MR imaging of BioCartilage augmented microfracture surgery utilizing 2D MOCART and KOOS scores

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ARTICLE INFO

Article history:

Received 13 October 2016

Received in revised form 10 August 2017

Accepted 19 August 2017

Available online 24 August 2017

Keywords:

Fibrocartilage

BioCartilage

MRI

MOCART

KOOS

ABSTRACT

Objectives: BioCartilage is a novel scaffold-based microfracture augmentation technique that has been shown to aid in chondrogenic differentiation of adult progenitor cells resulting in formation of more hyaline-like cartilage. As this cartilage repair technique becomes more commonplace, it is essential that the musculoskeletal radiologist and orthopedic surgeon gain familiarity with the surgical technique and its post-operative MR imaging findings.

Methods: We present several case studies regarding MRI findings (modified clinical 2D MOCART) and clinical outcome (KOOS) scores in patients who have undergone this novel surgical procedure. For data analysis KOOS scores were dichotomized to scores greater or less than 80, and MOCART scores were dichotomized to scores greater or less than 50. A fisher exact test was then performed to determine if there was any correlation between parameters of the modified 2D MOCART and KOOS scores (Tables 2 and 3).

Results: Marrow elements travel through the microfracture holes and interact with the scaffold created by BioCartilage, rather than creating their own fibrin scaffold, as is typically anticipated from a marrow stimulation procedure. Interestingly, the amount defect fill, presence of an intact surface, intact subchondral bone, or lack of effusion did not correlate with positive outcomes. Parameters that trended towards significance included presence of adhesions and subchondral lamina. Completeness of cartilage interface, homogeneity, and signal intensity also failed to reach statistical significance. In our experience, patients that demonstrated mild repair tissue surface irregularity, but with preservation of greater than 50% thickness compared to surrounding native cartilage, mild irregularity of subchondral plate, with vertical low signal intensity lines (sequela of prior microfracture surgery), and mild or no bone marrow edema pattern demonstrated higher KOOS scores.

Conclusion: Biocartilage in conjunction with microfracture is an encouraging cartilage restoration technique that promotes regeneration of more robust hyaline-like cartilage compared to the fibrocartilage formed after conventional microfracture. The T2 mapping properties of the repair tissue after successful BioCartilage augmented microfracture surgery are very similar to that of the adjacent native cartilage. Although there appear to be characteristic trends in a successful repair, further research is warranted to elucidate any correlations between specific characteristics of the repair and patient clinical outcomes.

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1. Introduction

Symptomatic full thickness articular cartilage defects often result in significant morbidity.¹ There are various techniques that have been employed to treat chondral lesions.² Microfracture is a common first-line treatment for patients with cartilage defects.^{3,4} The technique aims to create a clot in the chondral lesion and populate it with platelets, growth factors, and bone marrow-

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derived stem cells. BioCartilage (Arthrex, Naples, FL) as an adjunct to standard microfracture with marrow stimulation surgery has emerged as a promising technique for cartilage restoration. As this novel cartilage repair technique becomes more commonplace, it is essential that the musculoskeletal radiologist and orthopedic surgeon gain familiarity with the surgical technique and its post-operative MR imaging findings. We present several case studies regarding MRI findings in patients who have undergone this novel surgical procedure.

2. Rationale for microfracture and biocartilage

Currently there are multiple and evolving techniques to repair cartilaginous lesions including microfracture, abrasion arthroplasty, osteochondral grafting, and cell based treatments.⁵ Microfracture techniques are indicated in lesions 1–4 cm² size.² In the procedure, a curette is used to trim any soft and fissured cartilage along the defect rim to create vertical shoulders of mechanically stable cartilage.³ The defect is debrided to the layer of the calcified cartilage without violating the subchondral plate. After thorough debridement, multiple defects are created in the subchondral plate with a microfracture awl. This allows marrow elements to gain access to the defect stimulating formation of reparative tissue. Fibrocartilaginous tissue formation subsequently occurs.

Traditional microfracture techniques however result in formation of fibrocartilaginous tissue that is not as robust as native hyaline cartilage.⁶ Novel techniques, however, have emerged to promote hyaline tissue formation. Some adjuncts aim to enhance the healing potential in the defect by repopulating it with cultured mesenchymal stem cells.⁷ BioCartilage is a scaffold-based augmentation technique that has been shown to aid in chondrogenic differentiation of adult progenitor cells resulting in formation of more hyaline-like cartilage.⁸

3. Evaluation of cartilage repair

Arthroscopic visualization, although invasive, is the most direct method for evaluation of cartilage defects and any subsequent repair. High resolution MR imaging however provides a non-invasive method of evaluation of the morphologic status of cartilage defects and the repair tissue throughout the postoperative period.^{9,10} The MOCART (Magnetic Resonance Observation of Cartilage Repair Tissue) grading system provides the most complete definition of pertinent variables for the description of articular cartilage repair tissue.¹¹ Several variables have been found to have a statistically significant correlation with clinical outcomes.¹² Successful repairs will demonstrate complete filling of the defect, homogenous structure of repair tissue, and intact subchondral bone. Conversely failed repairs will demonstrate incomplete filling of the defect, nonhomogenous or cleft tissue formation, subchondral edema, granulation tissue, cysts or sclerosis.¹² A modification of the clinical 2D MOCART score (Table 1) has been shown to have high intra and inter observer reliability, and was applied to the following cases.¹³

The knee injury osteoarthritis outcome score (KOOS) is a 42 item self-administered questionnaire that assesses patient outcomes in pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life.¹⁴ Scores are transferred onto a 0–100 scale, with zero representing extreme knee problems and 100 representing no knee problems.¹⁴ The

Table 1

Modification of the clinical 2D MOCART score developed by Marlovits et al.^{11–13}

Parameter	Item	Points
Defect Fill	Subchondral Bone Exposed	0
	Incomplete <50%	5
	Incomplete >50%	10
	Complete	20
Cartilage Interface	Hypertrophy	15
	Complete	15
	Demarcating Border Visible	10
	Defect Visible <50%	5
Surface	Defect Visible >50%	0
	Surface Intact	10
	Surface Damaged <50% of Depth	5
Adhesions	Surface Damaged >50% of Depth	0
	Yes	5
Structure	No	0
	Homogenous	5
Signal Intensity	Inhomogenous or Cleft Formation	0
	Normal	30
	Nearly Normal	10
Subchondral Lamina	Abnormal	0
	Intact	5
Subchondral Bone	Not Intact	0
	Intact	5
Effusion	Granulation Tissue, Cyst, Sclerosis	0
	No Effusion	5
Total Points	Effusion	0
		100

KOOS is a valid, reliable and responsive instrument that can be used for longitudinal follow up of various knee injuries.^{14–16}

The following cases describe post-surgical MRI findings using the 2D MOCART score of patients who underwent Biocartilage in conjunction with a microfracture procedure as well as their clinical outcome (KOOS) scores.

4. Characteristic preoperative and postoperative findings

Case 1

(A) Pre-operative axial proton density MRI in a 40 year-old male demonstrating a full thickness (grade 4) chondral defect along the central to lateral margin of the trochlea (yellow arrows). (B) 8 month post-operative axial proton density MRI following arthroscopic debridement and bone marrow stimulation using BioCartilage augmented microfracture technique. Proton density images demonstrate regenerative tissue in the microfractured area. Repair tissue is often inhomogenous and of slightly lower signal intensity than the surrounding native cartilage. Patient KOOS: 93. Modified 2D MOCART score: 65.

Case 2

A 39-year-old man with a grade 4 chondral lesion along the lateral trochlear facet. Pre-operative (A,B) and post-operative (D,E) axial MR images. Arthroscopic images of the chondral lesion (C) and BioCartilage microfracture repair site (F). The defect has completely filled in with repair tissue. The repair tissue is of lower signal intensity than the surrounding native cartilage. There is complete integration of tissue with both the subchondral bone and surrounding native cartilage. There is slight central loss of thickness at the repair site, but not greater than 50%. There is irregularity and mild sclerosis of the subchondral bone as a result of prior microfracture. Patient KOOS: 90. Modified 2D MOCART score: 50.

Case 3

(A,B) Pre-operative axial proton density MR images demonstrating a full thickness chondral defect (red arrows) within the lateral trochlear facet in a 13 year-old male. (C,D) 6 month post-operative MRI after microfracture with Biocartilage repair. Note the residual subchondral edema resulting from microfracture technique (yellow arrowhead). The surface of the repair tissue is

slightly irregular and of uneven thickness over the microfractured area (red arrows figure C). Integration of the repair tissue to the native cartilage is focally incomplete at the border, with interspersed bridging and discontinuity. There is a junctional fissure that is more easily visible on the fat suppressed images (yellow arrow, figure D).

(A) Pre-operative sagittal proton density-weighted image demonstrating a full thickness chondral defect (yellow arrows). (B) Post-operative sagittal proton density-weighted image demonstrates the operative bed filled in with reparative tissue that has integrated. The repair tissue is isointense to the surrounding cartilage on proton density images, but demonstrates slight surface irregularity (arrowhead). However, there is preservation of at least 50% of its thickness compared to the surrounding native cartilage. There is persistent irregularity of the subchondral plate from prior microfracture, but without subchondral cysts or repair tissue detachment (blue arrows). (C) Color T2 cartilage mapping confirms majority of the repair tissue is biochemically comparable to that of the adjacent native cartilage (red arrows figure C). Patient KOOS: 87. Modified 2D MOCART score: 70.

Case 4

(A) Pre-operative sagittal proton density MR image demonstrating full-thickness chondral delamination (arrows) along the anterolateral margin of the trochlea, with underlying irregularity of the subchondral plate in a 36 year-old male status post skiing injury. (B) Sagittal proton density MRI 24 months post-operatively following BioCartilage augmented repair. Note the subchondral microfracture defects. There is complete integration of the repair tissue both with the underlying subchondral bone and its surrounding borders, with adequate preservation of its thickness along the superior and middle margins (blue arrows). There is poor incorporation of the repair tissue with the native cartilage along its inferior border (red arrows). (C) Post-operative sagittal T2 color map demonstrates slightly greater T2 relaxation times at the repair site due to the still-altered ultrastructure of the repair tissue. There is also a relatively homogenous T2 mapping appearance (yellow arrows). This area demonstrates an inhomogenous T2 color map appearance (red arrows).

Sagittal T2 map with illustration of region of interest (ROI) analysis. The repair tissue (RT) was 47.5 ms, and the adjacent healthy cartilage (HC) was 37.2 ms. The T2 properties of the repair tissue after BioCartilage augmented microfracture surgery in this case are slightly prolonged compared to those of the adjacent native cartilage. This is due to the incomplete integration of the repair tissue along the inferior junctional border of the microfracture site (yellow arrows). The patient KOOS: 80. Modified 2D MOCART score: 70.

Case 5 (Poor Clinical Outcome)

(A) Proton density MR demonstrates poor integration of the repair tissue with the underlying subchondral bone (yellow arrows) and the surrounding native cartilage (blue arrows). (B) Fat suppressed PD demonstrates that the subchondral bone is very irregular, with bone marrow edema pattern (red arrows). The repair tissue has irregular borders, and is of inhomogeneous signal intensity (purple arrows). Patient KOOS: 24. Modified 2D MOCART score: 10.

Case 6 (Poor Clinical Outcome)

(A) Axial fat suppressed PD pre-operative MR in a 42-year-old woman demonstrates a large full-thickness chondral defect (grade 4) with a joint effusion (red star). (B) Axial 19 month post-operative MRI shows irregularity of the subchondral bone, with marrow edema pattern and subchondral cyst formation (red arrows). There is incomplete (poor) filling of the defect, predominately centrally, and the repair tissue has inhomogenous signal intensity and thickness (blue arrows). There is a joint effusion (red star). Patient KOOS 24. Modified 2D MOCART score: 20.

5. Discussion

BioCartilage is a dehydrated micronized allogeneic cartilage extracellular matrix that contains type II collagen, proteoglycans (aggrecan and decorin), and cartilaginous growth factors. It provides scaffolding over a microfracture defect, signals autologous cellular interactions within the scaffold, and promotes regeneration of more hyaline-like cartilage. This results in improved quality of the repair tissue that is formed after bone marrow stimulation compared with microfracture alone.¹⁷ BioCartilage is often used in conjunction with autologous blood containing platelet-rich plasma (PRP).¹⁸ Marrow elements travel through the microfracture holes and interact with the scaffold created by BioCartilage, rather than creating their own fibrin scaffold, as is typically anticipated from a marrow stimulation procedure. An in vivo baboon model demonstrated gross appearance of hyaline cartilage at early time points as well as newly formed cartilage cells with normal appearing proteoglycan content.⁸ The potential complications of this technique are rare and are similar to those of standard arthroscopic procedures. The inclusion criteria for Biocartilage implantation is generally the same as for microfracture surgery in any of the three knee compartments. Biocartilage is potentially useful in chondral lesions greater than 4 cm², which are not amenable for Osteo-articular Transfer System (OATS) surgery. For patients undergoing microfracture, the expected success and failure rate also is dependent on patient factors including size and location of the lesion, number of lesions, and patient age.¹⁹ Similar to other chondroplasty procedures, follow-up post-operative MRI's following Biocartilage implantation surgery are not routinely performed, unless there is re-injury, new or persistent symptoms. Due to the cost of allograft cartilage and the instrumentation kit, Biocartilage procedures are generally more expensive than microfracture alone. However, given that it is routinely performed as a single stage operation, Biocartilage implantation is generally less expensive than other staged articular cartilage restoration procedures, such as Autologous Chondrocyte Implantation (ACI) surgery (Figs. 1 and 2).

MR evaluation is the non-invasive gold standard for assessment of cartilaginous defects and repair procedures.²⁰ Advantages include evaluation of deeper structures including subchondral bone, cysts, and deep osteophytes.²¹ Cartilage specific sequences

Fig. 1. Gross appearance of hyaline-like cartilage at early time points.⁸

allow for optimal evaluation of gross structure, morphology, and tissue composition. Currently the proton density-weighted fast spin-echo (FSE-PD) and three-dimensional (3D) fat-suppressed (FS) T1-weighted gradient-echo (3D-FS T1W GRE) sequences are most commonly used.²² Other techniques such as delayed gadolinium enhanced magnetic resonance imaging of cartilage (dGEMRIC), and T1rho mapping are used to evaluate depletion of proteoglycans in repair tissue.²³ T2 mapping is used to determine the degree of organization within the collagen network of cartilage, however a limitation is it does not correlate with collagen content.²³ The scoring systems applied also need to accurately reflect the parameters of cartilage repair to allow for comparison

across treatment groups. The modified clinical 2D MOCART scoring system has demonstrated the highest intra and inter observer reliability for “total points,” and good homogeneity among individual items.¹³ Macroscopic scoring provides an overall assessment of the repair tissue as a whole. Limitations however include an inability to distinguish between major and minor disruptions in repair tissue.²⁴ With these evolving MRI techniques and scoring systems their correlation to clinical outcomes is still debated. A recent systematic review sought to determine the clinical and radiologic outcome of morphological MRI in cartilage repair. Despite its advantages, conclusive evidence to determine whether morphological MRI is reliable in predicting clinical outcome after cartilage repair currently is lacking.²¹ Ultimately its additional value in determining clinical outcome has yet to be determined.

The purpose of this case series was to present the MRI findings of patients undergoing a novel adjunct to traditional microfracture. For data analysis KOOS scores were dichotomized to scores greater or less than 80, and MOCART scores were dichotomized to scores greater or less than 50. A fisher exact test was then performed to determine if there was any correlation between parameters of the modified 2D MOCART and KOOS scores (Tables 2 and 3). Interestingly, the amount defect fill, presence of an intact surface, intact subchondral bone, or lack of effusion did not correlate with positive outcomes. Parameters that trended towards significance included presence of adhesions and subchondral lamina. Completeness of cartilage interface, homogeneity, and signal intensity also failed to reach statistical significance. Despite these variables failing to reach statistical significance, larger patient populations are necessary to further elucidate any clinical correlations as our sample size was small. In our experience patients that demonstrated mild repair tissue surface irregularity, but with preservation of greater than 50% thickness compared to surrounding native cartilage, mild irregularity of subchondral plate, with vertical low signal intensity lines (sequela of prior

Fig. 2. 12 weeks newly formed cartilage cells, normal appearing proteoglycan content.⁸

Table 2

Modified 2D MOCART Score and KOOS Score in Each Case.

	Modified 2D MOCART Score	KOOS Score
Case 1	Total Score: 65 Complete fill (20), Complete cartilage interface (15), Surface intact (10), Yes adhesions (5), inhomogenous structure (0), signal intensity nearly normal (10), subchondral lamina intact (5), subchondral bone sclerosis (0), effusion present (0)	93
Case 2	Total Score: 50 Incomplete fill >50%(10), Complete cartilage interface (15), Surface damaged <50% depth (5), Yes adhesions (5), inhomogenous structure (0), signal intensity nearly normal (10), subchondral lamina not intact (0), subchondral bone sclerosis (0), no effusion present (5)	90
Case 3	Total Score: 70 Incomplete fill >50%(10), incomplete cartilage interface with demarcating border visible (10), Surface damaged <50% depth (5), Yes adhesions (5), homogenous structure (5), signal intensity normal (30), subchondral lamina intact (5), subchondral bone sclerosis (0), effusion present (0)	87
Case 4	Total Score: 70 Incomplete fill >50%(10), incomplete cartilage interface with demarcating border visible (10), Surface damaged <50% depth (5), Yes adhesions (5), homogenous structure (5), signal intensity normal (30), subchondral lamina intact (5), subchondral bone sclerosis (0), effusion present (0)	80
Case 5	Total Score: 10 Incomplete fill <50%(5), cartilage interface with visible defect <50% (5), Surface damaged >50% depth (0), no adhesions (0), inhomogenous structure (0), signal intensity abnormal (0), subchondral lamina not intact (0), subchondral bone sclerosis and edema (0), effusion present (0)	24
Case 6	Total Score: 20 Incomplete fill <50%(5), cartilage interface with demarcating border visible (10), Surface damaged >50% depth (0), yes adhesions (5), inhomogenous structure (0), signal intensity abnormal (0), subchondral lamina not intact (0), subchondral bone sclerosis and cysts (0), effusion present (0)	24

Table 3

Association of Modified 2D MOCART Total, Subscores, and KOOS Scores.

Total Score	P = 0.067
Fill	P = 1.0
Complete Cartilage	P = 0.47
Surface Intact	P = 1.0
Adhesions	P = 0.33
Homogeneity	P = 0.47
Signal Intensity	P = 0.47
Lamina Intact	P = 0.47
Subchondral Bone Intact	P = 1.0
No Effusion Present	P = 1.0

microfracture surgery), and mild or no bone marrow edema pattern demonstrated higher KOOS scores.

6. Conclusion

Biocartilage in conjunction with microfracture is an encouraging cartilage restoration technique that promotes regeneration of more robust hyaline-like cartilage compared to the fibrocartilage formed after conventional microfracture. The T2 mapping properties of the repair tissue after successful BioCartilage augmented microfracture surgery are very similar to that of the adjacent native cartilage. It is essential for the radiologist and orthopedic surgeon to recognize the imaging characteristics that determine a successful or failed chondroplasty and the modified 2D MOCART provides a useful tool to assess the global quality of repair tissue. Although there appear to be characteristic trends in a successful repair, further research is warranted to elucidate any correlations between specific characteristics of the repair and patient clinical outcomes.

Conflict of interest

None.

References

- Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31,516 knee arthroscopies. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc.* 1997;13(August (4)):456–460.
- Bedi A, Feeley BT, Williams RJ. Management of articular cartilage defects of the knee. *J Bone Joint Surg Am.* 2010;92(April (4)):994–1009.
- Steadman JR, Rodkey WG, Briggs KK, Rodrigo JJ. The microfracture technic in the management of complete cartilage defects in the knee joint. *Orthopade.* 1999;28(January (1)):26–32.
- Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc.* 2003;19(June (5)):477–484.
- Farr J, Cole B, Dhawan A, Kercher J, Sherman S. Clinical cartilage restoration: evolution and overview. *Clin Orthop.* 2011;469(October (10)):2696–2705.
- Furukawa T, Eyre DR, Koide S, Glimcher MJ. Biochemical studies on repair cartilage resurfacing experimental defects in the rabbit knee. *J Bone Joint Surg Am.* 1980;62(January (1)):79–89.
- Wong KL, Lee KBL, Tai BC, Law P, Lee EH, Hui JHP. Injectable cultured bone marrow-derived mesenchymal stem cells in varus knees with cartilage defects undergoing high tibial osteotomy: a prospective, randomized controlled clinical trial with 2 years' follow-up. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc.* 2013;29(December (12)):2020–2028.
- Malinin T, Temple HT, Carpenter EM. Induction of regeneration of articular cartilage defects by freeze-dried articular cartilage allograft. .
- Eckstein F, Burstein D, Link TM. Quantitative MRI of cartilage and bone: degenerative changes in osteoarthritis. *NMR Biomed.* 2006 Nov;19(7):822–854.
- Chang G, Sherman O, Madelin G, Recht M, Regatte R. MR imaging assessment of articular cartilage repair procedures. *Magn Reson Imaging Clin N Am.* 2011;19 (May (2)):323–337.
- Marlovits S, Striessnig G, Resinger CT, et al. Definition of pertinent parameters for the evaluation of articular cartilage repair tissue with high-resolution magnetic resonance imaging. *Eur J Radiol.* 2004;52(December (3)):310–319.
- Marlovits S, Singer P, Zeller P, Mandl I, Haller J, Trattinn S. Magnetic resonance observation of cartilage repair tissue (MOCART) for the evaluation of autologous chondrocyte transplantation: determination of interobserver variability and correlation to clinical outcome after 2 years. *Eur J Radiol.* 2006;57(January (1)):16–23.
- Goebel L, Orth P, Müller A, et al. Experimental scoring systems for macroscopic articular cartilage repair correlate with the MOCART score assessed by a high-field MRI at 9.4 T—comparative evaluation of five macroscopic scoring systems in a large animal cartilage defect model. *Osteoarthritis Cartil OARS Osteoarthritis Res Soc.* 2012;20(September (9)):1046–1055.
- Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynon BD. Knee injury and osteoarthritis outcome score (KOOS)—development of a self-administered outcome measure. *J Orthop Sports Phys Ther.* 1998;28(August (2)):88–96.
- Roos EM, Roos HP, Ekdahl C, Lohmander LS. Knee injury and osteoarthritis outcome score (KOOS)—validation of a Swedish version. *Scand J Med Sci Sports.* 1998;8(December (6)):439–448.
- Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes.* 2003;1:64.
- Fortier LA, Barker JU, Strauss EJ, McCarrel TM, Cole BJ. The role of growth factors in cartilage repair. *Clin Orthop.* 2011;469(October (10)):2706–2715.
- Milano G, Sanna Passino E, Deriu L, et al. The effect of platelet rich plasma combined with microfractures on the treatment of chondral defects: an experimental study in a sheep model. *Osteoarthritis Cartil OARS Osteoarthritis Res Soc.* 2010;18(July (7)):971–980.
- Oussedik S, Tsitskaris K, Parker D. Treatment of articular cartilage lesions of the knee by microfracture or autologous chondrocyte implantation: a systematic

- review. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc*. 2015;31(April (4)):732–744.
20. Crema MD, Roemer FW, Marra MD, et al. Articular cartilage in the knee: current MR imaging techniques and applications in clinical practice and research. *Radiogr Rev Publ Radiol Soc N Am Inc*. 2011 Feb;31(1):37–61.
21. de Windt TS, Welsch GH, Brittberg M, et al. Is magnetic resonance imaging reliable in predicting clinical outcome after articular cartilage repair of the knee? A systematic review and meta-analysis. *Am J Sports Med*. 2013 Jul;41(7):1695–1702.
22. Recht M, Bobic V, Burstein D, et al. Magnetic resonance imaging of articular cartilage. *Clin Orthop*. 2001;(October (391 Suppl)):S379–S396.
23. Ronga M, Angeretti G, Ferraro S, De Falco G, Genovese EA, Cherubino P. Imaging of articular cartilage: current concepts. *Joints*. 2014;2(September (3)):137–140.
24. Smith GD, Taylor J, Almqvist KF, et al. Arthroscopic assessment of cartilage repair: a validation study of 2 scoring systems. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc*. 2005;21(December (12)):1462–1467.