Osteochondral talar lesions and ankle biomechanics

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Chapter 8

Local talar geometry and size of osteochondral defects of the ankle as crucial input for a focal metal implant

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Abstract

Background
Osteochondral defects (OCDs) of the talus are a common cause of deep ankle pain. Nearly 20% of patients have residual complaints after arthroscopic debridement, curettage and bone marrow stimulation. For this group, alternative treatment methods are necessary.

Purpose
To determine local talar geometry and size of the lesion as input for the development of a focal implant for treatment of secondary OCDs.

Methods
A schematic design of the implant was made. Necessary measurements were determined for dimensioning of the implant. CT scans of the ankle of 52 consecutive patients with a symptomatic talar OCD were evaluated. The OCDs were measured in medio-lateral (width), antero-posterior (length), and cranio-caudal direction (depth). Location was determined in antero-posterior direction. Talar geometry at the location of the lesion was determined by measuring the angle of the talar shoulder and the talar radius. All dimensions were expressed by the median, interquartile range, and minimum-to-maximum range, excluding the outliers. A statistical analysis was performed to detect differences between medial and lateral OCDs. From the measurements of the OCDs and its talar geometry, the diameter and height of the implant could be determined.

Findings
Median width for medial lesions was 13.9 mm (range 7.1 to 24.5), for lateral lesions 10.0 mm (range 4.5 to 19.0). Median length for medial lesions was 15.5 mm (range 5.9 to 35.8), and for lateral lesions 8.6 mm (range 2.9 to 17.1). Medial OCDs were larger in width and length than lateral lesions (p=0.038 and p=0.000, respectively). Median height for medial lesions was 10.4 mm (range 3.7 to 18.9) and for lateral lesions 8.1 mm (range 5.5 to 16.2) (p=0.100).

Median distance from the anterior border of the superior articular talar surface was 46° for medial lesions (range 23 to 80) and 37° for lateral OCDs (range 0 to 86) (p=0.070).

The angle of the shoulder of the talus at the location of the defect, measured in the coronal plane, was 97° for medial lesions (range 67 to 110) and 89° for lateral lesions (range 70 to 117) (p=0.001).

Talar radius at the location of the OCD was median 34.9 mm for medial lesions (range 16.1 to 65.4) and 31.8 mm (range 8.7 to 65.9) for lateral lesions (p=0.195).

Median implant diameter to cover the defects was 20.2 mm for medial lesions (range 10.8 to 38.7) and 14.0 mm (range 5.9 to 30.0) for lateral lesions (p=0.007). Median height of the implant was 5.7 mm (range 2.2 to 13.3) for medial lesions and 5.1 mm (range 1.8 to 12.8) for lateral lesions (p=0.001).

Interpretation
Variation in size, location and talar geometry at the location of OCD was found which implies the focal implant has to be available in a range of sizes and shapes to fit most OCDs. Furthermore, the significant differences in size and talar geometry for medial and lateral OCDs indicates that 2 different sets of implants are needed for medial and lateral OCDs.
Local talar geometry and size of OCDs

Introduction
Osteochondral defects (OCDs) of the talus often arise after an ankle sprain or fracture [6, 19, 21, 26, 34], and occasionally occur idiopathically [26]. They cause deep ankle pain during weight-bearing and are often associated with swelling, catching, locking, diminished range of motion, stiffness and limited function. Over 80% of patients that are arthroscopically treated for an OCD have a good to excellent result [39]. However, still nearly 20% has residual complaints, often limiting activities in daily life.

Over the past decade, lesion size has been studied as outcome predictor for the arthroscopic microfracture procedure [12-14]. Several studies show excellent results for lesions smaller than 15 mm, but that larger lesions have a higher failure rate [12-14]. More recently, lesion depth was added to width and length as being significantly negatively correlated with outcome of arthroscopic microfracturing [4].

An alternative intervention for secondary talar OCDs or large primary talar OCDs could be a metal implant [31-33]. Such implants were previously applied for large defects in the hip, knee and shoulder joint, to cover defects of the femoral head and condyle, and the humeral head, respectively [7, 8, 10, 15, 16, 20, 30, 35]. The metal implant restores the smooth, continuous loadbearing surface to slow down or stop further mechanical wear. An advantage of its use is that the required operative procedure is relatively simple and reproducible [8, 10]. In the hip, knee and shoulder, this intervention demonstrated improved subjective outcome and reduced pain [8, 10, 15, 20, 30]. In the ankle a focal metal implant could hypothetically reduce pain by covering the subchondral bone and reduce deterioration of the surrounding joint surface.

Analogous to the development process of such a metal implant for the hip and the knee joint, it is key to match the size and shape of the metal implant to the local surface geometry of the talus, as this should achieve the goal of preservation of the functional structures. For OCDs in the shoulder, hip and the knee joints, the size and shape of the implant matches the geometry of the humeral head, and the femoral head and condyle, respectively. These both have a spherical surface with a constant radius. This however does not apply for the talus. Since the talus has different curvatures in all three directions, the geometry at the location of the OCD is more complex.

To accommodate the talar geometry at the location of OCDs, a schematic design of the implant was made that through scaling should serve groups of patients. Using this design as starting point, the crucial dimensions of the implant could be determined: the size of the lesion in antero-posterior (length), medio-lateral (width) and cranio-caudal (depth) direction, the angle of the talar shoulder in the coronal plane and the talar radius in the sagittal plane. Although several three-dimensional (3D) techniques exist to measure the complex shapes of bones [18, 25, 38], two-dimensional measurements were performed in individual slices of computed tomography scans. Because the main 3D shape of the implant was already set, only the maximum boundaries of the lesion and curvatures needed to be determined. Furthermore, the implant was not designed for personalized care, but to be available in a number of sizes that can serve the majority of patients.
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This paper reports on the measurements of geometry, size and location of talar OCDs, which were used for the development of the talar Hemicap®.

Materials and methods
The implant for medial talar OCDs now exists and is called the HemiCAP® (HemiCAP®, Arthrosurface©) [32]. For development of this implant, a schematic design was made. To facilitate surgical implantation the geometry of the cap of the implant would have to meet certain conditions. It would be convenient if the cap would be round as seen from above (Fig. 1a), angled as seen from the front (Fig. 1b), and curved as seen from the side (Fig. 1c). Furthermore, it would be of benefit to make the implant equal in size in the coronal plane in the medio-lateral and the cranio-caudal direction. The final implant would consist of a cap attached to a screw (Fig. 1d).

The metal cap would have three articular surfaces: the dome, the ridge and the medial or lateral wall. The development of this implant design requires extra measurements of the OCDs. A schematic drawing was made of the talus in the coronal plane, to determine the additional measurements and calculations required for the dimensioning of the cap. Diameter and height of the cap had to be determined. First, the diameter of the cap was determined. $S_1$ was considered

![Diagram of talar dome](image)

**Figure 1** Schematic design of the implant and talar dome: (a) Round from above (oblique view of talar dome), (b) Angled from the side (coronal view), (c) Curved from the side (sagittal view), (d) Final design of the implant, consisting of a cap secured to a screw.
This paper reports on the measurements of geometry, size and location of talar OCDs, which were used for the development of the talar Hemicap®.

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Angle \( \alpha \) would be the angle of the metal cap seen from the front (in the coronal image). The direction of height H would be the direction of the screw on which the metal cap would be placed. For radius of the cap, the largest length of S1 and D is decisive.

![Figure 2](image.png)

**Figure 2** Schematic drawing of the talus in the coronal plane to aid in determining the dimensions of the implant.

- \( S_1 \) = size in medio-lateral direction
- \( S_x \) = same length as \( S_1 \)
- \( P \) = most inferior point of \( S_x \) on the medial or lateral talar facet
- \( L_1 \) = line intersecting the beginning of \( S_1 \) and \( P \)
- \( D \) = diameter of implant
- \( L_2 \) = line perpendicular to \( L_1 \) at the shoulder of the talus
- \( H \) = height of the metal implant

Size 2 (\( S_x \), green) considered the same length as Size 1 (\( S_1 \), green), called Size X (\( S_x \), green). Point \( P \) (\( P \), black) = most inferior point of \( S_x \). Line 1 (\( L_1 \), dotted blue) drawn between the beginning of \( S_1 \) and \( P \). Diameter of the metal cap (\( D \)) is length between the beginning of \( S_x \) and \( P \). Line 2 (\( L_2 \), dotted blue) drawn perpendicular to \( L_1 \) and in the middle of the beginning of \( S_1 \) and \( P \). Height of the metal cap (\( H \), along pink line) is distance between along \( L_2 \) between \( L_1 \) and the surface of the talar shoulder.
Computed tomography (CT) was chosen as imaging modality for evaluation of the OCDs. The geometry of bone is more precisely imaged by CT than by MRI [9]. MRI scans in general show more deviations in geometry by local artefacts and variance in fluid contents, like for instance by oedema or infection [27]. The appearance of oedema in MRI images may make it harder to determine the osseous boundaries of the lesion [17].

Fifty-two consecutive CT scans of patients with a symptomatic OCD of the ankle performed over a period of 2 years, were evaluated. These were considered to be a representative sample of the group of symptomatic OCD patients. Since size and location of talar OCDs has been studied before [17] and the goal of this study was dimensioning of a focal implant, this study emphasized on measuring size and location in relation to talar geometry at the location of the lesion. All patients with a symptomatic OCD were included, also those with secondary lesions. No exclusion criteria were applied. Patient charts were reviewed to determine gender, side (R/L), whether it concerned a primary or secondary lesion and the cause of the OCD.

Conform our routine clinical protocol, CT scanning was performed with the patient in a supine position, from 3 cm above the ankle joint line to the sole of the foot (CT scan Helical dual; Twin Flash, Elscint, Israel or MX Twin Flash, Picker, Cleveland, Ohio, USA). If possible, both feet were flat against a footplate, thus aiming for a neutral orientation of the foot. Axial slice thickness was 0.6 mm. Coronal and sagittal reconstructions had a slice thickness of 1.2 mm. The pixel resolution was 512 by 512. Sagittal slices were outlined parallel to the medial side of the talus. Coronal slices were outlined perpendicular to the medial side of the talus. A correction factor was applied transforming pixel values into mm.

Size of the OCD was measured in 3 directions. From each scan, coronal and sagittal images were selected in which the OCD appeared to be the largest. From the coronal images, width (S1) was measured in medio-lateral direction and depth (S2) in cranio-caudal direction (Fig. 3). From the sagittal images, length of the OCD in antero-posterior direction was measured (S3) (Fig. 4).

Because the aim was to measure the required sizes for the implant, cartilage thickness had to be taken into account. Effectively, the cartilage thickness was assumed to be half the radiological joint space width. Coronal images were selected. Since CT scanning only shows the bony contours of the defects, extra lines had to be drawn to take into account cartilage thickness. Because available standard radiologic image viewers do not allow drawing these extra lines at the same time, the selected CT slices were downloaded and imported and further processed into Microsoft Visio (version 11, 2005). Lines were drawn along the bony border of the tibial plafond and the superior talar surface. Next, lines were drawn along the bony borders of the medial or lateral talar facet, and the medial malleolus or fibula. Finally, in the middle of these lines, new lines were drawn to determine the estimate of the cartilaginous surface of the talus (yellow lines). Along this middle yellow line, size was measured in medio-lateral and cranio-caudal direction (yellow lines, Fig. 3). In the sagittal plane the lesion was measured antero-posteriorly, along the bony borders of the lesion (Fig. 4).
It was noted whether it concerned a medial or lateral OCD. Antero-posterior location of the defect was determined relative to the anterior border of the talar articular surface in the sagittal plane. Sagittal images were selected in which the lesion projected most anteriorly. The proximal talar surface was considered to be part of a circle. This circle was drawn so it corresponded to the border of the superior articular surface. It was made sure the exact fit of the circle was at the location of the lesion. The anterior articular border, where the proximal talar articular surface makes a relatively sharp angle with the talar neck, was determined. The angle between the radial line from the centre of the circle to the beginning of the anterior articular border of the talus ($0^\circ$)
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and the radial line from the centre of the circle to the beginning of the OCD in antero-posterior direction was measured \(\alpha\) (Fig. 4).

To measure talar geometry at the location of the OCD, the angle of the talar shoulder and the talar radius at the location of the OCD were measured. The first was measured in the coronal plane (angle \(\alpha\)) (Figure 3), the second in the sagittal plane \(R\) (Fig. 4).

This leads to the following measurements, lines and calculations:

**In the coronal plane:**
- \(S_1\) = size of the OCD in medio-lateral direction (width)
- \(S_2\) = size of the OCD in cranio-caudal direction (depth), at the medial or lateral talar facet
- \(S_n\) = size of the OCD in cranio-caudal direction, when the \(S_2\) would be considered equal to \(S_1\)
- \(P\) = most distal point of \(S_1\) on the medial or lateral talar facet
- \(L_1\) = line intersecting the end of \(S_1\) and \(P\)
- \(D\) = length of \(L_1\) between \(S_1\) and \(P\) (diameter of the metal cap)
- \(L_2\) = line intersecting the shoulder of the talus, perpendicular to \(L_1\)
- \(H\) = length of line between \(L_2\) and the cartilaginous surface of the talar shoulder (this is the height of the metal cap)

**In the sagittal plane:**
- \(S_3\) = size of the OCD in antero-posterior direction (length)
- \(R\) = talar radius at the location of the lesion
- \(\theta\) = anterior articular border of the talus, set at 0 degrees
- \(X\) = beginning of the lesion as measured from the anterior articular border in degrees

All data are reported as median, quartiles Q1 and Q3, minimum and maximum values and represented in boxplots with the outliers. Outliers are data points more than 1.5 interquartile range (Q3-Q1) below the first quartile or above the third quartile. The Mann-Whitney U test was performed to evaluate if there were any statistical differences in the measurements between medial and lateral OCDs, with \(p < 0.05\) indicating a significant difference. In case no difference is found only one focal implant is needed for medial and lateral OCDs. In case of a difference, a medial and a lateral implant has to be developed.

**Results**

Fifty-two CT scans of 49 patients were evaluated. Two patients had a bilateral defect, and one patient a medial and lateral defect in one ankle. Thirty patients were male and 22 female. There were 27 right and 25 left ankles. Thirty-seven primary and 15 secondary OCDs were found. There were 30 medial and 22 lateral OCDs. Review of patient charts revealed an evident trauma in 35 patients. Twenty-seven were ankle distortions, 8 because of sports. In 2 patients it was specifically mentioned the defect occurred idiopathically. In 12 patients it was noted the cause was unknown. In 3 patients nothing was mentioned about the cause.
Local talar geometry and size of OCDs

Median width for medial lesions was 13.9 mm (range 7.1 to 24.5), for lateral lesions 10.0 mm (range 4.5 to 19.0). Median length for medial lesions was 15.5 mm (range 5.9 to 35.8), and for lateral lesions 8.6 mm (range 2.9 to 17.1). Medial OCDs were larger in width and length than lateral lesions (p=0.038 and p=0.000, respectively). Median height for medial lesions was 10.4 mm (range 3.7 to 18.9) and for lateral lesions 8.1 mm (range 5.5 to 16.2). No significant difference was found for height (p=0.100).

Median distance from the anterior border of the superior articular talus surface was 46° for medial lesions (range 23 to 80) and 37° for lateral OCDs (range 0 to 86). This was not significant (p=0.070). The angle of the shoulder of the talus at the location of the defect, measured in the coronal plane, was wider for medial than for lateral lesions, i.e. 97° for medial lesions (range 67 to 110) and 89° for lateral lesions (range 70 to 116) (p=0.001). Talar radius at location of the OCDs was not significantly different for medial and lateral lesions (p=0.195).

Diameter of the cap to cover the defect was median 20.2 mm (range 10.8 to 38.7) for medial lesions and 14.0 mm (range 5.9 to 30.0) for lateral lesions. Height of the cap to cover the lesion was median 5.7 mm for medial OCDs (range 2.2 to 13.3) and 5.1 mm (range 1.8 to 12.8) for lateral OCDs. Concerning diameter to cover the defect, this was median 20.2 mm (range 10.8 to 38.7) for medial lesions and 14.0 mm (range 5.9 to 30.0) for lateral lesions. Diameter and height of the cap were both significantly different for medial and lateral OCDs (p=0.007 and p=0.001, respectively).

Values are shown in Figure 5.

Discussion

In this study a schematic design of an implant was made and a measurement method was developed to determine talar geometry, size and location of talar osteochondral lesions. These measurements facilitated the development of the implant. Measurements of talar radius and angle of the talar shoulder were later translated into offset sizes. The focal implant can be used for treatment of secondary OCDs and is available in 10 sizes, consisting of combinations of offset sizes in antero-posterior and medio-lateral direction (www.arthrosurface.com).

It was found that width and length were significantly larger in medial compared to lateral OCDs. This implies that the average size of a focal implant to cover the defect is larger for medial than for lateral OCDs. Furthermore, concerning talar geometry, it was found that the angle of the shoulder of the talus at the location of the lesion was significantly larger for medial compared to lateral OCDs. This implies that the angle of implantation is different for medial and lateral OCDs. When aiming device is placed perpendicular at the coronal angle of the implant, it may have a lower angle in lateral than in medial OCDs. This may have consequences when a fibular osteotomy is performed to reach the lesion. To cover medial and lateral lesions, two different sets of implants need to be developed because of difference in size and geometry.

The measurements for implant design showed that diameter and height of the implant are significantly larger for medial OCDs. No difference was found between medial and lateral OCDs concerning depth of the lesion and location in antero-posterior direction.
Local talar geometry and size of OCDs

- a. Boxplot of the size of the OCDs in mm in medio-lateral direction.
- b. Boxplot of the size of the OCDs in mm in cranio-caudal direction.
- c. Boxplot of the size of the OCDs in mm in antero-posterior direction.
- d. Boxplot of the location of the OCD, median distance from the anterior border of the superior articular talar surface (degrees).
- e. Angle of the talar shoulder in the coronal plane at the location of the lesion (degrees).
- f. Talar radius in the sagittal plane at the location of the lesion (mm).
- g. Diameter (mm).
- h. Height (mm) that may be required for a future focal metal cap (*Statistically significant, p<0.05).
Local talar geometry and size of OCDs

Figure 5 Boxplot of (a) the size of the OCDs in mm in medio-lateral direction, (b) cranio-caudal direction, (c) antero-posterior direction, (d) the location of the OCD, median distance from the anterior border of the superior articular talar surface (degrees), (e) angle of the talar shoulder in the coronal plane at the location of the lesion (degrees), (f) talar radius in the sagittal plane at the location of the lesion (mm), (g) the diameter (mm) and (h) the height (mm) that may be required for a future focal metal cap (*Statistically significant, p<0.05).
Some outliers were measured in this series. Outliers are not accidental or random measurements, for instance when inadequate measurements are performed, but apparently larger or smaller values that are seldom occurring. The outliers in this series are at the larger end of the spectrum. An explanation for this may be that only symptomatic lesions were included in the study. It is very well possible that smaller OCDs are more often asymptomatic, and therefore these patients are not seen in the hospital. These smaller OCDs are more likely to involve possible outliers at the smaller end of the spectrum. Only symptomatic cases were included in this series.

To appreciate the collected data in this small study it is important to compare the findings to the literature. Overall, in spite of the small sample size, it can be stated that the measurements of sizes of the OCDs and of talus geometry correspond to what was found in literature. It was found that medial OCDs were larger in width and length. This is corresponding to the findings of Elias et al., who collected extensive data on localization and morphology of 424 patients with an OCD from MRI images [17]. They found a significant difference for lesion depth as well. In their series, lesions were smaller in all three directions compared to the present study (differences < 5 mm for all directions). The measurement of smaller sizes in the study of Elias et al. may be explained by the fact that they searched radiology reports for osteochondral lesions, thereby possibly including asymptomatic lesions. These lesions are likely to be smaller in size.

The findings in the present study are mainly corresponding with the findings of Orr et al., who studied anatomic location and morphology of 68 symptomatic, operatively treated osteochondral lesions of the talus from MRI images [24]. They also found that medial lesions were larger in width and length, and that there was no difference between medial and lateral lesions with regard to lesion depth. Sizes were similar (difference maximum 3.9 mm, most < 3 mm) in all directions compared to the present measurements.

The findings in this study could not well be compared with the findings of Choi et al., since they did not describe defect size of medial and lateral lesions separately. They studied lesion size in 117 patients that were arthroscopically treated for a talar OCD. Measurements were performed in MRI images. When all medial and lateral OCDs are taken together, the lesions in the present study were a bit smaller in width and length (differences < 2.5 mm), but a bit larger in depth [12]. Elias et al., Orr et al. and Choi et al. all performed measurements of OCDs in MRI images. Bony oedema surrounding the defects may make it harder to determine the osseous boundaries of the lesions in MRI images [9]. The difference in imaging modality chosen for the evaluation of the defects may contribute to the small differences found in size.

Concerning talar geometry, the angle of the talar shoulder, as measured in the coronal plane at the location of lesion, was larger on the medial side than on the lateral side. The talus radius was larger on the medial side than on the lateral side, however, this was not significant (p=0.195). Both findings correspond to the findings of Leumann et al. and Wierworski et al. who studied (coronal) talar edge geometry for osteochondral plug transplantation [22, 37].

For the development of a focal implant, average dimensions are not important, but the variation is. Since for treatment it is important to be able to treat the majority of the OCDs. The hemicap
that is now available is developed for medial lesions. For a lateral hemicap the geometry and
dimensioning would have to be different, based on the findings of this study.
This study has several limitations. First of all, the study size is small as compared to previous
studies [12, 17, 24]. This may have led to measurements that are not completely representative for
all talar OCD patients. However, the group consists 52 consecutive patients with OCDs that were
presented at the hospital, and therefore they are considered to be a good reflection of the group
of OCD patients that are symptomatic.
The aim was to perform measurements for the development of a focal implant as an alternative
treatment modality. Therefore the choice could have been made to only measure the size,location and talar geometry at the location of secondary lesions, and lesions larger than 15 mm in
diameter, in which outcomes of arthroscopic microfracture procedures are known to be poor [12,
13]. Secondary OCDs are on average larger, but the variation does include sizes similar to primary
OCDs [12]. Hence, the inclusion of primary OCDs appears to be valid.
No reproducibility analyses of the measurements were performed. Neither this was done in the
previous mentioned studies [12, 17, 24]. Performing these analyses would have been of benefit to
the validity of the measurements.
Finally, cartilage thickness was considered to be equal on the tibial and talar side. From previous
studies it is known however that the average cartilage thickness of the distal tibia is 1.3 mm [5, 11,
23, 28], and for the superior talar dome this is average 1.2 mm [1-3, 5, 11, 23, 28, 29, 36]. Although
there is a slight difference in distal tibial and proximal talar cartilage thickness, this average
difference of 0.1 mm is negligible in relation to the size of the defect.
Previous publications have reported on size and location of talar OCDs, but never in relation to
talar geometry [4, 12-14]. Neither, measurements were made to design a new implant. In this study
sizes of talar OCDs were measured, their location was determined, and measurements of talar
geometry at location of the OCD were performed. These measurements have led to the
development of a new treatment modality.

Disclosure
Arthrosurface Inc., Franklin, MA provided financial support for performing the measurements. The
company had no influence on the study design, interpretation of data, or writing of the
manuscript. None of the investigators received external personal funding.
References

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