Treatment of osteochondral defects of the talus
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Summary
Chapter 1
General introduction

An osteochondral defect (OCD) involves the articular cartilage and its subchondral bone. Symptomatic OCDs of the talus most frequently appear in the second and third decade of life. A traumatic insult, usually ankle sprain, is the most frequent etiologic factor. The typical symptom of a chronic lesion is persistent or intermittent deep ankle pain during or after activity. Plain radiographs may disclose the lesion. For further diagnostic evaluation, computed tomography (CT) and magnetic resonance imaging (MRI) have demonstrated similar accuracy. CT scanning is preferred for preoperative planning because it better visualizes the bony defect. The integrity of the subchondral bone seems crucial in the development and the treatment of OCDs. There are numerous treatment methods. The general aim of this thesis was to improve the outcome for the patient by optimizing arthroscopic treatment and evaluating alternative treatment. The specific aims were to review and summarize the literature, evaluate primary arthroscopic treatment, improve preoperative planning, accelerate aftertreatment, analyze a novel metal resurfacing inlay implant, develop an animal model specifically for talar OCDs, investigate the effect of demineralized bone matrix and platelet-rich plasma, and improve the reporting of outcomes.

Part I – Current concepts

Chapter 2
Treatment of osteochondral defects of the talus

Current concepts of treatment types, their indications, and future developments in treatment were reviewed. Based on the results presented in the literature, a treatment algorithm was presented that was mainly guided by the size of the lesion. In the algorithm, asymptomatic or low-symptomatic lesions are treated nonoperatively. The primary surgical treatment of defects up to 15 mm in diameter consists of arthroscopic débridement and bone marrow stimulation. Retrograde drilling combined with a bone graft is an alternative for large cystic talar lesions. Fixation of the fragment is preferred in adolescents or in (sub)acute situations in which the fragment is 15 mm or larger. Osteochondral autograft transfer and autologous chondrocyte implantation, with or without a cancellous bone graft, were recommended for secondary cases as well as large lesions.

Chapter 3
Advancements in ankle arthroscopy

Ankle arthroscopy has gradually changed from a diagnostic to a therapeutic tool during the past 30 years. Most arthroscopic procedures can be performed by using the anterior working area with the ankle in dorsiflexion or plantar flexion; there is no need for routine ankle distraction. Anterior ankle problems, such as the anterior impingement syndrome, are approached by anteromedial and anterolateral portals and, if necessary, an accessory portal. Most OCDs can be reached from anterior with the ankle in plantar flexion. For a far posterior location, the OCD can be approached from posterior. The two-portal hindfoot endoscopic technique (i.e., both arthroscopic and endoscopic surgery), with the patient in the prone position, provides excellent access to the posterior ankle compartment and to posteriorly located extra-articular structures.
Part II – Primary arthroscopic debridement and bone marrow stimulation

Chapter 4
Computed tomography of the ankle in full plantar flexion: a reliable method for preoperative planning of arthroscopic access to osteochondral defects of the talus

The purpose of chapter 4 was to assess whether a preoperative CT of the ankle joint in full plantar flexion is a reliable and accurate tool to determine the anterior arthroscopic accessibility of talar OCDs. Twenty consecutive patients were prospectively studied. All patients had an OCD of the talar dome and had a preoperative CT scan of the affected ankle in maximum plantar flexion in a metal-free 3-dimensional footplate. Accessibility of the OCD was defined by the distance between the anterior border of the OCD and the anterior distal tibial rim. Two investigators measured this distance on sagittal CT reconstructions. The reference standard was the distance between the same landmarks measured during anterior ankle arthroscopy by an orthopaedic surgeon blinded to the CT scans. Intraobserver and interobserver reliability of CT, as well as the correlation and agreement between CT and arthroscopy, were calculated. The measured distance between the anterior border of the OCD and the anterior distal tibial rim ranged from -3.1 to 9.1 mm on CT and from -3.0 to 8.5 mm on arthroscopy. The intraobserver and interobserver reliability of the measurements made on CT scans (intraclass correlation coefficients [ICC] >0.99; p <0.001), as well as the correlation between CT and arthroscopy (r = 0.98; p <0.001), were excellent. This study showed that measurements on CT scans of the ankle in full plantar flexion are a reliable and accurate preoperative method to determine the in situ arthroscopic location of talar OCDs.

Chapter 5
Arthroscopic accessibility of the talus quantified by computed tomography simulation

The dual purpose of this chapter was (1) to quantify the anterior arthroscopic reach of the talus (i.e., proportion of the talar dome anterior to the anterior distal tibial rim) with the ankle in full plantar flexion, and (2) to identify predictive factors of the arthroscopic reach. CT scans were obtained of 59 ankles in full plantar flexion in the 3-dimensional footplate. The arthroscopic reach of both the medial and lateral talar domes was assessed on sagittal reconstructions using a custom-made software routine. Intraobserver and interobserver reliability were calculated by ICCs. Various predictive factors of the arthroscopic reach were analyzed by multivariate linear regression analysis. The arthroscopic reach was 48.2% ± 6.7% (range, 26.7% - 60.7%) of the medial talar dome and 47.8% ± 6.5% (range, 31.2% - 65.1%) of the lateral talar dome (p = 0.62). The intraobserver and interobserver reliability of both measurements were excellent (ICC, 0.99). The clinical plantarflexion angle was a statistically significant predictive factor of both the medial and lateral arthroscopic reaches (i.e., increased plantar flexion corresponded to increased area of access), while joint laxity, gender, and age were not predictive. The following conclusions could be drawn: (1) almost half of the talar dome is accessible anterior to the anterior distal tibial rim, and (2) the plantarflexion angle is an independent predictive factor of the arthroscopic reach both medially and laterally.
Chapter 6
Arthroscopic treatment for osteochondral defects of the talus: outcomes after 8 to 20 years of follow-up

The primary aim of chapter 6 was to assess the long-term clinical and radiographic outcomes of arthroscopic debridement and bone marrow stimulation for talar OCDs. The secondary aim was to identify prognostic factors that affect the long-term results. Fifty (88%) of 57 eligible patients with a primary OCD treated with arthroscopic debridement and bone marrow stimulation were evaluated after a mean follow-up of 12 years (range, 8 – 20 years). Clinical assessment included the Ogilvie-Harris score, Berndt and Harty outcome question, American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score, and Short Form-36 (SF-36) as well as resumption of work and sports. Weight-bearing radiographs were compared with preoperative radiographs with use of an ankle osteoarthritis classification. Various possible prognostic factors were recorded and analyzed with use of univariate logistic regression, including the size, location, and classification of the defect, patient age and body mass index, traumatic etiology, and duration of symptoms. The Ogilvie-Harris score was excellent in 20% of patients, good in 58%, fair in 22%, and poor in 0%. According to the Berndt and Harty outcome question, 74% of patients rated the ankle as good, 20% as fair, and 6% as poor. The median AOFAS score was 88 (range, 64 – 100). Of the eight subscales of the SF-36, six were comparable with population norms and two were superior in the study group. Ninety-four percent of patients had resumed work and 88% had resumed sports. The radiographs indicated an osteoarthritis grade of 0 in 33% of the patients, I in 63%, II in 4%, and III in 0%. Compared with the preoperative osteoarthritis classification, 67% of radiographs showed no progression and 33% showed progression by one grade. None of the prognostic factors was significantly associated with the Ogilvie-Harris score or progression of osteoarthritis. This study suggested that initial success rates of arthroscopic debridement and bone marrow stimulation for OCDs of the talus are maintained over time. No factors that were predictive of the outcome could be identified.

Chapter 7
Potential pitfall in the microfracturing technique during the arthroscopic treatment of an osteochondral lesion

The microfracture procedure may create small osseous fragments upon retrieval of the microfracture awl, which may stay behind in the joint and act as loose bodies. It was emphasized that the joint should be carefully inspected and flushed at the end of each procedure.

Chapter 8
Pulsed electromagnetic fields after arthroscopic treatment for osteochondral defects of the talus: double-blind randomized controlled multicenter trial

In chapter 8, the detailed study protocol was described of a prospective, double-blind, randomized, placebo-controlled multicenter trial conducted in five centers in the Netherlands and Belgium. We hypothesized that pulsed electromagnetic field (PEMF) treatment compared to sham-treatment after arthroscopy leads to earlier resumption of sports, and aimed at 25% increase in patients that resumed sports. Sixty-eight patients were randomized to either active PEMF-treatment or sham-treatment for 60 days, 4 h daily. The primary outcome measures were (a) the percentage of patients that resumed and maintained sports, and (b) the time to resumption of sports, defined by the Ankle Activity Score. Secondary outcome measures included resumption of work, subjective and objective
scoring systems (AOFAS score, Foot and Ankle Outcome Score [FAOS], numeric rating scales of pain and satisfaction, and EuroQol-5D), and CT. This trial will provide level-1 evidence on the effectiveness of PEMF in the management of osteochondral ankle lesions after arthroscopy.

Part III – Secondary surgical treatment with a metal resurfacing inlay implant

Chapter 9
Novel metallic implantation technique for osteochondral defects of the talus: a cadaver study

A metal resurfacing inlay implant with 15 offset sizes was developed for the treatment of localized OCDs of the medial talar dome. The aim of chapter 9 was to test the following hypotheses: (1) a matching offset size is available for each talus, (2) the prosthetic device can be reproducibly implanted slightly recessed in relation to the talar cartilage level, and (3) with this implantation level, excessive contact pressures on the opposite tibial cartilage are avoided. The prosthetic device was implanted in 11 intact fresh-frozen human cadaver ankles, aiming its surface 0.5 mm below cartilage level. The implantation level was measured at four edges of each implant. Intra-articular contact pressures were measured before and after implantation, with compressive forces of 1,000 - 2,000 N and the ankle joint in plantigrade position, 10° of dorsiflexion, and 14° of plantar flexion. There was a matching offset size available for each specimen. The mean implantation level was 0.45 ± 0.18 mm below cartilage surface. The defect area accounted for a median of 3% (range, 0.02% – 18%) of the total ankle contact pressure before implantation. This was reduced to 0.1% (range, 0.02% – 13%) after prosthetic implantation. These results suggested that the implant can be applied clinically in a safe way, with appropriate offset sizes for various talar domes and without excessive pressure on the opposite cartilage.

Chapter 10
Treatment of secondary osteochondral defects of the talus with a metal resurfacing inlay implant: a prospective study

The aim of chapter 10 was to evaluate the clinical effectiveness of the metal resurfacing inlay implant for OCDs of the medial talar dome after failed prior surgical treatment. Twenty consecutive patients, aged 20 to 60 years (mean, 38 years), were prospectively studied for 2 to 5 years (mean, 3 years). There was statistically significant reduction of pain in each of four situations (i.e., rest, walking, stair climbing, and running; p ≤0.01). The median AOFAS score improved from 62 (range, 28 – 75) preoperatively to 87 (range, 42 – 100) at final follow-up (p <0.01). The FAOS improved on all subscales (p ≤0.03). The mean SF-36 physical component scale improved from 36 ± 8.2 preoperatively to 45 ± 7.8 at final follow-up (p <0.01); the mental component scale did not change significantly. On radiographs, progressive degenerative changes of the opposing tibial plafond were observed in two patients. One patient required additional surgery for the OCD. This study showed that the metal implantation technique is a promising treatment for OCDs of the medial talar dome after failed previous treatment.

Chapter 11
Direction of the oblique medial malleolar osteotomy for exposure of the talus

A medial malleolar osteotomy is often indicated for operative exposure of posteromedial OCDs and fractures of the talus. To obtain a congruent joint surface after refixation, the oblique
osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. The purpose of chapter 11 was to determine this direction in relation to the longitudinal tibial axis for use during surgery. Using anteroposterior mortise radiographs and coronal CT scans of 46 ankles (45 patients) with an OCD of the talus, two observers independently measured the intersection angle between the tibial plafond and the medial malleolus. The bisector of this angle indicated the osteotomy perpendicular to the tibial articular surface. This osteotomy was measured relative to the longitudinal tibial axis on radiographs. ICCs were calculated to assess reliability. The mean osteotomy was $57.2^\circ \pm 3.2^\circ$ relative to the tibial plafond on radiographs and $56.5^\circ \pm 2.8^\circ$ on CT scans. This osteotomy corresponded to $30.4^\circ \pm 3.7^\circ$ relative to the longitudinal tibial axis. The intraobserver (ICC, 0.90 - 0.93) and interobserver (ICC, 0.65 - 0.91) reliability of these measurements were good to excellent. It was concluded that a medial malleolar osteotomy directed at a mean $30^\circ$ relative to the tibial axis enters the joint perpendicularly to the tibial cartilage, and will likely result in a congruent joint surface after reduction.

Chapter 12
Clinical tip: aiming probe for a precise medial malleolar osteotomy

The use of a right-angled aiming probe was described to identify both the posterior and anterior parts of the intersection between the tibial plafond and medial malleolus, in order to perform a precise medial malleolar osteotomy.

Part IV – Alternative treatment

Chapter 13
Osteochondral defects of the talus: a novel animal model in the goat

An experimental animal model of the ankle joint was not available. The aim of chapter 13 was to test a newly developed animal model for OCDs of the ankle in vivo. OCDs were created in the talus of goat hind legs using a posterolateral surgical approach. The defects were filled with either autologous cancellous bone or donor demineralized bone matrix (DBM) or left empty as control. After 12 weeks of healing, the specimens were analyzed with radiography, macroscopy, µCT, histology, histomorphometry, and fluorescence microscopy. It was possible to create a standardized defect in each talus. The implanted material remained in place. The analyses showed that most bony tissue was generated in the defects filled with autologous bone and least in the control defects. Our findings showed that a standard OCD can be created in the talus by a relatively simple procedure in a large animal that allows qualitative and quantitative evaluation. It was concluded that the model can be used in future experiments to investigate alternative treatment methods before they are introduced into clinical practice.

Chapter 14
Demineralized bone matrix and platelet-rich plasma for osteochondral defects of the talus: an experimental goat study

The purpose of chapter 14 was to evaluate the effectiveness of DBM with and without platelet-rich plasma (PRP) in the treatment of OCDs of talus. We hypothesized that treatment with DBM would result in more bone formation than no treatment in control OCDs, and that PRP would further enhance the regenerative capacity of DBM. A standardized 6-mm OCD was
created in each talus of 16 adult goats. According to a randomization scheme, one OCD of each goat was treated with allogeneic DBM hydrated with normal saline (n = 8) or hydrated with autologous PRP (n = 8). The contralateral OCD (n = 16) served as control. After 24 weeks, the animals were euthanized and the tali excised. Various outcome parameters were analyzed with use of macroscopic evaluation, µCT, histology, histomorphometry, and fluorescence microscopy. None of the analyses revealed statistically significant differences between the groups for any of the parameters analyzed in any volume of interest. For example, the mean bone volume fraction of the defect, as measured by µCT, was 0.56 ± 0.17 for DBM hydrated with normal saline and 0.52 ± 0.18 for DBM hydrated with PRP, compared to 0.53 ± 0.12 and 0.54 ± 0.14 for the internal controls, respectively (p >0.05). In contrast to our hypotheses, no beneficial treatment effect of DBM with or without PRP was found for OCDs of the caprine talus.

Part V – Outcome measures

Chapter 15
Outcome measures

Outcome assessment is critical in evaluating the efficacy of orthopaedic procedures. Frequently used clinical outcome scores for talar OCDs were discussed in chapter 15. In addition, the chapter discussed scoring systems based on postoperative imaging. The following conclusions were drawn: (1) the AOFAS score is a frequently used outcome measure for talar OCD, but has some limitations, (2) the FAOS and the Foot and Ankle Ability Measure are functional patient-reported outcome scores that are useful in the clinical assessment of patients with a talar OCD, (3) the 11-point numeric rating scale is a suitable, valid, and practical scale to assess pain intensity, and (4) postoperative imaging can be used for objective assessment of repair tissue.

Chapter 16
Translation and validation of the German Foot and Ankle Outcome Score

The FAOS is a 42-item questionnaire divided into five subscales, which has been validated in several languages. Germany had no validated outcome score for general foot and ankle pathology. The aim of this study was to develop a German version of the FAOS and to investigate its psychometric properties. Forward and backward translations were executed according to official guidelines. The final version of the FAOS was investigated in 150 patients with various foot and ankle disorders. All patients completed the FAOS, SF-36, numeric rating scales for pain and disability, and the Hannover questionnaire. The FAOS was re-administered after one week. Test-retest reliability, internal consistency, minimal detectable change, construct validity, and floor and ceiling effects were analyzed.

Test-retest reliability and internal consistency of each subscale were excellent (ICC, 0.88 - 0.95; Cronbach’s alpha, 0.94 - 0.98). The minimal detectable changes of each subscale were 17.1 to 20.8 at the individual level and 2.0 to 2.4 at group level. There were moderate to strong correlations between FAOS subscales and physical outcomes and low to moderate correlations between FAOS subscales and mental outcomes. Floor and ceiling effects were not present. These outcomes indicated that the German version of the FAOS is a reliable and valid instrument for use in foot and ankle patients.
Chapter 17

General discussion and summary

Chapter 17
General discussion

The treatment of talar OCDs provides a challenge for the orthopaedic surgeon. This thesis has contributed to the treatment of patients with talar OCDs in various ways. The literature was reviewed and a treatment algorithm was proposed. The long-term outcomes of arthroscopic bone marrow stimulation reassured the durability of the technique and set the reference standard for other procedures to equal. CT scans showed that almost half of the talar dome is accessible in the anterior working area with the ankle in full plantar flexion. The trial on acceleration of the rehabilitation with PEMF is only months before final follow-up. A novel metal implantation technique led to good clinical outcomes in most patients at a mean follow-up of 3 years. A medial malleolar osteotomy for exposure of the talus enters the joint perpendicularly to the tibial cartilage at the intersection with the medial malleolus when directed at a mean 30° angle relative to the long tibial axis. DBM and PRP were investigated with use of a newly developed goat model. They were not effective in the treatment of goat OCDs compared to control defects. Finally, various outcome measures were reviewed, and a guideline for their use was provided. The German version of the FAOS was translated and validated.

Several recommendations can be made for treatment of talar OCDs on the basis of the thesis and the current literature. Arthroscopic bone marrow stimulation remains the primary surgical treatment for chronic OCDs up to 15 mm. If the primary treatment fails, various secondary treatment options remain, including OATS, (matrix-induced) ACI, cancellous bone grafting, and metal resurfacing. The choice depends on patient and lesion characteristics as well as surgeon preferences.

There are still many possibilities for future research to further ameliorate the perspective of patients with a talar OCD. Future research should focus on improving the bone marrow stimulation technique, for example, by identifying the most effective depth and distance of subchondral bone penetration. The ultimate goal of OCD treatment is to regenerate the complete osteochondral unit by a construct that results in repair of the subchondral bone as well as an integrated layer of hyaline cartilage. However, inferior methods will have to be used until such an ideal treatment is available.

Great diversity and variability between studies provide the surgeon interesting choices with an important role for the patient and his or her demands. Sufficiently powered, randomized controlled trials with uniform methodology and validated outcome measures, as well as the optimization of current treatment methods and development of new methods, may form the foundation of the optimal treatment plan for future talar OCDs.