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Treatment of chondral defects by hydro jet. Results of a preliminary scanning electron microscopic evaluation

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Abstract Introduction: Arthroscopic methods in treatment of chondral defects aim to get smooth cartilage surfaces. Mechanical and thermal methods are used. Often the clinical results are poor or moderate. The treatment of chondral defects by using a hydro jet is an innovative measure. This study was aimed to evaluate the quality of the chondral surfaces after mechanical, thermal and hydro jet treatments in an in vitro scanning electron microscopy (SEM) study. **Materials and methods:** Femoral osteochondral pieces of the lateral condyle were obtained intraoperatively from patients undergoing total knee arthroplasty for primary knee OA. Partial-thickness cartilage degree II defects were smoothed by a mechanical shaver, bipolar radio frequency energy (RF) and hydro jet (84.1 KPa). SEM was carried out to evaluate the effects of the treatment. **Results:** Mechanical shaving produces a rough surface with groves and open lying collagen fibers. The surface, after bipolar cool ablation (coablation) was also uneven. The matrix was destroyed by massive vacuolization. Hydro jet treatment produces a relatively smooth surface without open lying collagen fibers. **Conclusion:** It is not possible to produce even surfaces by mechanical shaving or bipolar treatment. Hydro jet treatment allows a precise cutting which causes a relatively smooth chondral surface.

Keywords Cartilage · Shaving · Coablation · Hydro Jet · Scanning electron microscopy

Introduction

Arthroscopic treatment of partial-thickness defects of articular cartilage is one of the most frequently performed procedures in joint surgery.

The effectiveness of the different procedures is controversial. On the one hand, mechanical debridement of the joint can cause a reduction of pain and swelling and improve movement and joint function.

The results of these measures are controversial. There are reports with good middle-term results [14]. Against this, Mosely et al. [10] found no effect of arthroscopic debridement in the treatment of gonarthrosis in a controlled double-blind study.

The goal of the treatment is to provide a stable and congruent joint surface. A smoothed surface can effect an improvement in joint gliding, reduction of crepitus, pain and development of chondral debris. Last but not the least, it should be possible to avoid the progression of destruction of the corresponding joint surface.

The method of chondral smoothing must be effective, inexpensive and without severe side effects.

Recent studies have demonstrated that mechanical debridement (e.g., by shaver systems, tongs, punches, and rasps) often causes a rough and irregular cartilage surface. The instrument itself causes grooves and wrinkles [3, 8].

A further therapeutic option in treatment of localized chondral defects is given by the application of thermal energy. On the one hand, high temperatures cause a vaporization of the collagen matrix and a necrosis of chondrocytes. These effects can be used in ablative arthroscopic techniques but they are not meaningful in chondral treatment. On the other hand, low-temperature (50–70°C) causes a sealing of the chondral surface by partly saving the chondrocytes [8]. Thermal chondroplasty is possible by using laser-energy or radiofrequency energy. It was shown in former studies that thermal energy produces smoother surfaces than does mechanical shaving [11, 16]. The disadvantage of the thermal

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treatment is a possible destruction of the deeper chondral layers.

The development of a complete osteonecrosis is surely the most severe complication [6].

The results of clinical studies regarding the effectiveness of mechanical and thermal chondroplasty are incoherent [11]. Innovative procedures in chondral surgery may have followed from this.

Hydro-jet technology has long been used for cutting various materials (metal, wood, concrete) in the industrial field.

As a consequence, it must be possible to cut selectively superficial chondral flakes in partial-thickness cartilage defects by preserving the non-diseased chondral tissue.

Aim of this investigation is to test a new chondral-cutting technique by hydro jet. The effectiveness of hydro jet cutting and the quality of the resulting joint surface are evaluated in comparison to mechanical and thermal debridement.

Materials and methods

Patients and specimen

Femoral osteochondral pieces of the lateral condyle were obtained intraoperatively from patients undergoing total knee arthroplasty for primary knee OA. The patients volunteered to participate in the study.

A total of nine patients (three males, seven females, age 65.3 [range 59–72 years], duration of complaints 20.4 [range 12–36] month) were included in the study. No patient had undergone operative treatment or intraarticular injections before.

The joint surface had chondral lesions extending down to < 50% of cartilage depth (degree II according to ICRS cartilage injury evaluation package [1]).

The specimen were placed in plastic bags and kept in freeze at -18°C until use. Before the experiments the specimen were thawed slowly at room temperature.

Treatment of chondral defects

The experiments were carried out at room temperature. The specimens were placed in a physiologic saline solution (0.15 M). Mechanical debridement was carried out by using a mechanical shaver system (arthrex).

The bipolar radio frequency energy (RF) was applied by an electro-surgical probe (3.0 mm \times 90 $^{\circ}$ ArthroWand# A 1330, Arthroscopic Electrosurgery System, ArthroCare Europe, Stockholm). Hydrojet was produced by an innovative instrument (exojet, Norderstedt).

The principle of its function is shown in Fig. 1. Exojet produces a hydro jet with a pressure ranging from 66.9 to 84.1 KPa.

The area of chondral damage was treated like in a clinic (paintbrush treatment pattern) using an

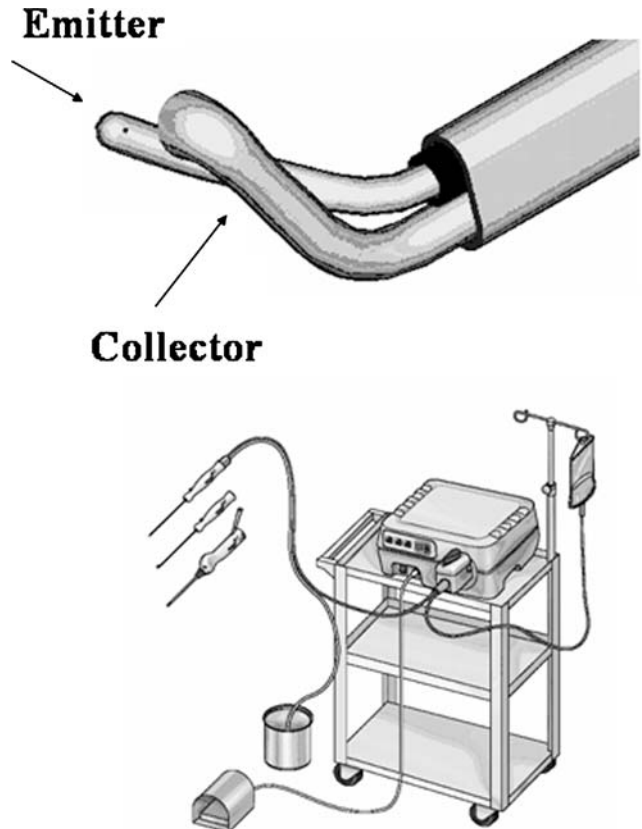


Fig. 1 Functional principle of “exojet”. The apparatus pumps sterile saline fluid into the fluid jet probe. The fluid is pumped into the “emitter”. On the end is located a jet with a diameter of 0.13 mm. Thus, a hydro jet is produced (ranging 9.7–12.2 pound/square inches). The emitter has a diameter of 1.25 mm. The hydro jet produced between the two ends of the probe is convenient for effective chondral smoothing

arthroscopic technique until the surface was observed to be smooth. Mechanical shaver treatment was terminated when the surface was considered as smooth by an experienced surgeon (SG). The bipolar RF-system was used in a non-contact mode (Level 4: 158–193 KHz/Vrms). Hydro jet was used until the surface was observed to be smooth (average of hydro jet pressure 84.1 KPa). The indications about the intensity of RF-energy and the hydro jet pressure were obtained from the product manufacturer’s data. Afterwards, the specimens were fixed in 70% alcohol until microscopic examination. Every method was performed in three specimen.

Scanning electron microscopy (SEM)

After chondral treatment, the specimens were fixed in 70% alcohol and with increasing ethanol concentrations. Then the specimens were critical point dried (critical point dryer, Balzers Union/Liechtenstein) and sputtered with gold (30 nm, ScD 005 Sputter coater BalTec). The structure of the cartilage was documented

Fig. 2 a–c SEM Image of surface after treatment (magnification x13). Treatment by mechanical shaver system produces rough and uneven surface. The instrument itself causes grooves and scrapes (a). Here a destruction of non-affected cartilage is possible. Coablation causes a smooth surface, too. It sheens, that the surface is sealed. But the surface is soft. In SEM groves caused by the electrodes are seen (b). After treatment with hydro jet results a smooth surfaces (c). The crack in the left side in (c) (af) is caused by an artefact during the drying

with the SEM (Stereoscan 260/Cambridge Instruments Ltd./United Kingdom) under different magnifications.

Results

Mechanical debridement by using shaver system

The treatment of the chondral defects causes removal of superficial flakes. A selective abrasion of flakes by preserving non-destructed tissue is not possible. The shaving produces an irregular and rough surface in macroscopic picture. As shown in Fig. 2a, the flakes are not completely removed and the surface is clawed by the instrument.

Ultra structurally, the surface is characterized by completely open lying collagen fibers (Fig. 3a).

Thermal treatment by using bipolar RF energy (coablation)

Macroscopically, the treatment causes a smoothing and sealing, which does not conform to the SEM image in low magnification (Fig. 2b). The RF-probe consists of multiple single electrodes. These electrodes produce a maximum of thermal energy, followed by a coagulations zone. This shows as grooves. In the trough of the grooves impressive signs of thermal damage are present: vacuoles and tears (Fig. 3b).

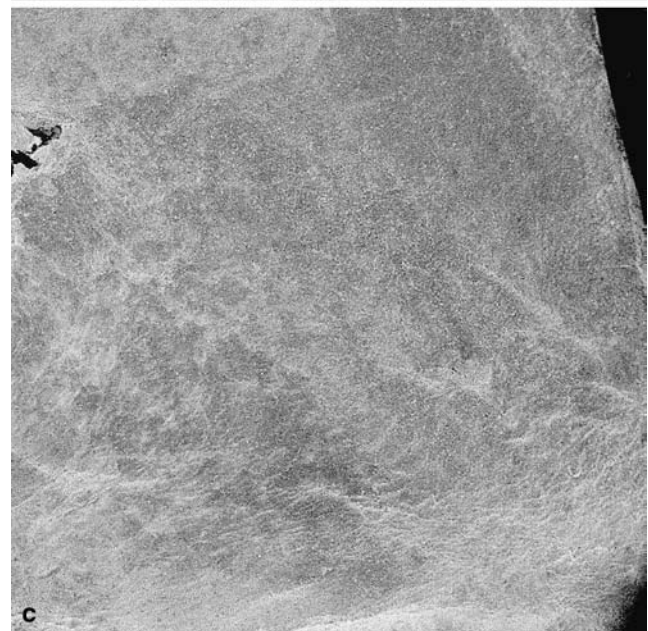
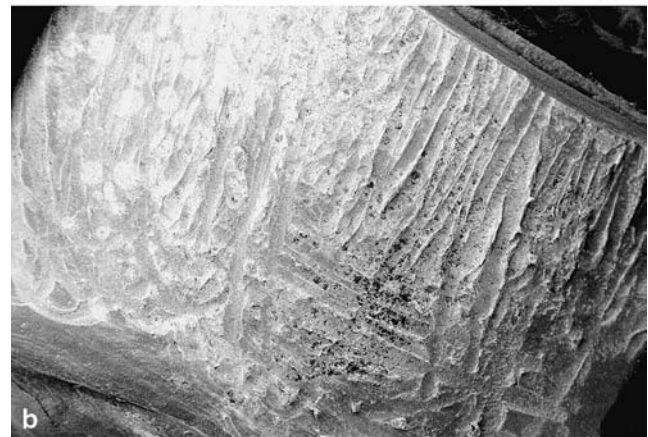
Debridement by using hydro jet

The hydro jet treatment produces a smooth and even surface. The removal of the superficial flakes is effective. In comparison to RF treatment, the chondral surface has a compact consistency during hook palpation.

In the SEM image a homogeneous and smooth surface is seen (Fig. 2c). Only a small number of collagen fibers lie open. Tears or vacuoles are not observable (Fig. 3c).

Discussion

OA is an idiopathic disease characterized by a progressive degeneration of articular cartilage. The genesis of chondral damage is complex. Numerous mechanisms are known to be involved in this process. Summarized, the process of chondral damage must be seen as a disproportion between anabolic and catabolic processes



followed by a mechanical failure. In an early stage of the disease, the cartilage shows tenderness, fissures, and fibrillation. Full-thickness chondral defects are the end point of this pathological process.

The complaints in the early stage of OA are crepitus and pain during joint motion. Arthroscopic debridement

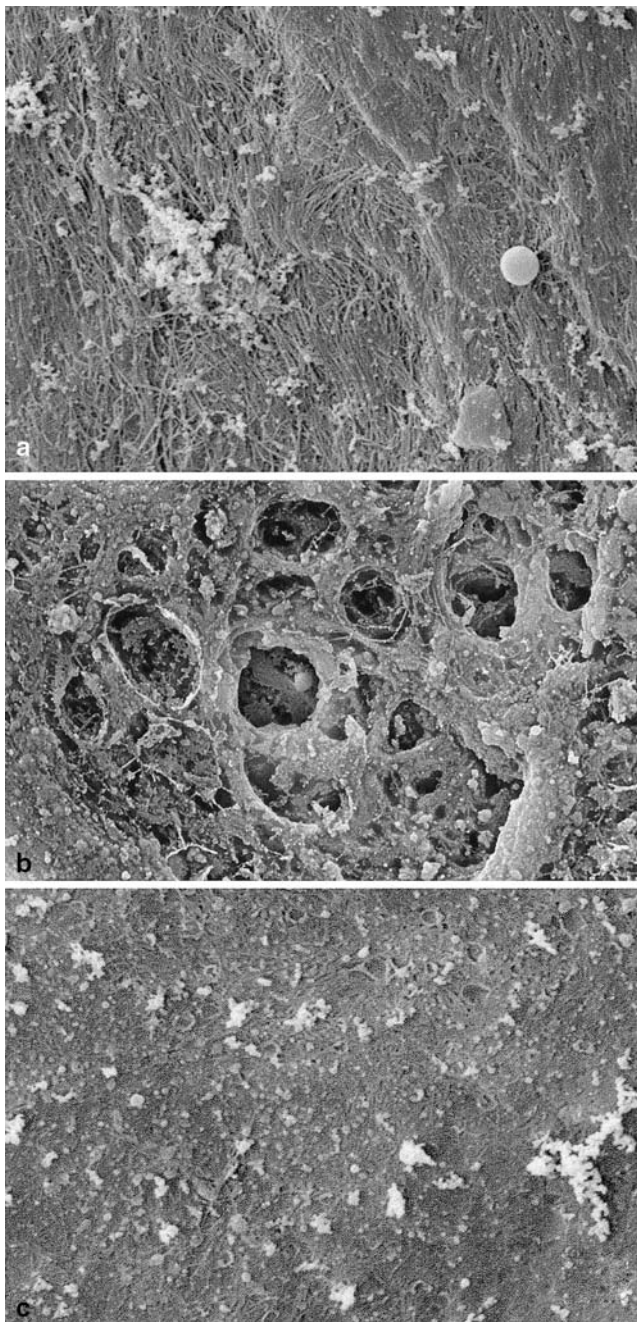


Fig. 3 a–c Ultrastructural changes after treatment (magnification $\times 3000$). The SEM picture after mechanical shaving is characterized by widely open laying collagen fibers (a). Thermal treatment by coablation causes vacuolization of the matrix (b). After hydro jet treatment, the surface is smooth also in high magnification (c). The superficial white flakes (af) are artefacts caused by impureness on the surface

of the chondral defects are aimed to reduce the crepitus and to improve the joints lubrication. There is much dispute about the “best method” in arthroscopic chondral treatment.

It is well known that mechanical shaving does not produce smooth and congruent joint surfaces. The mechanical instruments cause grooves. This method is only convenient to remove superficial chondral flakes.

Our results suggest that it is not possible to get a smooth and mechanical stable surface by shaving [5]. Additionally, the shaving itself produces chondral tears. These tears can be possible starting points for progressive mechanical destruction of the joint surface. Furthermore, shaving alters “healthy” articular cartilage surrounding and below the lesion site. The surface after shaving does not differ from an untreated surface in an OA joint [2]. Open lying collagen fibers characterize the SEM picture of the surface. These open lying fibers and the collagen matrix may become an unprotected target of destructive metabolic and immunologic processes.

These circumstances may be a cause for the only moderate or poor clinical results after shaving [10, 13, 14]. In the last decade thermal procedures became important. Thermal chondroplasty is possible by using Laser-energy or RF-energy (mono-polar or bipolar).

Regarding laser-chondroplasty by using Holmium, YAG-laser ($\lambda = 2,100$ nm) or excimer-laser ($\lambda = 308$ nm) was reported in recent studies. The results of clinical and experimental studies were different [4, 9, 12]. On the one hand, laser treatment produces smooth surfaces. On the other hand, it has been speculated that laser-treatment stimulates chondral matrix synthesis. Spivac et al. [15] demonstrated a stimulation of matrix synthesis 6–7 days following laser application. However, after 12 days these effects were not seen. Similar effects like laser treatment are seen after RF-application. Currently, both mono-polar and bipolar RF-probes are available for arthroscopic use.

Mono-polar RF energy produces high temperatures in the tissue of about 400°C . Ohmic heating surrounding the probe tip is the primary source of thermal energy. The mean effect of this high temperature application is an explosive boiling of the chondral matrix and cells with high uncontrolled depth effect. This method is for cutting and coagulation. In chondral treatment, collateral damage is not avoidable. To that extent this method achieved only little importance in chondroplasty [7, 8].

The bipolar thermal treatment, in contrast, is a controlled, non-heat-driven process. The bipolar RF-probe produces lower temperatures ($40\text{--}70^{\circ}\text{C}$). The word “Coablation” is an acronym of “cool” and “ablation”. With this technology RF-energy is applied to a conductive medium (saline solution), causing a highly formed plasma field to build around the energized electrodes. A disintegration of macromolecules is produced by this plasma field.

This technique produces thermal disintegration of macromolecules followed by a superficial plasma layer. The mean effect of this procedure is a melting of the superficial tissue surface. The surface is macroscopically smooth and even [17].

The results of clinical studies to evaluate the effectiveness of the chondral bipolar treatment are contradictory. In the treatment of isolated patellar chondral lesions, Owens et al. [11] found a superior result after bipolar RF-treatment. Other investigator did not find any benefit in this method [14, 16]. After RF-treatment

we found in SEM severe thermal damage. The RF probes produce grooves between the single electrodes. In the trough the chondral matrix is characterized by vacuoles. Chondrocytes do not exist.

Turner et al. [17] found in their experiments with bipolar RF-treatment matrix, temperatures over 70°C. These temperatures are able to destroy the cartilage matrix and chondrocytes irreversibly. Our results suggest that RF-treatment is potentially dangerous. Therefore it should be used very carefully in the case of chondral lesions.

The treatment of partial-thickness chondral defects by high-pressure hydro jet is an innovative technique. It is convenient to produce relatively smooth surfaces in comparison to shaving or RF-treatment. This may be caused by the precise cutting. This is known from diverse technical procedures. A “selective” debridement of loose flakes appears possible.

The jet removes mostly loose and superficial flakes. Mechanically resistant and profound chondral layers are little altered. Of course we are not able to give any information about the vitality of the “spared” chondrocytes by means of this SEM evaluation.

On the other hand, the hydro jet produces only little amounts of open lying collagen fibers. This suggests that here exists a possibility of reduced catabolic processes in the joint. Of course, this study has limitations and further in vitro and clinical investigations are necessary in future.

We are not able to prognosticate the in vivo reaction of the hydro-jet-treated surface. We believe the absence of pore lying collagen fibers and the smooth surface may reduce catabolic and immunological processes. Thus, this method can be an alternative for the mechanical shaving or thermal chondroplasty in arthroscopic surgery in future.

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