A Retrospective Study Assessing Safety and Efficacy of Bipolar Radiofrequency Ablation for Knee Chondral Lesions

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Abstract

Objective: Bipolar radiofrequency (bRF) ablation is gaining popularity as a treatment modality for unstable knee chondral lesions of the knee. Limited reports of osteonecrosis and chondrolysis have been published; however, there is little data examining the safety of this treatment in larger series. This study aims to evaluate the safety and efficacy of bRF in the treatment of chondral lesions encountered during knee arthroscopy. **Design:** A retrospective evaluation of adverse outcomes in patients that underwent treatment of chondral lesions using bRF was undertaken. Secondary outcome measures included change in patient reported outcome scores and its correlation to patient demographics and quality of chondral and meniscal lesions using Chondropenia Severity Score. **Results:** Only 2.2% and 2.7% of the patients had a postoperative complication or required a reoperation, respectively. None of the complications were directly related to the use of bRF. A statistically significant difference was observed when comparing pre- and postoperative scores in all normalized categories ($P < 0.0001$). No statistically significant correlation was found between change in self-reported scores and Chondropenia Severity Score. **Conclusion:** Bipolar radiofrequency ablation is a safe modality in treatment of chondral lesions.

Keywords

knee arthroscopy, chondroplasty, chondral lesions, radiofrequency ablation

Introduction

Articular cartilage lesions and meniscal tears are frequently found during knee arthroscopic surgery. Chondral lesions are encountered in more than 60% of knee arthroscopies and 60% of those lesions are associated with meniscal injury.^{1–3} The aforementioned pathologies result in the degenerative process in the knee joint due to the loss of the protective load force distribution and are associated with the development of knee osteoarthritis.^{4,5} Despite growing evidence that arthroscopic debridement of degenerative meniscal tears has minimal beneficial effect when compared with nonoperative treatment,^{6,7} there is less high-quality evidence on the efficacy of operative treatment versus conservative management for unstable chondral lesions.^{7,8} Arthroscopic treatment for unstable chondral lesions involves debridement, traditionally using a basket punch and/or a mechanical shaving device (MSD). However, it is difficult to achieve smooth articular surface using these mechanical instruments with the potential of removing normal underlying cartilage.^{9,10}

In recent times, bipolar radiofrequency (bRF) ablation has gained popularity in arthroscopic knee surgery as a

treatment modality for chondral lesions. Voloshin *et al.*¹¹ showed in a second-look arthroscopic evaluation that only 3 out of 25 lesions treated with bRF demonstrated progression and more than 50% showed partial or complete filling of the originally treated defect. This study was over a short period and repeat arthroscopy was conducted on only a small sample of the cohort. Spahn *et al.* showed superior results 4 years and 10 years postoperatively in patients with grade 3 chondral lesions treated with bRF versus MSD.^{10,12,13} A systematic review by Rocco *et al.* in 2016 including 10 studies, 6 of which used bRF, showed that radiofrequency ablation provides significant better clinical outcomes in treatment of chondral defects over MSD with low complication rates.⁸

Thermal chondroplasty using radiofrequency ablation carries concerns about the risk of osteonecrosis, chondrolysis, and progression of partial thickness chondral lesions.

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Bonutti *et al.* related the use of radiofrequency as a cause of osteonecrosis in 10 patients.¹⁴ A correlation between chondrocyte death with exposure temperature of $>50^{\circ}\text{C}$ and length of exposure was reported.¹⁵ Hogan and Diduch reported a case with progression of partial thickness chondral lesion treated with bRF on a second-look arthroscopy.¹⁶ On the other hand, *in vitro* assessment by Amiel *et al.* showed that with bRF probes they were able to provide a well-controlled debridement. A defined margin of chondrocyte death extended only to 200 μm with no significant effect on adjacent tissue metabolic activity.¹⁷

Currently, no large longitudinal studies exist looking at outcomes for patients treated with bRF for arthroscopic knee chondroplasty. Particularly, there are no studies evaluating safety with this treatment tool. Hence, we aim to undertake a retrospective analysis of all patients undergoing knee arthroscopic chondroplasty using bRF ablation and report on complications, reoperation rates, and outcomes. The hypothesis of this study is that the use of bRF ablation therapy to treat chondral lesions of the knee is a safe procedure with low morbidity.

Methods

All patients who underwent knee arthroscopic surgery with debridement of unstable chondral tissue with the use of a bRF ablation (Arthrocare Multivac 50, Smith and Nephew) were included. A retrospective analysis was undertaken using a research database and patient files. Ethics approval to conduct the analysis was granted by our local research ethics and governance unit.

Study Group

Operative details were prospectively entered into a research database. The data collection occurred over a 6-year period, during which time the indications for this surgery did not alter. Only patients who underwent a chondroplasty using a bRF device (Arthrocare bRF Multivac 50) as part of the arthroscopic procedure were analyzed. Inclusion criteria were all patients who had undergone knee arthroscopic chondroplasty with use of bRF, with or without treatment of other lesions within the knee including treatment of meniscal tears and removal of loose bodies. In general, patients only underwent arthroscopic knee surgery if they had failed a minimum period of 3 months of conservative treatment. Patients were excluded if they had undergone revision knee surgery, associated osteotomy or ligament reconstructive surgery, and associated marrow stimulation techniques such as microfracture or chondrocyte implantation.

Surgical Technique

Two fellowship-trained knee surgeons (SJM, DBC) performed all operations. The surgical technique involved an

Table 1. Chondropenia Severity Score (CSS) for the Assessment of the Number and Size of Chondral Lesions as Well as Meniscal Injury.

Compartment	Site of Lesion	Score	Scoring System
Patellofemoral joint	Patella		ICRS Grade
	Trochlea		Normal = 10
Medial compartment	Medial femoral condyle		Grade IA = 8
	Medial tibial plateau		Grade IB = 6
			Grade IIA = 5
			Grade IIB = 3
Lateral compartment	Lateral femoral condyle		Grade IIIA = 2
	Lateral tibial plateau		Grade IIIB = 1
			Grade IV = 0
Menisci	Medial meniscus		100% remaining = 20
			$>2/3$ remaining = 15
	Lateral meniscus		$1/3$ - $2/3$ remaining = 10
			$<1/3$ remaining = 5
Total score			0 remaining = 0

arthroscopic assessment using an above-knee tourniquet and normal saline irrigation. The knee articular cartilage surfaces were probed and graded with regard to chondral loss using the Outerbridge grading system.¹⁸ The Chondropenia Severity Score (CSS) (**Table 1**) was recorded for each patient. This scoring system is an arthroscopic stratification tool that summates a score range of 0 to 100 and is divided into 4 grades (A, 100-85; B, 84-71; C, 70-56; D, <56). These grades represents the quality of chondral and meniscal tissue throughout all knee compartments.¹⁹ If a meniscal tear was present, this was treated with either partial resection or repair if amendable. Only chondral lesions that demonstrated unstable tissue with flap fissuring or flap formation on probing were treated. Areas of cartilage loss without unstable tissue were not treated. Treatment to these lesions was performed independent of size.

The chondral debridement commenced with a gentle shaving using a 4 mm chondrotome if large chondral flaps were present. The bRF was then used to remove and shrink the remaining unstable chondral tissue to stabilize the margins and prevent propagation of fissures or flaps. The device was held between 1 and 3 mm off the surface of the lesion to create a plasma bubble that ablates the adjacent tissue. The probe is moved continuously in short bursts over the region of interest, so as to minimize focal or nonuniform chondral shrinkage. In order to maintain reduced joint temperatures, continuous fluid irrigation was used. For the last 3 years, intraarticular temperature monitoring was also available on the console of the device that offers instantaneous feedback of joint temperatures. Joint temperatures did not exceed 30°C on temperature monitoring. Once the debridement was completed, the chondral surface was probed to ensure that the lesion had been adequately debrided with smooth and stable margins.

Outcome Measures

Patient demographics of age, sex, side of surgery, and body mass index (BMI) were recorded. Operative data that were recorded included chondral lesion location (patella, trochlea, medial femoral condyle, medial tibial plateau, lateral femoral condyle, lateral tibial plateau), number of lesions treated, size of lesions, and whether the lesions were bipolar (kissing lesion) or unipolar. In addition, associated meniscal treatment including repair or debridement was noted. The involved meniscus was recorded as well as the percentage of meniscal tissue removed if debridement was performed. The location of the tear was also recorded (posterior root, posterior horn, body, and anterior horn).

The primary outcome measures included requirement for further surgery, any specific complications related to the use of bRF and any other complications of surgery. Secondary outcome measures were change in the Knee Osteoarthritis Outcome Score (KOOS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) between preoperative assessment and 3-month postoperative review. The KOOS system has subgroup measures quantifying knee symptoms, stiffness, pain, function, and quality of life. Individual domain score and the total score were normalized to percentages.²⁰ The Likert version of the WOMAC consists of 3 scales (Pain = 0-20; Stiffness = 0-8; and Physical Function = 0-68), with higher scores indicating worse outcomes.²¹ The total of the 3 scales was used for assessment in change between preoperative and postoperative improvement. The total change in KOOS score was correlated to CSS, age, sex, BMI, and chondral and meniscal characteristics.

Statistical Analysis

Statistical analysis was performed using IBM SPSS statistics 22 software. Descriptive statistics were used to report primary outcome measures in terms of frequency and sample proportion. Student's *t*-test was used to compare change in scores in case of presence or absence of meniscal pathology. Pearson's correlation coefficient was used to assess factors associated with patient-reported outcome scores. A *P* value of <0.05 was considered statistically significant.

Results

Demographics

A total of 824 patients were identified from the database that met the inclusion criteria of having a knee arthroscopic chondroplasty using bRF. There were a total of 16 patients who underwent bilateral knee surgeries; hence, a total of 840 operations were undertaken. The mean age was 47 years, with a range of 12 to 87 years. Sixty-one percent of all cases were males and 39% were females. The mean BMI of the

Table 2. Summary of Cohort Demographics.

Total number of operations included	840
Patients completed pre- and postoperative scores	492
Patients attended follow-up with no scores	343
Patients lost to follow-up	5
Male, female	61%, 39%
Right knee, left knee	55%, 45%
Mean age in years (range)	47 (12-87)
Mean BMI (range)	28.8 (16-59)
Number of chondral lesions per knee (1, 2, 3)	(62%, 29%, 9%)
Associated meniscal pathology	273 (55%)

BMI = body mass index.

cohort was 28.8, with a range of 16 to 59. Fifty-five percent involved the right knee and 45% the left knee (see **Table 2**).

The mean CSS of the cohort was 71 (SD = 14.5, range 18 to 96). The mean CSS of knees with and without meniscal pathology was 66 and 77, respectively. A significant negative correlation was found between CSS scores and patients age ($R = -0.6$, $P < 0.0001$). A statistically significant but weak negative correlation also found between CSS and BMI ($R = -0.18$, $P < 0.0001$).

Chondral Lesion Characteristics. Sixty-two percent of patients had 1 chondral lesion treated, 29% had 2 lesions treated, and 9% had 3 lesions treated. The most common lesion involved the medial femoral condyle (27%), followed by the patella (21%) and the trochlea (9%). The mean lesion size was 358 mm², with a range of 7 to 820 mm².

Associated Meniscal Pathology. A total of 273 (55%) patients underwent an associated treatment of meniscal lesion, while the remaining 219 (45%) received chondroplasty alone using bRF. Of those patients who had an associated treatment of a meniscal tear, 78% involved the medial meniscus, 12% involved the lateral meniscus, and 9% involved both menisci.

Complications and Associated Surgeries

A total of 19 patients (2.2%) had a postoperative complication, none of which was related directly to the use of bRF. For a list of general complications, see **Table 3**. A total of 23 patients (2.7%) underwent further surgery in the following 6 months. None was considered to be related to use of the bRF (**Table 4**).

Secondary Outcomes

Fifty-nine percent of patients ($n = 492$) had a completed preoperative and postoperative KOOS data set, with another

Table 3. Postoperative Complications.

Complication	Number of Patients (%)
Persistent pain	6 (0.7%)
Deep vein thrombosis	5 (0.6%)
Infection	3 (0.4%)
Hemarthrosis	2 (0.2%)
Stress fracture	1 (0.1%)
Thrombophlebitis	1 (0.1%)
Joint effusion (negative aspiration)	1 (0.1%)

Table 4. Number of Patients Who Underwent Subsequent Surgery within 6 Months.

Surgery	Number of Patients (%)
Second arthroscopy	16 (2%)
Unicompartment knee replacement	4 (0.5%)
Total knee replacement	2 (0.2%)
ACL reconstruction	1 (0.1%)

ACL = anterior cruciate ligament.

41% ($n = 343$) having attended for follow-up but without a postoperative KOOS score. A total of 0.6% ($n = 5$) were lost to follow-up. For patients who completed preoperative and postoperative KOOS and WOMAC, the mean preoperative normalized total KOOS was 45.9 (range 0 to 89), and the mean postoperative normalized total KOOS was 65.5 at a mean follow-up period of 129 days. The improvement in the total normalized KOOS was statistically significant ($P < 0.001$). Similarly, the improvement in the total WOMAC scores after treatment with bRF for chondral lesions was statistically significant (preoperative mean = 37.7, SD = 18.6; postoperative mean = 19.4, SD = 17.3, $P < 0.001$). A total of 69 patients (14%) had a similar or worse total KOOS scores after bRF treatment. The mean CSS for those patients was 70 (Grade C). The pain and quality-of-life domains of KOOS showed greatest improvement compared with the symptoms domain that showed the least change (see **Table 5**).

bRF Only Group. A total of 28 cases with chondral lesions were treated only using bRF. No prior shaving or punch was required to debride these lesions. This group demonstrated similar improvement in all score categories that was statistically significant (see **Table 6**). None of these cases had postoperative complications or required further operations during an average follow-up of 145 days.

Factors Associated with Change in Outcome Scores

A statistically significant but weak negative correlation was noted between age and change in normalized KOOS

symptoms and total score ($R = -0.18$, $P < .0001$). No statistically significant correlation was found between change in self-reported scores and CSS scores, BMI, lesion size, or number. When comparing the status of meniscal pathology and its effect on outcome scores, absence of meniscal pathology showed a statistically significant improvement in the change in KOOS symptoms category (no meniscal lesion: mean change = 20.1, SD = 18.9; associated meniscal lesion: mean change = 15, SD = 19.9; $P = 0.004$). **Figure 1** demonstrates the changes in KOOS scores for cases with or without meniscal pathology.

Discussion

The capacity for articular cartilage to heal following injury is poor. These lesions may progress to fibrillation with increased permeability of the chondral surface affecting the ability to bear compressive forces.^{5,22} In addition, the roughened surface may break into loose bodies that cause pain and crepitus and provoke inflammatory response in the form of reactive synovitis.¹⁰

Traditionally, debridement of unstable chondral defects has been performed using mechanical instrumentation (MSD). The disadvantages of this technique are the difficulties in achieving a smooth and stable zone of transition with normal host tissue with the potential to remove underlying viable cartilage.^{23,24}

Chondroplasty with radiofrequency ablation devices have been gaining popularity. These devices use heat to produce a smooth cartilage surface by ablation, neo-surface formation (collagen fibers oriented parallel to the joint surface), and annealing effect (reducing cartilage permeability).²³ Monopolar device passes energy from the tip of the probe through the tissue to a skin electrode. This device produces an uncontrolled high temperature at the probe tip. Alternatively, bipolar (bRF) instrument works by utilizing 2 electrodes in close proximity to each other between which potential difference is delivered with an alternating current in the range of 400 to 500 kHz. The fluid or tissue between the electrodes are superheated and thus ionized creating a plasma-like state. Once ionized, the material is washed away in the surrounding fluid.²⁵ Chondroplasty using bRF technology is gaining popularity as it is perceived as a precise way of achieving stable margins for chondroplasty while minimizing adjacent healthy tissue removal. In addition, a variety of probes are present and provide the surgeon with visual and tactile feedback.¹¹ However, the cost of this treatment tool is considerably higher than mechanical debridement techniques.

In reviewing literature, few studies have reported on the safety of bRF in chondroplasty. Moreover, there are contradictory results regarding the potential effect of bRF on surrounding healthy cartilage and underlying bone.^{4,26-28} Proposed chondrocyte death and osteonecrosis (ON) may be based on transient effect. For instance, Enochson *et al.*²⁹

Table 5. Preoperative and Postoperative Outcome Scores.

Outcome Scores Subclass	Preoperative, Mean (SD)	Postoperative, Mean (SD)	Change in Score, Mean (SD)	P Value
Symptoms	53.9 (19.4)	71.6 (19.4)	17.6 (19.7)	<0.0001
Pain	53 (17.8)	74.8 (18.3)	21.5 (19.3)	<0.0001
Function in daily living	61.7 (20.5)	80.7 (18.7)	19 (19.9)	<0.0001
Function in sport	29.3 (24.2)	47.7 (28.6)	18.4 (31.8)	<0.0001
QOL	31.2 (18.8)	52.8 (23.5)	21.5 (24.3)	<0.0001
KOOS Total	45.9 (16.8)	65.6 (18.9)	19.6 (19)	<0.0001
WOMAC Total	37.7 (18.6)	19.4 (17.3)	18.3 (18)	<0.0001

QOL = quality of life; KOOS = Knee Osteoarthritis Outcome Score; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.

Table 6. Preoperative and Postoperative Outcome Scores for bRF-Only Group.

Outcome Scores Subclass	Preoperative, Mean (SD)	Postoperative, Mean (SD)	P Value
Symptoms	57 (18.9)	68 (15.5)	<0.0001
Pain	56 (16.9)	71 (15.2)	<0.0001
Function in daily living	62 (18.5)	80 (17.2)	<0.0001
Function in sport	31 (28.4)	38 (28.9)	<0.0001
QOL	31 (18.2)	48 (21.8)	<0.0001
KOOS Total	47 (16.4)	61 (15.9)	<0.0001
WOMAC Total	37 (17.0)	21 (15.3)	<0.0001

bRF = bipolar radiofrequency ablation; QOL = quality of life; KOOS = Knee Osteoarthritis Outcome Score; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.

showed well-defined areas of immediate cell death but a significant increase in proliferation of articular chondrocytes in vitro.

Several studies reported on osteonecrosis in knee arthroscopy without the use of bRF.³⁰⁻³² Johnson *et al.* reported on 7 cases of ON after arthroscopy, and they attributed it to alteration in load distribution after management of meniscal pathologies.³⁰ On the other hand, Cetik *et al.* reported on ON with the use of bRF and found that ON occurred in only 2 cases (4%), and of all the cases 2 cases had partial meniscectomy. They concluded that with the proper use of bRF the risk of ON is minimal.⁴ The noncontact “paintbrush” method, continuous fluid flow, and probe settings to the lowest value recommended by the manufacturer are techniques to avoid any possible adverse effects.^{12,23}

Long-term follow-up comparing bRF with MSD in knee chondroplasty have been published by Spahn *et al.*^{10,12,13} They conducted a randomized controlled trial on 60 patients comparing the use of bRF with MSD in treatment of grade 3 MFC defects with concomitant medial meniscectomy. During the recovery period, the bRF group showed better outcomes in terms of less bleeding (20.8 mL vs. 70 mL, $P < 0.001$), earlier return to activities (17 days vs. 22 days, $P = 0.002$), and less pain at 6 hours, 24 hours, and 6 weeks post-surgery. At 6 weeks and 1 year, patients from the bRF group had statistically significant higher KOOS scores in each domain. In their 4-year follow-up results, revision rate was

significantly higher in the MSD group (48% in MSD vs. 14% in bRF, $P = 0.006$). The bRF group also had significantly higher KOOS scores ($P < 0.001$). Recently published 10-year results showed that joint space width narrowed continuously in both groups ($P < 0.001$) but more rapidly in the MSD group. Owens *et al.*³³ in a prospective randomized trial showed superior clinical outcomes in treating grade 2 and 3 patellar lesions using radiofrequency in comparison with MSD. Similarly, Uribe³⁴ showed favorable clinical outcomes with bRF over MSD in the treatment of trochlear lesions. Rocco *et al.* included 10 studies in his systematic review and demonstrated that bRF provides an efficient and safe technique in treatment of grade 2 and 3 chondral defects.⁸

In 2007, Voloshin *et al.*¹¹ published their second-look arthroscopy results of 25 patients after treatment of partial thickness chondral defects using bRF. Only 12% of defects demonstrated unstable borders with defect progression while 66% showed partial or complete filling of defect with stable repair fibrocartilage like tissue. Defects at the tibio-femoral joint where more predictive of healing than lesions at the patellofemoral joint.

The results of our study showed that there is a statistically significant improvement in patients' self-reported outcome scores (KOOS and WOMAC) after using bRF in arthroscopic treatment of chondral lesions regardless of preoperative or intraoperative factors that might affect the

Figure 1. Line graph demonstrating the improvement in mean KOOS scores after treatment of chondral lesions using bRF in cases with or without meniscal pathology. KOOS = Knee Osteoarthritis Outcome Score; QOL = quality of life; bRF = bipolar radiofrequency.

results. This procedure had a low postoperative complication rate of 2% and none was related directly to the use of bRF. Advanced age and presence of meniscal pathology were predictors of less improvement in patients' symptoms after treatment of chondral lesions using bRF.

This study focused on assessing a large cohort of patients who underwent knee arthroscopy using bRF by 2 orthopedic surgeons with strict inclusion criteria. This reduced operative variability and the patient pool size allows for a more robust study. Although this is a retrospective study, all patient demographics and primary outcome measures were recorded in prospective fashion on a secured database to minimize recall bias. This is the first study to utilize a validated intraoperative scoring system (CSS) that accounts for variety of intraarticular pathologies. The aim of our study is to assess the efficacy and safety of bRF in the treatment of chondral lesions.

Some of the inherent limitations of this study are that it is a retrospective analysis of patient data without a control group; however, every effort was made to achieve accurate

preoperative and follow-up records and to help establish a preoperative baseline. The study did not include correlation of arthroscopic findings and intraoperative grading with preoperative radiographs. The study also suffered from a low rate of follow-up scores and the outcome was limited to KOOS WOMAC score results. Thus, further magnetic resonance imaging changes or arthroscopic review may be relevant in future studies. Also, there may have been patients who underwent further surgery that were lost to follow-up.

Conclusion

In conclusion, the use of bRF in treatment of chondral pathologies is a safe modality with low rate of complications. Further studies with long-term follow-up are needed to investigate its efficacy in comparison to other modalities or nonoperative treatment.

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Declaration of Conflicting Interests

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Ethical Approval

Ethical approval for this study was obtained from Hunter New England Human Research Ethics Committee (EX20104-01)*.

Informed Consent

Verbal informed consent was obtained from all subjects before the study.

References

1. Årøen A, Løken S, Heir S, Alvik E, Ekeland A, Granlund OG, *et al.* Articular cartilage lesions in 993 consecutive knee arthroscopies. *Am J Sports Med.* 2004;32(1):211-5.
2. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31,516 knee arthroscopies. *Arthroscopy.* 1997;13(4):456-60.
3. Hjelle K, Solheim E, Strand T, Muri R, Brittberg M. Articular cartilage defects in 1,000 knee arthroscopies. *Arthroscopy.* 2002;18(7):730-4.
4. Cetik O, Cift H, Comert B, Cirpar M. Risk of osteonecrosis of the femoral condyle after arthroscopic chondroplasty using radiofrequency: a prospective clinical series. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(1):24-9.
5. Christoforakis J, Pradhan R, Sanchez-Ballester J, Hunt N, Strachan RK. Is there an association between articular cartilage changes and degenerative meniscus tears? *Arthroscopy.* 2005;21(11):1366-9.

6. Thorlund JB, Juhl CB, Roos EM, Lohmander L. Arthroscopic surgery for degenerative knee: systematic review and meta-analysis of benefits and harms. *BMJ*. 2015;350:h2747.
7. Australian Knee Society. Position statement from the Australian Knee Society on arthroscopic surgery of the knee, with particular reference to the presence of osteoarthritis: updated February 2016. Available at: <http://www.kneesociety.org.au/resources/aks-arthroscopy-position-statement.pdf>.
8. Rocco P, Lorenzo DB, Guglielmo T, Michele P, Nicola M, Vincenzo D. Radiofrequency energy in the arthroscopic treatment of knee chondral lesions: a systematic review. *Br Med Bull*. 2016;117(1):149-56.
9. Hunt SA, Jazrawi LM, Sherman OH. Arthroscopic management of osteoarthritis of the knee. *J Am Acad Orthop Surg*. 2002;10(5):356-63.
10. Spahn G, Kahl E, Mückley T, Hofmann GO, Klinger HM. Arthroscopic knee chondroplasty using a bipolar radiofrequency-based device compared to mechanical shaver: results of a prospective, randomized, controlled study. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(6):565-73.
11. Voloshin I, Morse KR, Allred CD, Bissell SA, Maloney MD, DeHaven KE. Arthroscopic evaluation of radiofrequency chondroplasty of the knee. *Am J Sports Med*. 2007;35(10):1702-7.
12. Spahn G, Klinger HM, Mückley T, Hofmann GO. Four-year results from a randomized controlled study of knee chondroplasty with concomitant medial meniscectomy: mechanical debridement versus radiofrequency chondroplasty. *Arthroscopy*. 2010;26(9):S73-80.
13. Spahn G, Hofmann GO, von Engelhardt LV. Mechanical debridement versus radiofrequency in knee chondroplasty with concomitant medial meniscectomy: 10-year results from a randomized controlled study. *Knee Surg Sports Traumatol Arthrosc*. 2015;24(5):1560-8.
14. Bonutti PM, Seyler TM, Delanois RE, McMahon M, McCarthy JC, Mont MA. Osteonecrosis of the knee after laser or radiofrequency-assisted arthroscopy: treatment with minimally invasive knee arthroplasty. *J Bone Joint Surg Am*. 2006;88(suppl 3):6975.
15. Chu CR, Kaplan LD, Fu FH, Crossett LS, Studer RK. Recovery of articular cartilage metabolism following thermal stress is facilitated by IGF-1 and JNK inhibitor. *Am J Sports Med*. 2004;32(1):191-6.
16. Hogan CJ, Diduch DR. Progressive articular cartilage loss following radiofrequency treatment of a partial-thickness lesion. *Arthroscopy*. 2001;17(6):E24.
17. Amiel D, Ball ST, Tasto JP. Chondrocyte viability and metabolic activity after treatment of bovine articular cartilage with bipolar radiofrequency: an in vitro study. *Arthroscopy*. 2004;20(5):503-10.
18. Cameron ML, Briggs KK, Steadman JR. Reproducibility and reliability of the Outerbridge classification for grading chondral lesions of the knee arthroscopically. *Am J Sports Med*. 2003;31(1):83-6.
19. Pro SL, Blatz BW, McAdams TR, Mandelbaum BR. Chondropenia Severity Score: an arthroscopic stratification tool of structural cartilage changes in the knee as correlated to patient reported outcomes (SS-28). *Arthroscopy*. 2012;28(6):e16.
20. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). *Arthritis Care Res (Hoboken)*. 2011;63(S11):S208-28.
21. Roos EM, Klässbo M, Lohmander LS. WOMAC Osteoarthritis Index: reliability, validity, and responsiveness in patients with arthroscopically assessed osteoarthritis. *Scand J Rheumatol*. 1999;28(4):210-5.
22. Edwards RB, Lu Y, Markel MD. The basic science of thermally assisted chondroplasty. *Clin Sports Med*. 2002;21(4):619-47.
23. Kosy JD, Schranz PJ, Toms AD, Eyres KS, Mandalia VI. The use of radiofrequency energy for arthroscopic chondroplasty in the knee. *Arthroscopy*. 2011;27(5):695-703.
24. Edwards R, Lu Y, Uthamanthil R, Bogdanske J, Muir P, Athanasiou K, et al. Comparison of mechanical debridement and radiofrequency energy for chondroplasty in an in vivo equine model of partial thickness cartilage injury. *Osteoarthritis Cartilage*. 2007;15(2):169-78.
25. Wienecke H, Lobenhoffer P. Basic principles of radiosurgical systems and their applications in arthroscopy. *Unfallchirurg*. 2003;106(1):2-12.
26. Barber FA, Iwasko NG. Treatment of grade III femoral chondral lesions: mechanical chondroplasty versus monopolar radiofrequency probe. *Arthroscopy*. 2006;22(12):1312-7.
27. Kaplan LD, Chu CR, Bradley JP, Fu FH, Studer RK. Recovery of chondrocyte metabolic activity after thermal exposure. *Am J Sports Med*. 2003;31(3):392-8.
28. Voss JR, Lu Y, Edwards RB III, Bogdanske JJ, Markel MD. Effects of thermal energy on chondrocyte viability. *Am J Vet Res*. 2006;67(10):1708-12.
29. Enochson L, Sönnergren HH, Mandalia VI, Lindahl A. Bipolar radiofrequency plasma ablation induces proliferation and alters cytokine expression in human articular cartilage chondrocytes. *Arthroscopy*. 2012;28(9):1275-82.
30. Johnson TC, Evans JA, Gilley JA, DeLee JC. Osteonecrosis of the knee after arthroscopic surgery for meniscal tears and chondral lesions. *Arthroscopy*. 2000;16(3):254-61.
31. DeFalco RA, Ricci AR, Balduino FC. Osteonecrosis of the knee after arthroscopic meniscectomy and chondroplasty: a case report and literature review. *Am J Sports Med*. 2003;31(6):1013-6.
32. Muscolo DL, Costa-Paz M, Ayerza M, Makino A. Medial meniscal tears and spontaneous osteonecrosis of the knee. *Arthroscopy*. 2006;22(4):457-60.
33. Owens BD, Stickles BJ, Balikian P, Busconi BD. Prospective analysis of radiofrequency versus mechanical debridement of isolated patellar chondral lesions. *Arthroscopy*. 2002;18(2):151-5.
34. Uribe JW. Electrothermal chondroplasty—bipolar. *Clin Sports Med*. 2002;21(4):675-85.