACL injuries[23]. If a slope-correcting PTO is required, lateral long leg standing views are recommended in order to visualize the entire bone. Surgical planning is performed according to the principles of deformity correction popularized by D. Paley[24]. In ACL deficient knees with excessive tibial slope, the aim of the surgical procedure is to correct the tibial slope to a normal value close to 7°[25]. However, it must be emphasized that knee recurvatum is increased by a slope-decreasing extension PTO. In these cases the amount of recurvatum increase will correspond to the degree of correction, in other words the height of the anterior wedge (Figure 2). A recurvatum deformity of > 10° is therefore considered being a contraindication for this type of procedure. In patients with a PCL deficiency, the tibial slope needs to be increased to allow to reduce posterior sagging of the tibia. This treatment is usually reserved for patients in whom PCL reconstruction cannot be considered which is the case for irreducible and fixed grade 3 PCL insufficiencies (Figure 3). A 5° slope increase is generally enough to neutralize posterior tibial translation after chronic PCL insufficiency[10], without increasing strain on the ACL.

In patients with previous surgeries and planned associated procedures, additional diagnostic methods like CT scans may be required to identify adequate hardware placement and to define the bone quality and the position of bone tunnels created by previous surgeries.

SURGICAL TECHNIQUES.

a) MOWO[26]

For MOW-PTO, the procedure starts with adequate soft tissue management. A skin incision of approximately 7 cm starts 1 cm distal to the medial tibiofemoral joint line and extends towards the distal tibia. Identification of the anterior tibial tuberosity and the attachment of the patellar tendon as well as the pes anserinus with the underlying medial collateral ligament (MCL) are the first steps of the procedure. The pes anserinus is dissected and retracted posteriorly. The MCL is released subperiostally and a Homann retractor is placed around the posteromedial tibia (Figure 4). This elevator is left in place to guide the posterior-tissue retractor (PTR) between the posterior cortex and the popliteus muscle (Figure 5). At this step of the procedure, 2 Kirschner wires are introduced under fluoroscopy, running from the proximal border of the pes anserinus and the concavity of the proximal tibia metaphysis towards the superolateral tibia plateau and the proximal end of the fibular head. The wires should run parallel to the concavity of the medial tibial plateau. An oscillating saw is used to perform the



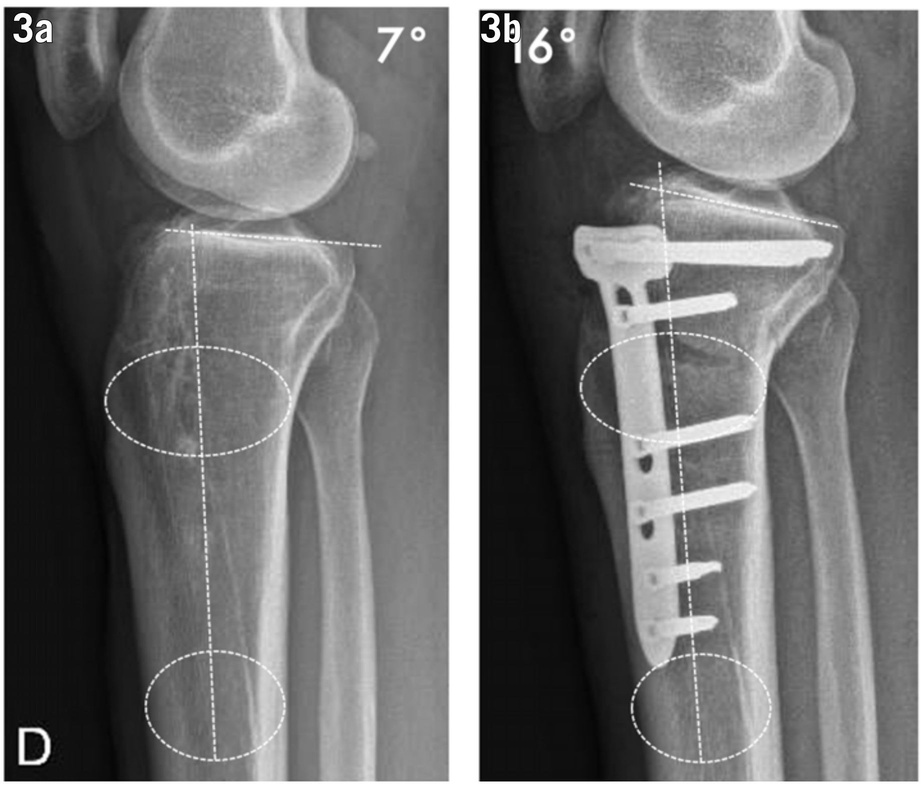


Figure 2: Example of a planning of an extension osteotomy for chronic ACL insufficiency.

Figure 3: (a and b) Example of a flexion osteotomy for chronic PCL insufficiency.

biplanar osteotomy. During the horizontal cut care must be taken not to violate the popliteal vessels. During the vertical cut, the patellar tendon should not be injured. Various techniques such as PSCG, CAS, fluoroscopy can be used to guide the saw and to improve the accuracy of the correction. The saw cut is then completed by specific osteotomes taking care to preserve an intact lateral bone bridge of approximately 1 cm (lateral hinge). The opening of the osteotomy is performed by placing a laminar spreader at the posteromedial border of the tibia. Before this step, it is mandatory to control the tibial slope. In order to avoid slope change, the geometry of the proximal tibia requires a trapezoidal opening with the large end being at the posteromedial corner of the osteotomy (Figure 6). The osteotomy gap can be filled with allograft bone or left in situ. When the desired opening has been achieved, the osteotomy is secured with a locking plate.

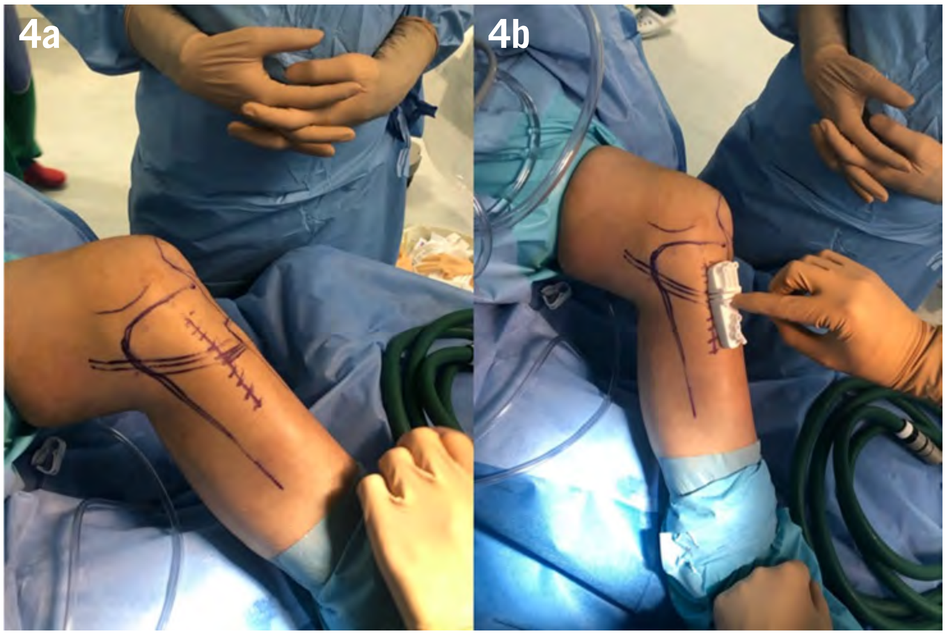


Figure 4: (a and b)Medial approach for the osteotomy: starting 1cm below the femoro-tibial joint line and extending 8-10 cm toward the distal tibia.

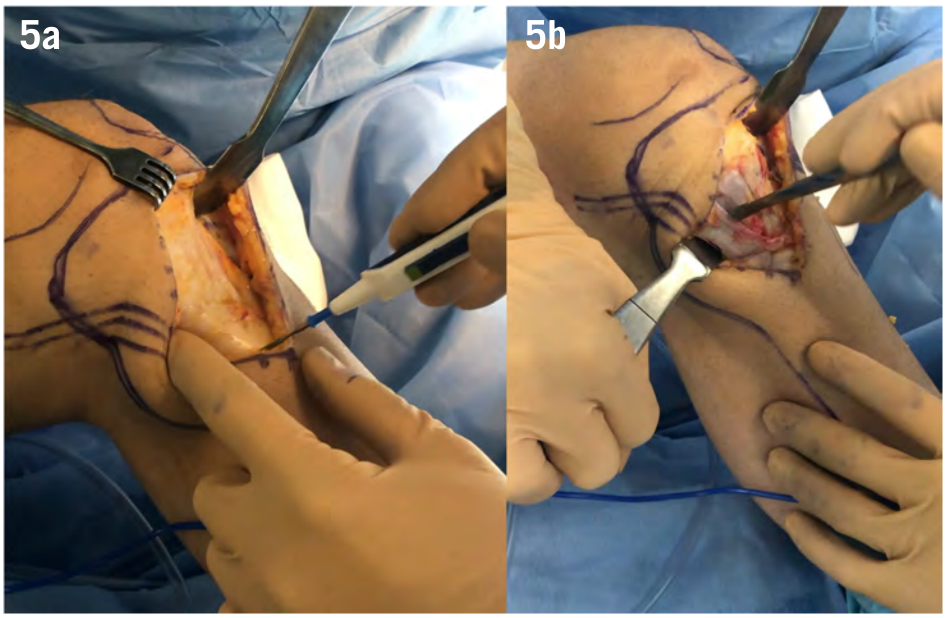


Figure 5: (a and b) Medial approach for the osteotomy: : the pes anserinus is dissected and retracted posteriorly. Starting at the posterior aspect of the MCL a periosteal elevator is used to dissect the soft tissue until the posterior cortex of the tibia is reached and the popliteus muscle carefully released. This elevator is left in place to guide the posterior-tissue retractor (PTR) between the posterior cortex and the popliteus muscle (this step can be done in flexion to facilitate insertion).

b) Slope-increasing OW-PTO

Most of the surgical procedure is the same if an increase of the tibial slope is to be achieved. However, in order to be able to induce a sagittal plane correction, a controlled section of the lateral hinge is recommended. This should be done under fluoroscopic control. For osteotomy opening, the laminar spreader needs to be placed anteriorly, thus inducing a triangular osteotomy shape at the medial tibia, with posterior compression and anterior opening.

c) Slope-decreasing PTO

The rare slope-decreasing, anterior closing wedge osteotomies are usually performed in conjunction with a second or third ACL revision reconstruction, hence combining the complexity of 2 challenging procedures. We perform these procedures on a hanging knee in a supine position and a mobile leg holder. Arthroscopic intraarticular steps are conducted first to address potential meniscus or cartilage problems, to eventually remove hardware and perform femoral ACL tunnel management. The supratuberosity PTO is performed through an 8-10 cm midline incision. Soft tissue identification includes the patellar tendon and medial as well as lateral soft tissues of the proximal anterior tibia. K-wires are inserted in an anteroposterior direction under fluoroscopy and serve for wedge height determination as well as estimation of the depth of the saw blade. Bone resection is done under fluoroscopy, taking care to leave the posterior cortex intact. After wedge resection, the osteotomy is closed anteriorly through gentle manual compression and fixed with either screws or staples. Finally, ACL revision reconstruction is finalized through tibial tunnel management, graft passage and fixation.

REHABILITATION

Postoperative management includes toe touch weight bearing for 6 weeks aided with the use of crutches (50 % body weight). Full weight-bearing is allowed at 6 weeks. Usually there is no restriction on the range of motion and no brace is used. A drain without suction is left in place for 24 hours. Patients receive thromboprophylaxis with low molecular-weight heparin for 45 days.

Dynamic evaluation using a dedicated motion capture engine is performed at 6 months post-surgery to analyze the biomechanical modifications during walking and running (Figure 7).

DISCUSSION

PTO is an effective procedure for the surgical management of several degenerative knee conditions like medial compartment overload or OA in varus malalignment[27–29]. In many patients it allows to preserve the joint, provides patients with good functional conditions and buys time before considering knee arthroplasty. In some more rare cases in patients with cruciate ligament deficiencies, it is a powerful tool to balance the knee in the sagittal plane[30–33].

Patients can reasonably expect to perform activities of daily living and recreational sports without debilitating pain or instability. We analyzed the ability of active patients to return to impact sports after PTO and unicompartmental knee

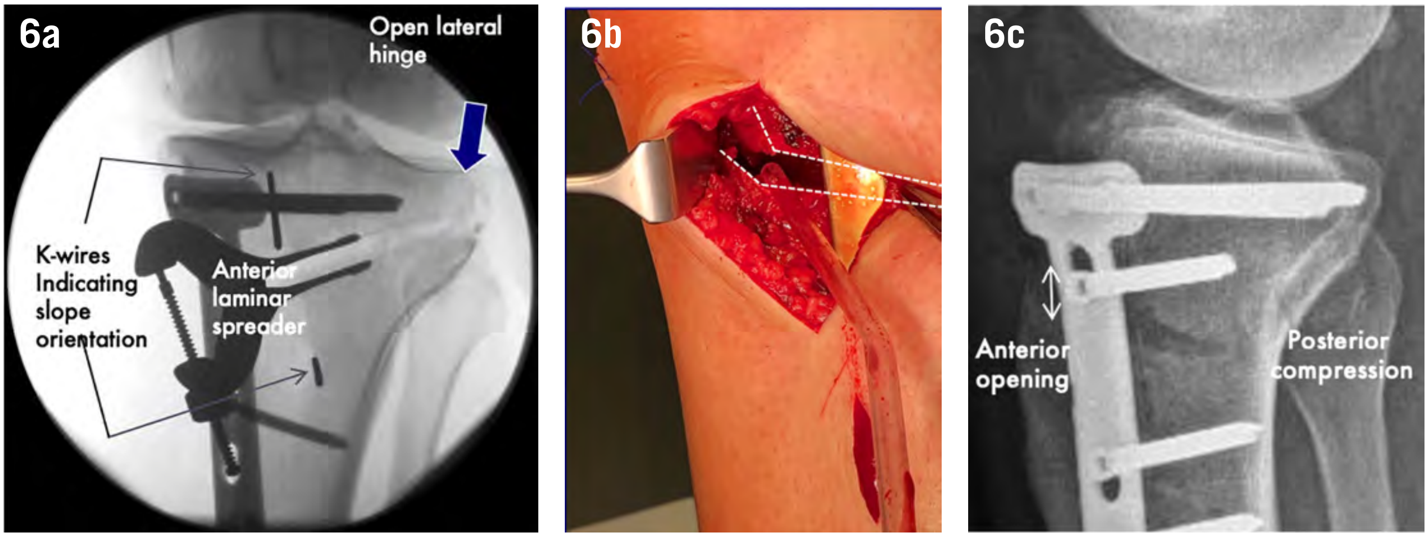


Figure 6: (a-c) Example of an extension osteotomy for chronic ACL insufficiency.

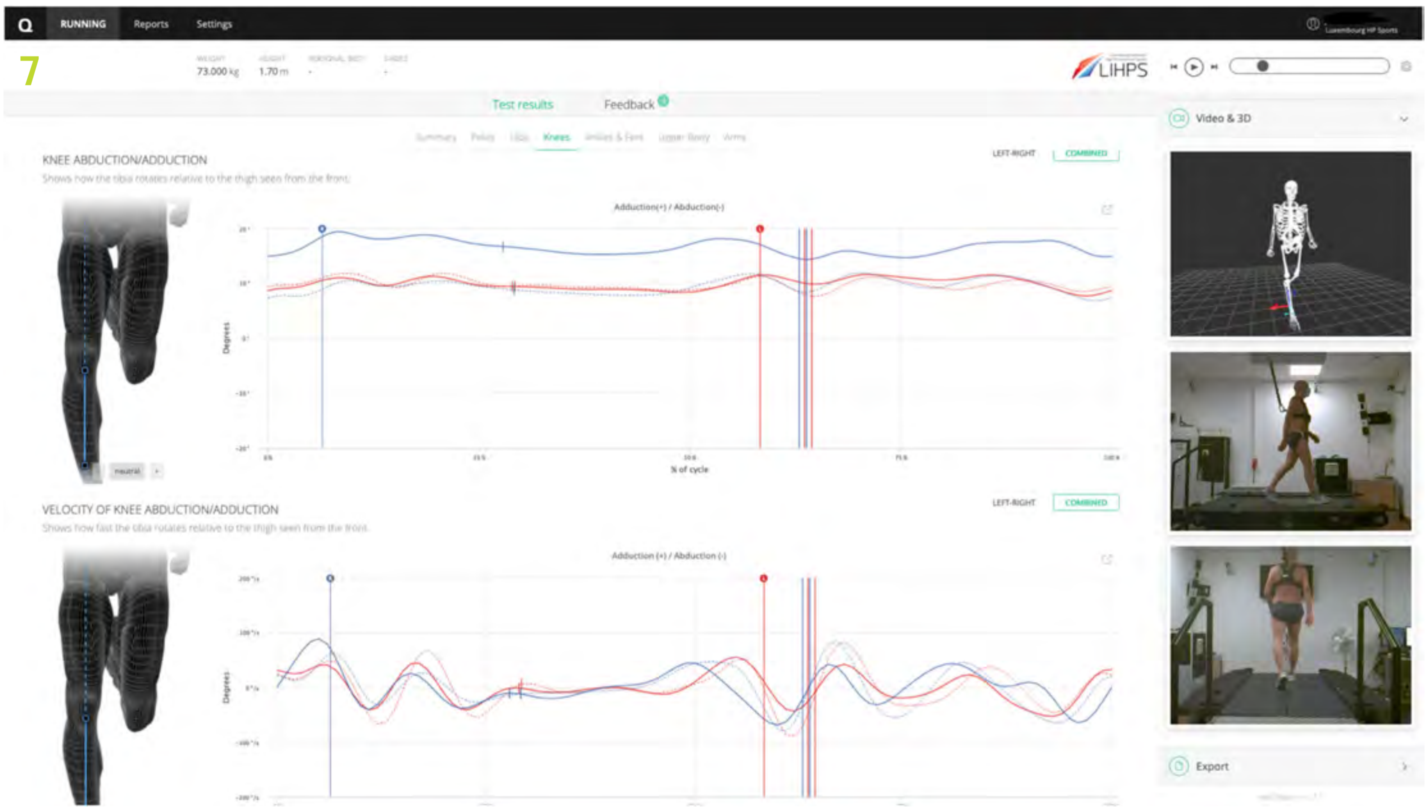


Figure 7: Dynamic evaluation using a motion capture engine at 6 months post-surgery after a double level osteotomy (PTO + DFO) for grade III medial OA and varus deformity.

arthroplasty (UKA) procedures[17]. Irrespective of their sporting level, the mean time to return to sports and previous professional activities was significantly lower in the PTO group (4.9 months for PTO group vs 5.8 months for UKA group and 3.0 months for PTO group vs 4.0 months for patients with a UKA). Twenty-four months after surgery, a significantly higher amount of patients who underwent a PTO were practicing impact sports (62 vs. 28%) and PTO patients had significantly better sports-related functional scores. These findings were in accordance with Bastard et al[34] who observed that all of their 30 patients treated with PTO returned to sports at 1 year; with 7 (23.3%) of them returning at a higher level than before the procedure. A systematic review by Ekhtiari et al[35] reported similar findings, with 85% of the 216 patients returning to a level of sports practice which was similar or better than before surgery. Salzmann et al[36] identified that the 3 preferred sports types after a PTO procedure were cycling (71%), swimming (45%) and hiking (30%). Another recent study[37] indicated that active sports participation in the year before surgery is one of the most important prognostic factors for returning to sports after HTO. These results do also suggest that operating high impact sport patients at an earlier stage of osteoarthritis with PTO may provide them with a higher probability to recover an activity level which can be expected to be similar or close to the one they had before the onset of osteoarthritis.

Does associating cartilage and meniscus repair surgeries improve the results of PTO ?

Focal articular cartilage defects and meniscal deficiency, either individual or in combination, are often associated with unicompartmental overload, especially if a frontal alignment deformity is associated. Performing an isolated cartilage or meniscal repair procedure in these patients may increase the risk of failure. For these reasons, adding a PTO to the intraarticular soft tissue procedure in case of focal cartilage defects or repairable meniscus tears with the ultimate goal of joint preservation seems mandatory from a biomechanical perspective. However, to date there is limited evidence that associated cartilage or meniscal repair procedures will add a significant benefit to the PTO. In a study comparing isolated Autologous chondrocyte implantation (ACI) with a combined ACI and PTO procedures in patients with varus deformity and local chondral defects, Bode et al[38] observed better outcomes in the combined ACI and PTO group compared to the isolated ACI group. However, one of the limitations of this study was the lack of a control group of patients with isolated PTO to ensure that this improvement was not exclusively due to the PTO procedure. In another study, Harris et al[39] tried to determine survival and clinical outcomes of PTO with or without articular cartilage surgery and/or meniscal allograft transplantation in patients with medial compartment chondral pathology, varus malalignment, and/or meniscal deficiency. They observed that survival and clinical outcomes of isolated PTO and PTO with associated intraarticular surgery were similar. In a meta-analysis published by Elattar et al[40], by analyzing 135 associated meniscus allograft transplantations with PTO procedures, the authors concluded that there was no clear scientific evidence of the synergetic protective relationship between meniscal allograft transplantation and unloading osteotomy in post-meniscectomy patients with malalignment. So there is no strong evidence to date that associated chondral reconstruction or meniscus repair procedures provide any benefit over isolated PTO, thus indicating that the biomechanical effect of PTO may be the major determinant for a successful outcome. Further studies are needed to standardize indications, select patients and analyze the short and long-term outcome for PTO in association with intraarticular soft tissue reconstruction procedures.

Is PTO a reasonable surgical option for high-level athletes?

PTO may provide a solution for athletes with underlying knee malalignment and symptomatic degenerative conditions in isolation or in association with ligamentous insufficiency who desire to continue competing at a high level. However, published evidence on the subject is sparse and none of the previously cited studies focused on elite athletes or addressed the athletes' ability to return to competitive

> ***Proximal tibial osteotomy is a powerful joint preservation surgery in physically active patients where cartilage or meniscus preservation procedures are insufficient or inappropriate. In some selected cases, it may allow for a return to high level sports practice.***

sports after surgery. At the end of an athletic career where athletes do often present with significant degenerative changes in their knee joints, PTO may help to prolong activity for a limited amount of seasons after a thorough postoperative return to play process. The cases of athletes achieving successful careers after PTO in the early stages of their career are anecdotal. Warme et al[41] described the case of a young collegiate American football player who returned to play and eventually entered an NFL team after a failed attempt of isolated fixation of an OCD lesion of the medial femoral condyle and later successful autologous chondrocyte implantation, combined with a PTO to off-load the medial compartment and better facilitate healing of the OCD lesion. In our own experience, the example of the female football player (case no. 4) illustrates the possibility to return to football after PTO in a neutrally aligned limb which was brought to slight valgus alignment. It is questionable if this experience would be similarly successful in a football player with varus alignment in whom a realignment procedure may negatively affect the individual playing technique. On the opposite, it might be successful in a type of sport that is less dependent on pivoting activities. These examples depending on gender-related alignment and type of sport illustrate the uncertainty of results in this specific subpopulation. Further studies are needed to standardize the indications and to better predict postoperative results in high level athletes.

CONCLUSION

PTO is a suitable surgical option for patients with early knee monocompartmental osteoarthritis and malalignment when nonsurgical management has failed. It can be performed in isolation or in association with ligament surgeries like ACL reconstruction. In comparison to joint replacement surgery, PTO allows for a higher return to impact activities (62% for PTO) and better sports related functional scores. In more rare cases, PTO can be used for tibial slope corrections in patients with chronic ligament insufficiencies. Evidence for PTO's in high level or professional athletes is sparse, but it may be an option for rare and selected cases. Further studies are needed to standardize indications and evaluate the outcome in these demanding patients.

CASE DISCUSSIONS

Case 1: PTO for varus malalignment and early medial tibio-femoral osteoarthritis (Figure 8)

The first case demonstrates the use of PTO in the treatment of early medial knee osteoarthritis and varus deformity in a 51 year old male patient. Seven years before he underwent a partial medial meniscectomy for a degenerative meniscus lesion. He developed medial knee osteoarthritis with significant pain during walking. Physical examination revealed varus alignment and medial joint line tenderness without sagittal or frontal laxity. Radiographic imaging at presentation showed degenerative changes of the medial compartment (Ahlback 2), and a varus deformity of 8 degrees located in the proximal tibia (MPTA: 80°/ LDFA :92°).

A MOWO was recommended in order to correct the frontal extra-articular deformity and overload of the medial compartment .

Case 2 : PTO for post-traumatic chronic PCL deficiency (Figure 9)

The second case demonstrates the use of PTO in the treatment of chronic PCL deficiency and varus malalignment. The patient was a 33 years old recreational athlete. Six years before he sustained a football accident with a direct trauma due to a collision with another player. A grade 3 PCL injury was diagnosed and treated non-surgically. The patient stopped playing football developed a painful and fixed posterior subluxation. Radiographic imaging at presentation showed no major degenerative changes of the medial compartment, and a bilateral varus deformity of 2°. The sagittal X-ray demonstrated a grade 3 side to side posterior laxity with a 12 mm posterior tibial translation at stress x-rays in 90° of flexion and a tibial slope of 7°. The patient used crutches for daily walking because of

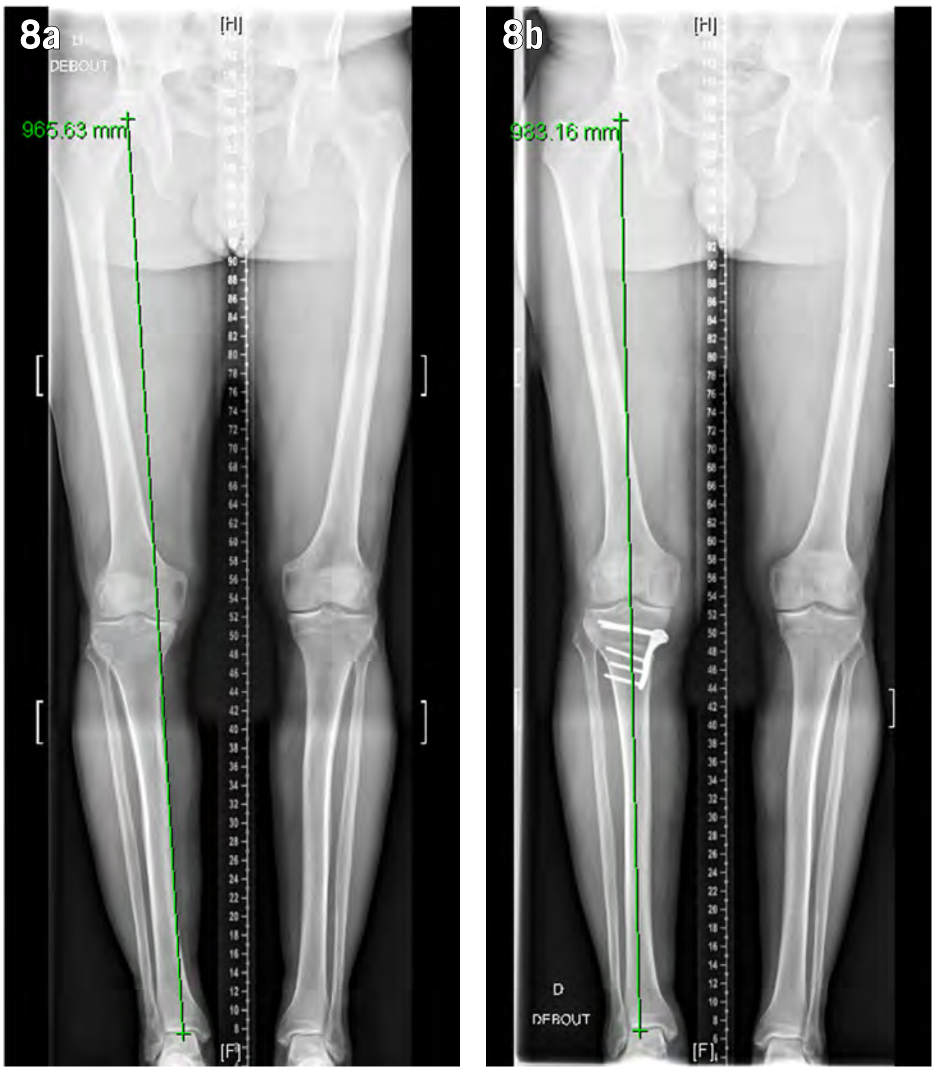


Figure 8: (a and b) Pre-operative and postoperative x-rays of the Case 1.

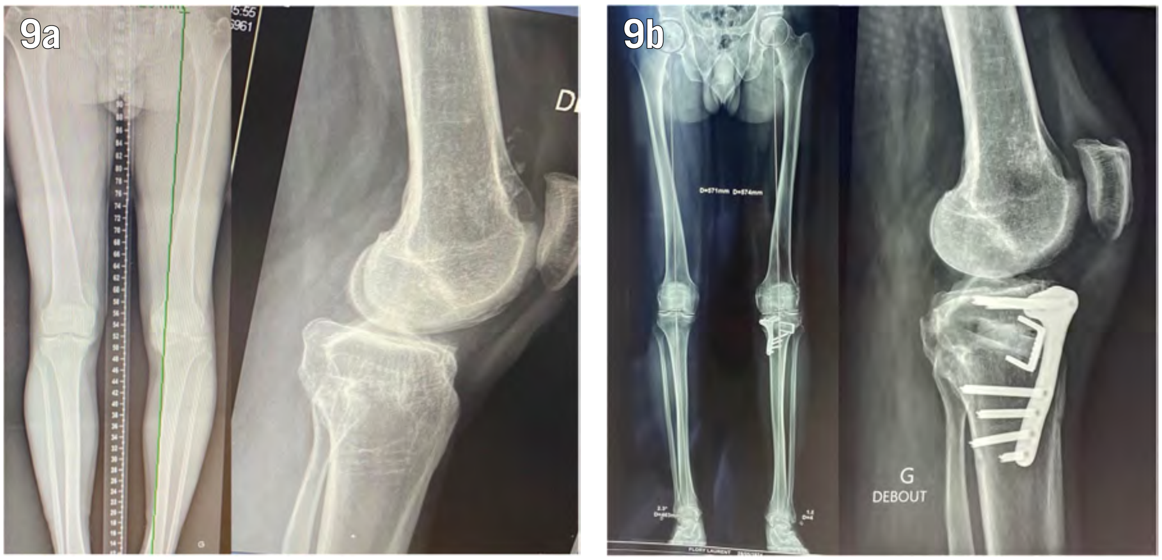


Figure 9: (a and b) Pre-operative and postoperative x-rays of the Case 2.

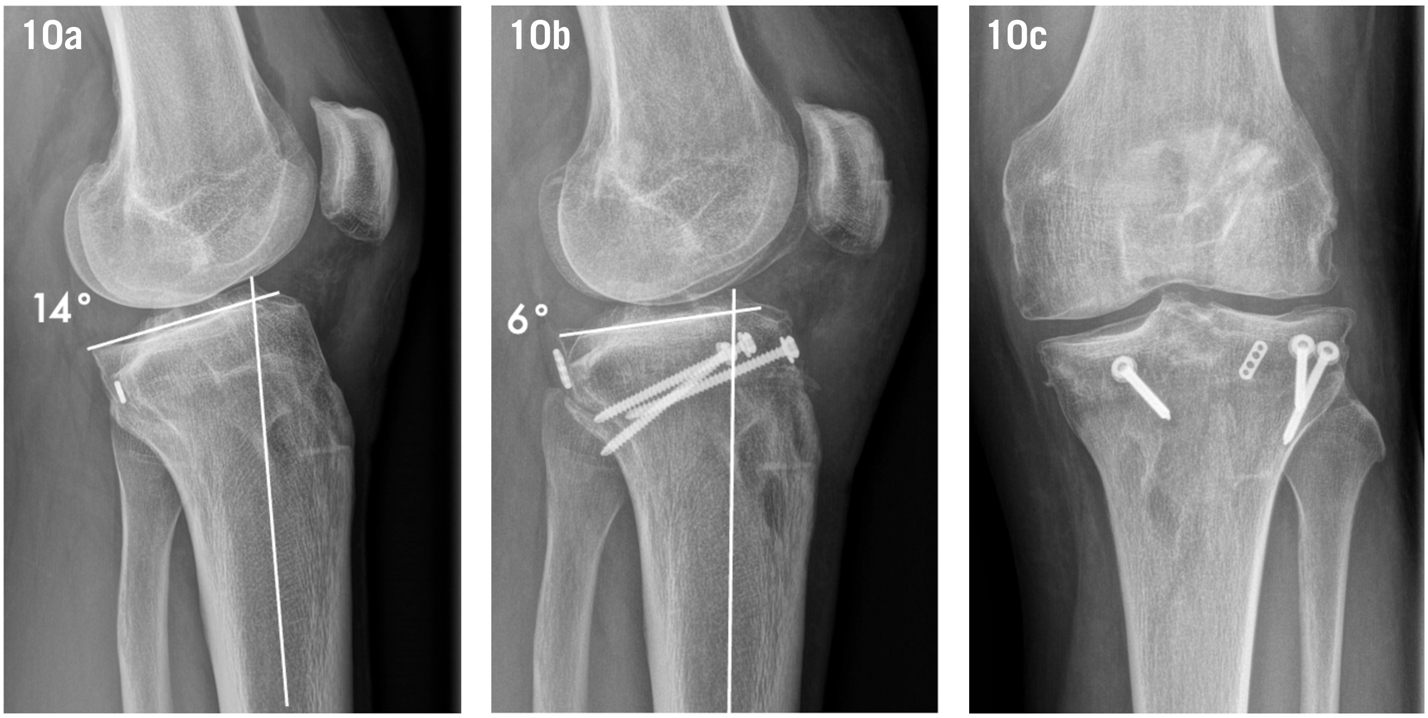


Figure 10: (a-c) Preoperative and postoperative X-rays of the case 3.

pain. Physical examination revealed slight varus alignment and posteromedial joint line tenderness. Range of motion was free. There was no pathologic posterolateral or posteromedial laxity. Because the posterior tibial translation was reducible during physical examination, a reduction test with a dynamic PCL brace was attempted for 3 months without success. Flexion osteotomy was therefore recommended to reduce the fixed posterior translation, thereby increasing the tibial slope to 15°, without changing the frontal alignment. At 3 years postoperatively the patient is pain free and resumed a normal life. He is able to perform manual work and participate in leisure sports activities. Spontaneous posterior tibial sagging has disappeared and monopodal stance radiographs show an improvement of posterior tibial translation of 12 mm.

Case 3: PTO for ACL reconstruction failure without frontal-plane malalignment (Figure 10)
The third case demonstrates the use of PTO in the treatment of ACL graft failure with excessive tibial slope and with normal limb alignment in the frontal plane. The patient was 31 years old and had an ACL injury few years before. He was operated a first time with an isolated ACL reconstruction and a second time for an ACL graft rupture. A second rupture of the graft occurred during a minor trauma. Clinical exam revealed subjective symptoms of instability, a positive Lachman test (++) and a positive pivot shift test (++) without frontal deformity. MRI imaging confirmed the second rupture of the graft without associated meniscus injuries. Radiographic imaging showed an HKA angle of 181° and a tibial slope of 14°.

A concomitant slope decreasing osteotomy with an ACL reconstruction using allografts was performed to treat the sagittal instability and to reduce the risk of a third graft rerupture.

Case 4 : PTO to treat a focal chondral defect (Figure 11)
The fourth case demonstrates the use of PTO

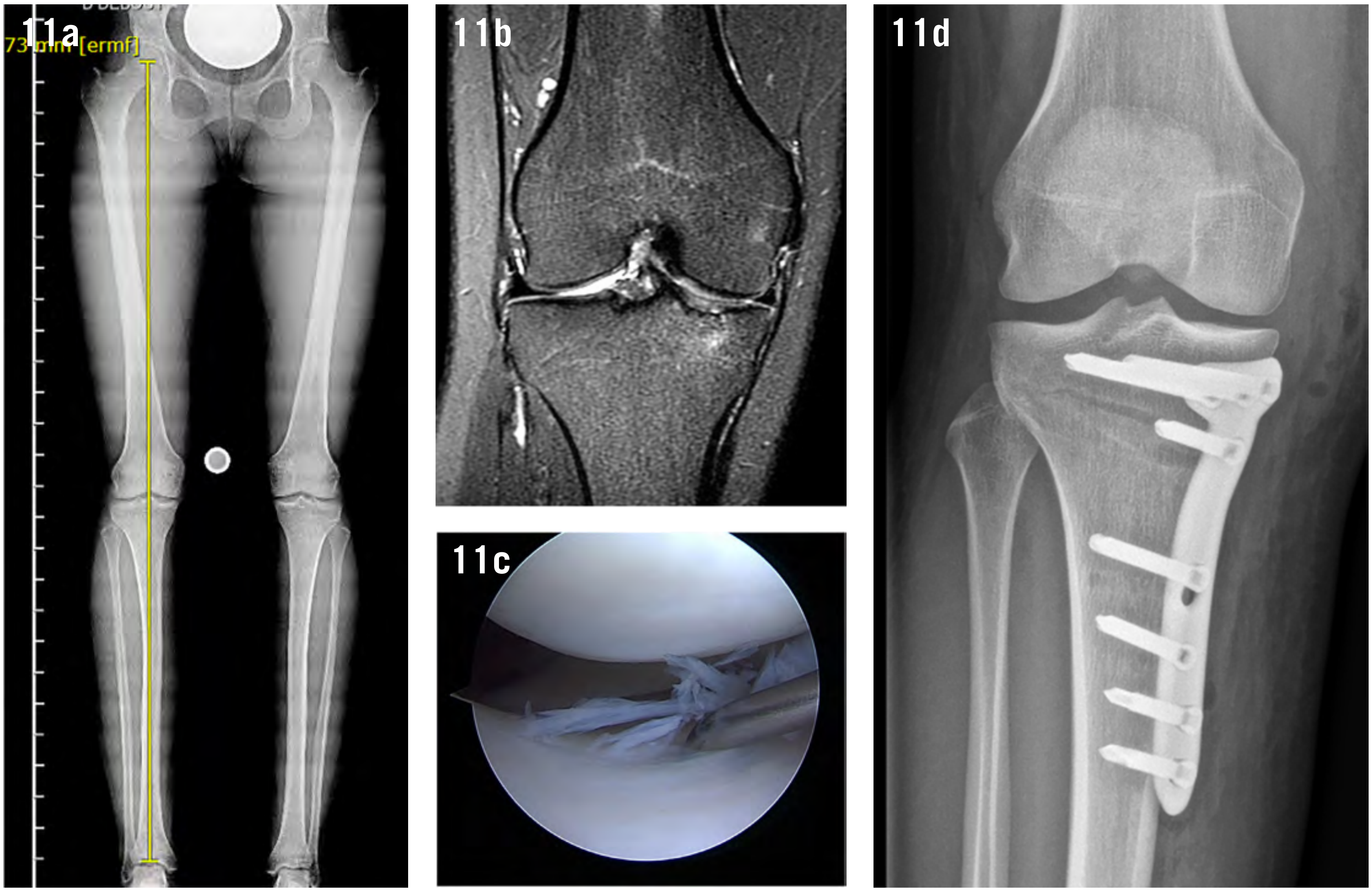


Figure 11: (a-d)Preoperative and postoperative images of the Case 4.

in the treatment of a focal chondral defect in a female professional football player. The patient was 27 years old and presented with a symptomatic isolated grade 4 focal chondral defect of the medial tibia plateau with pain during activities of daily living and inability to play football. The full leg x-ray shows a neutral limb alignment and the MRI confirms the medial tibial chondral defect. Non-surgical treatment failed to treat this lesion. A first arthroscopic evaluation with a debridement and microfracturing of the lesion did not improve symptoms. Therefore, a valgus MOWO was performed to unload the medial compartment. At 9 months after surgery, the pain disappeared and the player returned to football.

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