Over the last decade, improvements in osteotomy techniques and fixation methods have resulted in an increasing interest in osteotomy procedures. The literature shows that the high tibial osteotomy is commonly used to treat and correct varus deformity in patients with medial osteoarthritis of the knee. Treatment of medial unicompartamental knee osteoarthritis is a common problem among physiologically young, active middle-aged patients. In recent years, high tibial osteotomy (HTO) and fixation with a rigid internal plate fixator has proven to be a precise correction technique providing good primary stability and has become a widely accepted treatment option. There are two different standard surgical procedures to unload the medial compartment by valgus HTO. Several authors have described the advantages of the medial open wedge osteotomy compared to the lateral closed wedge osteotomy. The medial open wedge HTO might avoid the risk of peroneal nerve damage or lesion and detachment of the tibialis anterior muscle. Regarding biomechanics, in a neutral aligned leg (0° varus/valgus) the medial compartment of the knee bears up to 60% of compressive loads. This load rises with increased varus deformity. This might be important for treatment of cartilage defects of the knee joint and the postoperative results. If a cartilage repair procedure is planned, a malalignment correction is mandatory in patients with cartilage defects and concomitant leg deformity. Focal cartilage defects of the knee often result in symptoms that patients describe as pain and disability. Due to the limited intrinsic capacity for spontaneous healing, surgical management is important to reduce patients’ symptoms and to restore the kinematics of the knee joint. In current literature, three different surgical restoration techniques are described to treat cartilage defects. These procedures are: marrow stimulation (MS) such as microfracturing, cell-based implantation and osteochondral grafting. All of these techniques have their advantages and disadvantages. Since the microfracture technique (MF) was established in the late 1970s, it has become one of the most frequently used cartilage repair procedures for focal defects. However, this treatment option is still controversial. In the past, some authors have promoted this procedure as beneficial, but others have confirmed a significant negative effect on the micro- and macroarchitecture of subchondral bone following the procedure. Aside from MS techniques, autologous chondrocyte
implantation is a cell-based method with the ability to promote hyaline-like cartilage repair that is more comparable to articular cartilage. Introduced by Brittberg et al. in 1994, this technique has been modified over the years to minimise the first-generation complications (periosteal hypertrophy/overgrowth) and to simplify the technique. The procedure is currently in its third-generation, matrix-induced autologous chondrocyte implantation (MACI). In contrast to these two cartilage repair methods, the osteochondral autologous transfer (OAT) is thus far the only procedure that provides real hyaline cartilage. OAT is often used for replacement of pathological subchondral bone in focal osteochondral defects. Besides the potential advantage of a single-stage operation, donor site morbidity remains a concern. In the literature, several studies analysed the above-mentioned techniques for knee cartilage repair, but no evidence supports any one surgical technique as a superior method. Nevertheless, these three cartilage repair methods are generally efficacious in improving symptoms caused by cartilage defects.

This paper will discuss the indications, treatment options and rehabilitation of HTO and cartilage repair in patients with symptomatic cartilage defects, combined with leg deformity.

**Indications**

There are several factors to take into consideration when undertaking an HTO procedure and cartilage repair. In addition to symptoms such as the patient’s pain or discomfort, their activity level and willingness to accept the regressive rehabilitation protocol and surgery

| Table 1: Degree of correction according to the main underlying pathology. (MF=microfracture, MACI=matrix-induced autologous chondrocyte implantation, OAT=osteochondral autograft transfer).
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Table 2: Systematic overview of cartilage defects and treatment strategy depending on the defect size. (MF=Microfracture, MACI=matrix-induced autologous chondrocyte implantation, OAT=osteochondral autograft transfer).
CONCOMITANT SURGERY

conditions, the individual expectation of the outcome is an important factor of success. Therefore, a detailed explanation of the planned operation and rehabilitation process is necessary to manage the patient’s expectations.

After examining the specific clinical symptoms to clarify the origin of the pain in the knee joint, radiological evaluation is requested to find the right treatment option for the patient. In addition to a full-leg weight-bearing radiograph and X-rays of the knee in three views (anteroposterior, standard and tangential patella), a conventional magnetic resonance image (MRI) is indicated, to evaluate the condition of the cartilage and bone marrow, and to exclude concomitant ligamentous lesions.

In case of measured concomitant varus malalignment, a valgus HTO could be indicated. The osteotomy could be planned either using appropriate specific computer software (e.g. mediCAD, Hetec) or conventionally, using radiographs. The correction angle and the height of the wedge base are planned according to the desired amount of correction using the Miniaci method, for example. The aim of the valgus-producing HTO is to unload the medial knee compartment, to correct the mechanical axis and to allow cartilage repair in the medial compartment. Our indications (Table 1) for open wedge HTO are varus deformities with symptomatic medial unicompartmental osteoarthritis of the knee, cartilage regenerative procedures, meniscus replacement or unicompartmental medial hypercompression (overload). Therefore, a preserved lateral meniscus and intact cartilage of the lateral compartment (maximum grade II) are prerequisites.

As described above, there are several options for treating cartilage lesions (Table 2). MRI scans are helpful for estimating the defect size and depth and to exclude corresponding tibial defects, such as ‘kissing lesions’. For chondral lesions we have to differentiate between two treatment options depending on the size of the defect — a benchmark is about 2 cm². In cases of small isolated symptomatic cartilage lesions with an intact subchondral bone, MACI is more suitable. Osteochondral defects require other treatment options to restore the whole defect. Similar to chondral defects, a defect size of 3 cm² is described as a benchmark to differentiate between operative techniques. Osteochondral autologous transfer would be a comprehensive solution for symptomatic focal localised smaller lesions in the weight-bearing region of the knee joint. For large osteochondral lesions (defect size up to 35 mm in diameter), the Mega-OATS technique would be recommended.

Alternatively, cancellous bone grafting combined with MACI is a possible treatment option for osteochondral defects larger than 3 cm² (defect size >20 mm, diameter up to 35 mm).

SURGICAL TECHNIQUE

All surgical procedures should be performed under general or spinal anesthesia, with the patient in a supine position. Using a tourniquet inflated to a pressure of 280 mm Hg routine arthroscopy can be performed through standardised portals to explore the whole knee joint and to exclude significant cartilage damage of the lateral knee compartment. After assessment of the joint, concomitant injuries such as meniscus lesions should be treated first, followed by debridement of the unstable cartilage in the medial compartment. If precise measurement of the defect indicates that further surgery is required, a cartilage repair procedure should be completed, followed by HTO.

Bone marrow stimulation

For bone marrow stimulation, first the unstable cartilage is dissected. A careful debridement of the chondral defect with a curette or shaver should be conducted to remove any sclerosis and to create stable borders around the defect. Microfracture is then performed using surgical awls...
to penetrate the subchondral bone. Microfracture holes should be made around the edge of the defect and continued towards the centre, keeping the holes 3 to 4 mm apart. The depth of the perforations should be approximately 3 mm. To ensure marrow stimulation the tourniquet is opened and arthroscopic fluid inflow is limited to control bleeding and bone marrow stimulation (Figure 1).

*Matrix-induced autologous chondrocyte implantation (MACI)*

This type of cartilage repair is a two-stage procedure and requires the patient to be in hospital at each stage of the planned operation.

The first stage of the MACI is a diagnostic arthroscopy of the joint. Then, a cartilage biopsy is taken from a non-weight-bearing cartilage area (2 to 3 cylindrical plugs are needed for cell harvesting). The chondrocytes are extracted from the biopsy, purified and expanded to a sufficient number of cells. The proliferated chondrocytes are seeded onto a three-dimensional matrix (Figure 3a). After 3 to 5 weeks the cells are ready for implantation. If necessary, the cell-loaded matrix could also be cryopreserved temporarily.

The second stage of the MACI procedure involves the implantation of the matrix-construct. A medial mini-arthrotomy of the knee joint is performed to expose the cartilage defect, allowing the size of the defect to be approximated. After preparation of the cartilage defect, without breaching the subchondral bone, the shape and size is measured using special curettes. The matrix construct is then trimmed to the correct size (Figure 3b) and placed down into the debrided base of the defect. It is important to ensure that the cells face to the subchondral bone side. The procedure concludes with the fixation of the construct with absorbable sutures (0 Vicryl, Ethicon). Stability can then be tested through cyclic bending of the knee joint (Figure 3c).

*MACI combined with cancellous bone grafting (sandwich)*

As previously mentioned, MACI is a two-stage procedure. According to the selected procedure, cancellous bone grafting of the defect bed could be performed at the first or during the second stage. We prefer bone grafting in the second stage. After a central
midline skin incision for an arthrotomy, the osteochondral defect is exposed, measured and prepared with a specific instrument (Mega-OATS), explained below. The prepared defect zone is filled with cancellous bone chips in successive layers up to the cartilage junction. Repetitive impaction using a bone impactor is performed. Finally, the cancellous bone graft is covered with a matrix construct as described above.

Osteochondral autologous transfer (OAT)

This method can be performed arthroscopically or through an open approach. Intraoperative, the cartilage defect is exposed and measured using circular templates (Figure 3a) and the size and number of required autografts determined. Either a single large cylindrical plug can be transferred, with the aim of obtaining a congruent surface, or many small cylinders (mosaicplasty) can be used to reconstruct the surface. Because of the risk of incongruity and increased gap formation, we prefer to use one single cylinder. Next, the OAT system (OATS, Arthrex) is used; the defect zone is prepared with a cylindrical, hollow chisel or recipient socket (Figure 3b), the cylinder is then removed and the depth is measured. To control the quality of the surrounding bone stock, the tourniquet can be deflated (Figure 3c). The cylinders are harvested from the lateral or medial edges of the trochlea with a special donor guide (Figure 3d). The donor harvester has a slightly larger diameter than the recipient harvester, so that the graft can be fixed using press-fit fixation and to ensure the chondral and osseous borders are stable. For correct implantation of the cylinder, a special guide can be used (Figure 3e and f).

Mega-OATS technique

A central midline skin incision, followed by a medial or lateral arthrotomy exposes the surrounding bone stock, the tourniquet can be deflated (Figure 3c). The cylinders are harvested from the lateral or medial edges of the trochlea with a special donor guide (Figure 3d). The donor harvester has a slightly larger diameter than the recipient harvester, so that the graft can be fixed using press-fit fixation and to ensure the chondral and osseous borders are stable. For correct implantation of the cylinder, a special guide can be used (Figure 3e and f).

Figure 4: (a) Mega-OATS technique, after debridement of the osteochondral defect the size is measured. (b) According to the defect size a fragment of the posterior femoral condyle is harvested using an osteotome. (c) Defect preparation with a hollow chisel. (d) Before implantation the prepared cylinder is marked to ensure correct placement (e) then implanted with specialised instruments.
the cartilage defect (Figure 4a). The edges of the defect are labelled with a sterile marker and the lesion is measured using a specific Mega-OATS template (Mega-OATS instruments, Arthrex). According to the defect size, a corresponding fragment of the posterior femoral condyle is harvested with the knee in maximal flexion using an osteotome (Figure 4b). The graft is then prepared according to the defect size using a hollow chisel. The diameter should be about 0.5 mm larger than the diameter of the prepared defect for press-fit fixation. Next, a K wire is placed and drilled in the centre, perpendicular to the surface of the defect area (Figure 4c). After measurement of the final depth of the defect, the Mega-OATS cylinder is implanted (Figure 4d and e).

High tibial open-wedge osteotomy (HTO)

The mechanical axis is planned and measured on a full-leg weight-bearing radiograph as mentioned above (Figure 5). Depending on the indication, the centre of the new mechanical axis is determined (Figure 6). The authors use the PEEKPower HTO-Plate instrumentarium system (Arthrex) for fixation. The radiolucent material properties ensure a clear view radiographically onto the osteotomy during the operation and postoperatively.

First, an 8 to 10 cm longitudinal skin incision is performed, beginning just above the level of the tibial tuberosity. The semitendinosus and gracilis tendon are carefully mobilised. Our standard technique for performing the osteotomy is in a bi-planar fashion that comprises osteotomies in both the axial and frontal planes. According to the cartilage status of the patellofemoral joint, the osteotomy is taken from either distal or proximal the tuberosity in the frontal plane. To reduce patellofemoral contact pressure, we recommend a distally directed osteotomy, so that the tibial tuberosity remains attached to the proximal bone block without changing the patellar height.

To control the rotation and slope, two Kirschner wires can be placed parallel to each other in the transverse and sagittal planes, proximal and distal to the axial osteotomy.

Then, the bi-planar osteotomy is started with the frontal plane osteotomy in the anterior third of the proximal tibia using an oscillating saw. The posterior two-thirds of the proximal tibia are sawed from the upper margin of the gracilis tendon to the tip of the fibular head. The opening process of the osteotomy must be performed gradually to leave the lateral cortex intact. The plate is then temporally fixed and the amount of correction controlled via fluoroscopy (Figure 7a and b). Finally, the osteotomy is secured using a fixed angle plate. In case of distally aimed frontal osteotomy, additional fixation of the tuberosity fragment with two bi-cortical screws is needed.

POSTOPERATIVE PROTOCOL

The postoperative protocol of the HTO involves 20 kg partial weight bearing for 6 weeks after surgery. Active and passive free range of motion is allowed. If the radiographic control shows no signs of insufficiency, full weight-bearing is allowed.

In patients with additional cartilage procedures, full weight bearing should not be allowed for the first 6 weeks, along with limited range of motion. Continuous passive motion using a motor splint is recommended for 6 to 8 weeks postoperatively. After this period a stepwise increasing load of 20 kg per week up to the patient’s body weight is permitted.

OUTCOMES FOLLOWING HTO AND CARTILAGE REPAIR

This manuscript aimed to determine clinical outcome of patients who underwent HTO with concomitant cartilage procedures to treat cartilage defects of the medial compartment of the knee joint and/or varus deformity. Combined valgus-producing HTO and cartilage repair is a treatment strategy in young and active patients with symptomatic chondral or osteochondral lesions of the medial femoral condyle and concomitant varus deformity. Typically, these patients are more active in sports and work, than patients undergoing HTO due to medial compartment osteoarthritis.
Therefore, besides symptom and pain relief, it is necessary for return to pre-operative work and sport activities. A systematic review of outcomes after HTO and HTO combined with biological knee reconstruction found that the survival at 5 years follow-up was 97.7% for HTO combined with cartilage surgery and 92.4% for isolated HTO. However, at all other time points, there were no significant survival differences between these two treatment groups. As mentioned before, there are various surgical options described to restore cartilage defects, but there is no consensus or gold standard treatment. However, as suggested in the literature, it may only be successful if concomitant malalignment is identified and addressed in the same operative procedure to prevent failures, due to overloading of the affected compartment of the knee joint.

Schuster et al performed a survivorship analysis of open-wedge HTO combined with abrasion/microfracture in severe medial osteoarthritis and varus malalignment in 91 knees of 85 patients with a mean age of 50.4 years. After 5 years, the survival rate was 95.2%, with 4 cases of conversion to arthroplasty, while 94.9% of patients were satisfied with the result after 5 years. These results were comparable with results of Sterett et al. Bode et al investigated a combined single-stage autologous chondrocyte implantation and HTO. Forty patients with an average age of 37 years, average varus deformity of 4.9° and average cartilage defect size of 4.6 cm² were treated and investigated at a mean follow-up of 60.5 months. The failure rate was 10% and the score results showed improved outcome. The mean duration of absence from work was about 95 days and the time to return
If a cartilage repair procedure is planned, a malalignment correction is mandatory in patients with cartilage defects and concomitant leg deformity.

References
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