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Osteochondral lesion depth on MRI can help predict the need for a sandwich procedure

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ABSTRACT

Purpose: Autologous subchondral bone grafting in combination with autologous chondrocyte implantation (ACI) (sandwich procedure) is a well-accepted procedure for the treatment of osteochondral lesions of the knee. This requires a different surgical technique and preoperative planning compared to ACI alone. In addition, pain from bone marrow donor site locations can be expected and should be part of patient consent and expectations. This study evaluates whether the MRI made as part of the standard preoperative cartilage patient work up has the diagnostic accuracy to predict the need for a sandwich procedure.

Methods and materials: Retrospectively, 185 preoperative MRI scans (PD and T2 sequences) of patients planned for ACI were included. The integrity of the subchondral bone and lamina was scored by four different observers (3 radiologists, and 1 orthopaedic resident). The depth of the defect was measured perpendicular from articulating surface to the bottom of the bony lesion. The area under the curve (AUC) for subchondral defect on MRI (i.e. lamina or bone defect or expert impression), depth measurements and eventual sandwich procedure were calculated. Also inter-observer Kappa values were determined.

Results: The AUCs for lamina (0.74–0.80) and bone defect (0.73–0.79) were fair and inter-observer Kappas ranged from 0.49 to 0.76, indicating a moderate-good inter-observer agreement and moderate prediction of the need for a sandwich procedure based on the presence of lamina and or subchondral bone defect on MRI. However, depth measurements resulted in an AUC of 0.90 (95% CI: 0.84–0.95,) with an optimal cut-off point at 6.5 mm depth of the lesion (90% sensitivity, 80% specificity) to predict the need for a sandwich procedure.

Conclusion: Ours is the first study examining MRI as a diagnostic tool in predicting the need for a sandwich procedure. Our results show that the integrity of the subchondral layer on MRI has a moderate role in predicting the need for an eventual autologous bone graft to augment ACI whereas in our cohort a depth of the lesion above 6.5 mm accurately predicts the need for a sandwich procedure. This can aid in optimising the preoperative planning and patient consent.

1. Introduction

Cartilage defects have limited self-healing capacity and if left untreated can be the cause of osteoarthritis of the knee joint [1]. In 2010, an estimated 300,000 knee cartilage procedures were performed in the United States alone [2]. The cartilage defects in the knee joint can vary greatly in size, location and depth.

Because symptomatic articular cartilage defects of the knee can be treated in multiple ways, these factors have to be evaluated prior to deciding the correct treatment. The most commonly applied interventions are microfracturing and Autologous Chondrocyte Implantation (ACI). ACI is a two-step intervention, first described by Brittberg et al. in 1994, where chondrocytes are harvested from non-weight-bearing cartilage in the knee, expanded in vitro and re-implanted during a second surgery [3]. For ACI to be successful a sufficient subchondral bone plate is required and therefore an adequate preoperative assessment is necessary. The application of the ACI to osteochondral defects is more challenging due to an insufficient or suboptimal subchondral bone plate for the fixation of the transplant. According to Peterson et al. ACI

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alone is sufficient for bony defects between 6 and 8 mm deep [4]. For deeper defects, autologous bone grafting combined with ACI (sandwich technique) is recommended [5]. Treatment without a bone graft can result in suboptimal congruity of the newly formed cartilage [6].

Currently, the need for a sandwich procedure is only assessed perioperatively. The sandwich procedure requires a different surgical technique and preoperative planning because autologous bone graft has to be harvested from the iliac crest to build-up a subchondral layer. In addition, the associated pain from bone marrow donor site location needs to be part of patient consent and expectations.

Magnetic Resonance Imaging (MRI) plays an important role both in assessing such cartilage defects and in the follow-up after cartilage treatment. It is widely used and a reliable preoperative tool to assess the cartilage quality and defect size [7]. As various studies have reported, MRI is used after treatment as an outcome measure. However, while MRI can evaluate tissue repair, strong evidence that MRI correlates to clinical outcome is still lacking. Correlation between MRI findings (Henderson score) and clinical outcome (ICRS and IKDC score) after cartilage repair was indeed shown by Blackman et al., proving it could be a good, non-invasive follow-up after surgery [8]. At the same time, little or no correlation between postoperative MRI findings and clinical outcome was reported in the systematic review and meta-analysis by de Windt et al. [9]. Further, to the best of our knowledge, the value of preoperative MRI in defining the need for a sandwich procedure has not been addressed.

This study fills that gap. It evaluates whether MRI is able to predict the need for a sandwich procedure in order to help optimise the preoperative planning and consent of patients scheduled for ACI.

2. Material & methods

Preoperative MRI images were analysed for all patients between 2009 and 2014 at our institute who were treated for a cartilage defect. These MRI images, in addition to physical examination and patient history, were used for initial indication of ACI surgery. This search yielded 234 patients who underwent ACI surgery. Forty nine patients were excluded because of poor MRI acquisition quality (metal artifact, distortions etc.) and absence of correct MRI sequences. A total of 185 patients who underwent ACI were included. This population consisted of 109 men and 76 women, with mean age 31.6 years (range 18–49). Their surgeries had been performed by 2 experienced surgeons.

Preoperative MRI scans were scored by four independent observers (2 experienced radiologists, 1 experienced resident radiologist and 1 experienced orthopedic resident) blinded for the procedure (ACI or sandwich procedure) used. The MRI images were acquired in coronal, transversal and sagittal planes using a 1.5T or 3T MRI scanner (Philips Achieva, Best, The Netherlands). A dedicated 8-channel knee coil was used on the 1.5T scanner and a 16-channel knee coil was used on the 3T scanner. Available MRI sequences on the 1.5T scanner included proton density (PD) images with voxel size = $0.5 \times 0.5 \times 3$ mm, TR/TE = 4000/12 ms (or DUAL TSE TR/TE = 2300/100), FOV = 170×170 mm, FA = 90; T2 images with fat suppression using SPAIR (Spectral Attenuation Inversion Recovery), voxel size = $0.5 \times 0.5 \times 3$ mm, TR/TE = 3200/60 ms, FOV = 170×170 mm, FA = 90; and T1 images with voxel size = $0.4 \times 0.4 \times 3$ mm, TR/TE = 540/15, FOV = 140×140 mm and FA = 90. On the 3T scanner the sequences were PD images with voxel size = $0.3 \times 0.3 \times 3$ mm, TR/TE = 6000/25, FOV = 150×150, FA = 90; And T2 SPAIR images with voxel size = $0.3 \times 0.3 \times 3$ mm, TR/TE = 5450/62, FOV 150×150 mm, FA = 90.

The observers used the MRI to assess both the cartilage and the underlying bone quality. The observers scored both morphology and signal intensities. Initially, consensus between the observers was reached on how to score the MRI images based on 4 datasets in 2 separate sessions. They evaluated the following parameters: (1) The presence of a full thickness cartilage defect (yes/no), (2) the status of subchondral lamina, the bony interface or plate between cartilage and subchondral bone (intact yes/no), (3) status of subchondral bone (intact yes/no) and (4) presence of bone marrow edema. Their expert opinion was also included in the analysis by asking each observer to decide whether they would perform a sandwich procedure based on the MRI alone. Finally, the depth of the defect was calculated on the PD images. This was measured from the 'interpolated' articulating surface perpendicular to the bottom of the bony lesion (Fig. 1).

Data was analysed using IBM SPSS statistics version 21. Receiver Operating Curve (ROC) analysis was used to determine whether the used MRI parameters could predict a sandwich procedure. The area under the curve (AUC) for all parameters (i.e. lamina or bone defect) and eventual sandwich procedure were calculated. For the depth of defect, optimal cut-off values were determined based on the AUC. Kappa values were calculated to test observer agreement. Kappa values were interpreted as follows: <0.20 poor agreement, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good and 0.81–1.00 very good agreement [10].

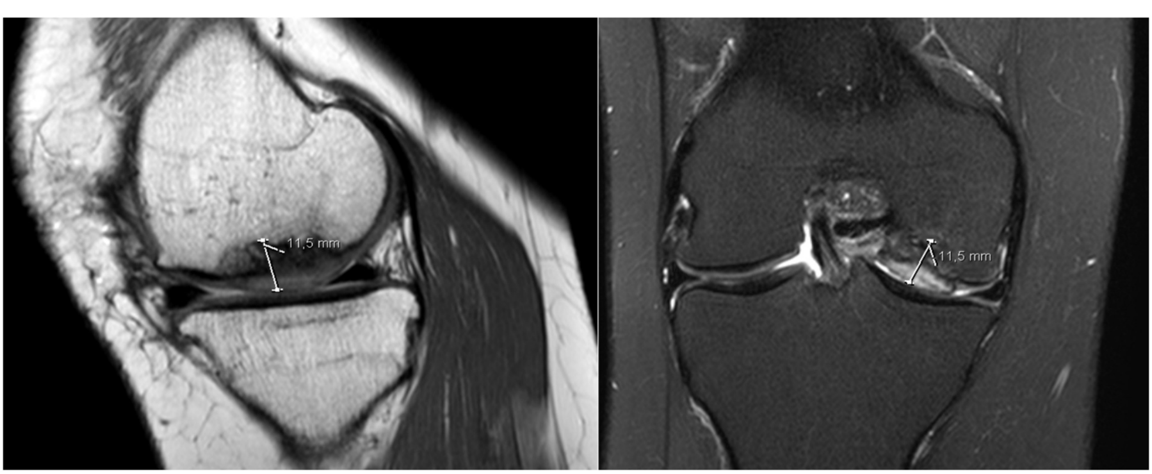

Fig. 1. Defect depth. Depth measurements on sagittal (left) and coronal (right) MRI images.

Table 1
Summary of the results of the 5 scored parameters showing the mean AUC, inter-observer agreement (Kappa) and the average absolute scores (number of patients) of all 4 observers.

Parameters	Mean AUC (range)	Mean Kappa (range)	Average absolute score
Full Thickness defect	0.61 (0.51–0.68)	0.29 (0.11–0.48)	146 (125–174)
Lamina defect	0.77 (0.74–0.80)	0.69 (0.63–0.76)	90 (79–106)
Sub. Bone defect	0.75 (0.73–0.79)	0.64 (0.49–0.74)	90 (71–106)
Bone Marrow Edema	0.66 (0.61–0.68)	0.54 (0.41–0.60)	121 (116–130)
Expert Opinion	0.80 (0.79–0.84)	0.64 (0.55–0.73)	42 (35–55)

3. Results

Of the 185 patients undergoing ACI, 20 (10.9%) had a sandwich procedure. Forty two patients (22.7%) had a grade III cartilage defect and 143 (77.3%) had a grade IV cartilage defect according to the ICRS Hyaline Cartilage Classification System [11].

3.1. Full-thickness cartilage defect

The ROC curve showed an AUC ranging from 0.51 to 0.68 (mean 0.61), which corresponds with poor accuracy (Table 1). Kappa values ranged 0.11–0.48 (mean 0.29), indicating fair agreement between the observers.

3.2. Presence of a lamina defect

The ROC curve showed an AUC ranging from 0.74 to 0.80 (mean 0.77), which corresponds with a moderate accuracy (Table 1). Kappa values ranged 0.63–0.76 (mean 0.69), showing good agreement between observers.

3.3. Presence of a subchondral bone defect

The ROC curve showed an AUC ranging from 0.73 to 0.79 (mean 0.75) which corresponds with a moderate accuracy (Table 1). Kappa values ranged 0.49–0.74 (mean 0.64), showing good agreement between observers.

3.4. Presence of a bone marrow edema

The ROC curve showed an AUC ranging from 0.61 to 0.68 (mean 0.66), which corresponds with a poor accuracy (Table 1). Kappa values ranged 0.41–0.60 (mean 0.54), indicating moderate agreement between observers.

3.5. Expert opinion based on MRI (to perform sandwich procedure)

The mean number of sandwich procedures predicted by the 4 observers was 42 out of 185 (range: 35–55). The ROC curve showed an AUC ranging from 0.79 to 0.84 (mean 0.80), which corresponds with a good accuracy (Table 1). Kappa values ranged 0.55–0.73 (mean 0.64), indicating good agreement between the observers.

3.6. Depth of bone defect

The mean defect depth was 3.8 mm (SD ± 4.6 mm, range 0–21 mm). The depth measurements show an AUC of 0.90 (95% CI: 0.84–0.95, p = 0.001), which corresponds with an excellent accuracy. Highest sensitivity and specificity were found at a depth of 6.5 mm (sensitivity: 0.90, specificity: 0.80) (Table 2).

Table 2
Defect Depth. Highest sensitivity and specificity found at a depth of 6.5 mm (sensitivity: 0.90, specificity: 0.80).

Depth (mm)	Sensitivity	Specificity
1.0	1.00	0.564
2.5	1.00	0.570
3.5	1.00	0.594
4.5	0.950	0.622
5.5	0.900	0.733
6.5	**0.900**	**0.796**
7.5	0.800	0.836
8.5	0.550	0.891
9.5	0.400	0.945
10.5	0.350	0.970
11.5	0.300	0.970
12.5	0.250	0.976
13.5	0.250	0.988
14.5	0.200	0.994
16.5	0.150	1.00
19.5	0.100	1.00
22.0	0.00	1.00

4. Discussion

This study evaluated the use of preoperative MRI for predicting the need for a sandwich procedure for ACI. Our results show substantial inter-observer agreement and moderate prediction of the need for a sandwich procedure based on the presence of lamina and or subchondral bone defect on MRI. Depth measurements resulted in the highest AUC (0.90) with the cutoff point at 6.5 mm.

Osteochondral defects are frequently encountered in cartilage pathology and different surgical interventions, such as ACI, have been developed and are being used for treatment of defects [12]. The indication for cartilage surgery is defined by a focal (osteo)chondral defect. This indicates a defect (that can vary in size) with clear boundaries surrounded by macroscopically healthy cartilage. Joint arthroplasty or hemi-arthroplasty is performed in situations where there is a generalized cartilage degeneration affecting the whole joint compartment without clear boundaries of healthy cartilage being present. The preoperative assessment is important when deciding whether ACI will be an option. This assessment includes identifying specific defect and patient characteristics that potentially affect treatment and treatment outcome. For example, radiologic imaging is used to exclude patients with osteoarthritis (X-ray) and estimate the defect size (MRI) to choose between MF and ACI. The guideline for cartilage repair therapy according to Dutch Orthopaedic Association states that “deep” defects should be treated using the sandwich procedure. More specifically, cartilage defects with ICRS grade V (total loss of cartilage) and a depth of more than 5 mm. However, there are no criteria as to how this defect depth should be measured and it is not specified whether this is on imaging or during the surgery. Currently, this estimation of defect depth is based on surgeons expertise as an arthroscopic evaluation always precedes the final decision for treatment [5].

As Campbell et al. stated, evidence for the preoperative use of MRI in cartilage surgery is lacking [7]. In their study the size of the cartilage defect was studied to determine whether it could be estimated sufficiently on preoperative MRI when compared to the findings during arthroscopy. Overall, MRI, they found, seemed to underestimate the size of the defect, although they only measured the surface area of the lesions and did not report on the depth of any defects. Further, little or no correlation between MRI findings and postoperative clinical outcome was found by de Windt et al., in their systematic review of studies that used a variety of methods [9]. Nevertheless, MRI could be of value in defining the need for a sandwich procedure preoperatively. Another imaging modality that could also be used to assess osteochondral defects is CT imaging. Due to its high spatial resolution and good visualisation of bony structures an accurate assessment of the subchondral defect depth is possible. However, evaluation on CT scans introduces radiation to patients and increases medical costs as it would mean an additional scan besides the current work-up. In our standard clinical work-up, MRI is used for the evaluation of (osteo)chondral defects we use it to assess bony structures as well.

In this study lamina and subchondral bone defects on MRI received substantial inter-observer agreement and moderately predicted the need for a sandwich procedure. Assessing the presence of lamina defects is difficult and can be poor due to the performed imaging modality. Voxel size and partial volume effects on MRI greatly influence accurate assessment of the lamina, a thin layer which consists of only 1–2 pixels.

The presence of full thickness defects and bone marrow edema was less accurate for predicting a sandwich procedure. As most full thickness cartilage defects still have a (partially) intact and or sufficient subchondral bone plate, an ACI procedure alone is adequate, with no need for a bone graft.

Depth measurements resulted in the highest AUC (0.90), which is an excellent accuracy. This is in line with the data described by previous studies (Brittberg et al. and Peterson et al.) [3,4]. The optimal cutoff point for predicting the need for a sandwich procedure was at 6.5 mm depth of the lesion (90% sensitivity, 80% specificity).

Expert opinion concerning the need for a sandwich procedure had the second highest AUC (0.80). However, experts may be biased by only taking the defect depth or size into consideration during their quick visual inspection of the MRI images, and thus, their opinion can be based on a less accurate depth assessment. Additionally, experts opinion showed no significant difference in inter-rater agreement. This shows that morphological assessment of cartilage defects alone by the radiologist observers is as predictive for eventual sandwich procedure as the combination of morphological and functional assessment of the cartilage defect done by the orthopaedic surgeon.

These results show that MRI parameters can be a predictor for deciding the need for a sandwich procedure. This can help in alternative planning of the surgery and better preparation for the surgeon and patient in terms of information, expectation management and consent. As the healthcare system moves increasingly towards personalized care [13], preoperative MRI scans and imaging can be used to plan the surgery and tailor treatment to the specific patient. The MRI defect depth can be used to decide which treatment the patient should undergo. In case of large defects, data from the MRI can be derived to calculate the defect volume for autologous bone grafting or even in case of very large defects the use of allografts [14,15]. Further, preoperative imaging can play a role when daily practice includes emerging technologies such as bioprinting and be used to produce three-dimensional models of the osteochondral defect to manufacture patient-specific osteochondral plugs or customized (bio)implants [16,17].

4.1. Strengths

This is the first study investigating MRI as a diagnostic tool in predicting the need for a sandwich procedure.

4.2. Limitations

First, it should be considered that the results shown here are based on single-centre data and that surgeon experience and bias can play a crucial role. The surgeons used the MRI when deciding whether or not to operate. This incorporation bias cannot be prevented, but we used four observers uninvolved in the decision process and we blinded these observers to the type of surgery chosen. Second, the sample size was fairly small and with 20 ACIs we had limited power. Therefore, the 6.5 mm cut-off we found needs external validation, preferably in a multi-centre and international cohort. Third, we used routine clinical MRI scans which included 1.5T as well as 3T scans, although both are able to accurately visualise the structures that were evaluated in the study. Additionally, Data was evaluated by radiologists and an orthopaedic resident instead of orthopaedic surgeons only. However, the inter-observer-agreement is in line with similar imaging studies. We do not believe that the observer characteristics highly influenced these results.

In conclusion, our results show that both the integrity of the subchondral layer on MRI and expert opinion moderately predict the need for an eventual autologous bone graft to augment ACI, whereas a lesion depth above 6.5 mm accurately predicts the need for a sandwich procedure.

Disclosure

No conflicts of interest to disclose.

Authors contributions

RN contributed to conception and design of the study and has written the manuscript. JB contributed to conception and design of the study and was involved in data collection and drafting. PJ contributed in design, data collection and in particular the statistical analysis and was involved revising the manuscript. TW and TL were involved in data collection and revising the manuscript. DS was involved in conception and design of the study and contributed to drafting and revising the manuscript. All authors have read and approved the final submitted manuscript.

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