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Osteochondral autograft transplantation (*mosaicplasty*): What is the impact of plug diameter in cartilage repair?

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Abstract

Purpose To compare the mechanical stress applied to our grafted defect area according to the diameter of the plugs used in the treatment of osteochondral lesion with osteochondral autograft transplantation (OAT) procedure.

Methods A biomechanical study was conducted on eight cadaveric knees. A 20-mm defect was created in the weight-bearing zone on the medial femoral condyle then filled either with three plugs of 8 mm, or with four plugs of 6 mm, or with 6 plugs of 4 mm diameter. After the preparation of the specimens, each knee was installed on a mechanical test bench (Instron 5566A). A continuous axial compression of 700 N at 10 mm.min⁻¹ was exerted on the joint. A K-scan 4000-type pressure sheet was used to record the contact area (mm²), the mean pressure (MPa), and the maximum pressure (MPa) on the area of interest. **Results** The differences found between the conditions were not statistically significant but showed tendencies. Filling the defect with six plugs of 4 mm restores a larger contact surface compared with the other plugs. The use of 8- and 6-mm grafts lead to a respective increase of 12% and 52% of the mean pressure compared with the 4 mm grafts. This difference was also found for the maximum pressure (36% and 129%). Regardless of the diameter of the plugs used, filling the lesion reduces the mean pressure exerted on the healthy cartilage by 19%.

Discussion A trend emerged towards a better restoration of the cartilage surface and a more harmonious distribution of the pressures exerted in favour of the grafts of smaller diameter. A larger study is needed to obtain a statistically significant result.

Keywords Biomechanics · Knee · Osteochondral autograft transplantation · Mosaicplasty

Introduction

Cartilage repair procedure in the young population represents a therapeutic challenge for the surgeon and is still a controversial subject nowadays. When chondral defects are between 2 and 4 cm², it is accepted that osteochondral autograft transfer (OAT), or mosaicplasty, can be used in order to restore the hyaline cartilage [1–5]. This procedure was developed in the 1990s by Hangody et al., in Hungary with good functional results [6]. It is widely used because it is easier to implement and less expensive than cartilage regeneration procedures.

However, the literature stays poor concerning the behaviour of osteochondral grafts filling a cartilage lesion. The main biomechanical studies found focus their interest on either studying the effect of a cartilage lesion and its filling on the stresses subjected to healthy cartilage [7–10], or on the importance of the congruence of the osteochondral grafts on the surface of the remaining cartilage [11, 12]. No answer

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is offered on the ideal number or diameter of grafts used to fill the cartilage lesion of the knee.

The aim of our study was to analyse the mechanical loads applied to our grafted defect area according to the diameter of the plugs used. We hypothesised that filling an osteochondral lesion using smaller diameter plugs allowed a better pressure distribution due to greater restoration of the cartilaginous surface.

Material and methods

Patient selection

Ten cadaveric knees, from five Caucasian donors, were obtained for the experiment. The protocol defined in this study was approved by the embalming laboratory of La Timone University (Marseille, France). The laboratory was responsible for the conservation in a cold room (approximately 0 °C) of the cadaveric subjects for the time of experimentation. All knees were examined to ensure the integrity of the joint capsule, ligaments and menisci, and the absence of prior cartilage surgery. A transverse section was performed at the level of the femur as well as at the level of the femur and of the tibia and the fibula to obtain a diaphysis length compatible with carrying out manipulations in compression. The soft parts around the bone segments were dissected and removed to keep only the elements of the femorotibial joint. The diaphysis was put in resin under a suction hood in PVC tubes, allowing the alignment between the main axis of the cylinder and the mechanical axis of the limb to be respected. After the examination of the ten knees, two knees were excluded because of their poor condition. Eight knees were therefore selected for the tests.

Experimentation

A careful dissection was first performed in order to access the femorotibial compartment to be studied. For simplicity and to ensure the reproducibility of placement of the pressure sensors, the patellar ligament was sectioned allowing the extensor apparatus to be raised with more direct access to the femorotibial compartments. The dissection made it possible to preserve the menisci, the cruciate ligaments, and the collateral ligaments to ensure the stability of the joint.

Each knee was installed on the mechanical test bench (Instron 5566A), tibia up. The clamping device used on the femur allowed us to position the joint optimally for the compression test, with vertical alignment of the diaphysis and a knee in full extension (Fig. 1). A K-scan 4000-type pressure sheet (Tekscan, South Boston, Massachusetts) was placed in the external femorotibial compartment. The use of these sensors allowed us to analyse the distribution

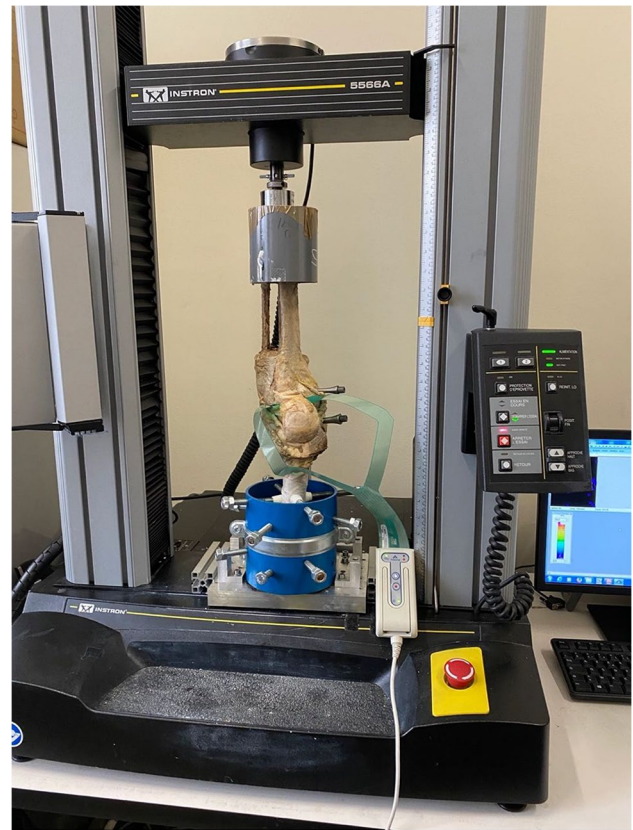


Fig. 1 The experimental setup. *The pins, visible on either side of the knee, come from a previous experience and have no impact on the biomechanics of the knee*

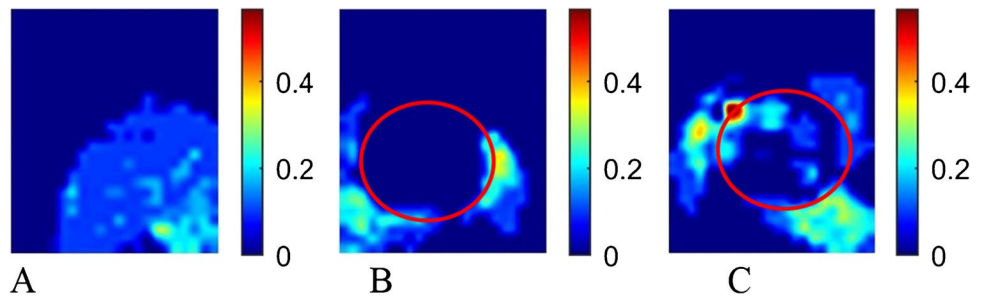
of the mechanical loads of the external femorotibial compartment in different experimental conditions. The same pressure sensor was used for each knee, thus avoiding the intrusion of experimental bias. After positioning the pressure sheet, a continuous uniaxial compression force of 700 N at 10 mm.min⁻¹ was applied following the longitudinal axis of the articulation [13]. This compression force was representative of the stresses experienced in the knee during monopodal gait for a 70 kg human subject.

For each test, the contact surface and the intra-articular pressures were measured by the sheet and recorded in real-time during the test. Each acquisition was synthesised in the form of an intensity map (Fig. 2).

Moreover, three compression tests were carried out on each knee. A first compression test without cartilage defect (WD), a second compression test with cartilage defect (D), and a final compression test with the filling of the cartilage defect (FD).

During the assay, three parameters were quantified: the contact area (mm²), the mean pressure (MPa), and the maximum pressure (MPa) on the area of interest.

Fig. 2 Pressure map for the three conditions presented (**A** without defect; **B** with defect; **C** with filling of cartilage defect). The red circle represents the defect area

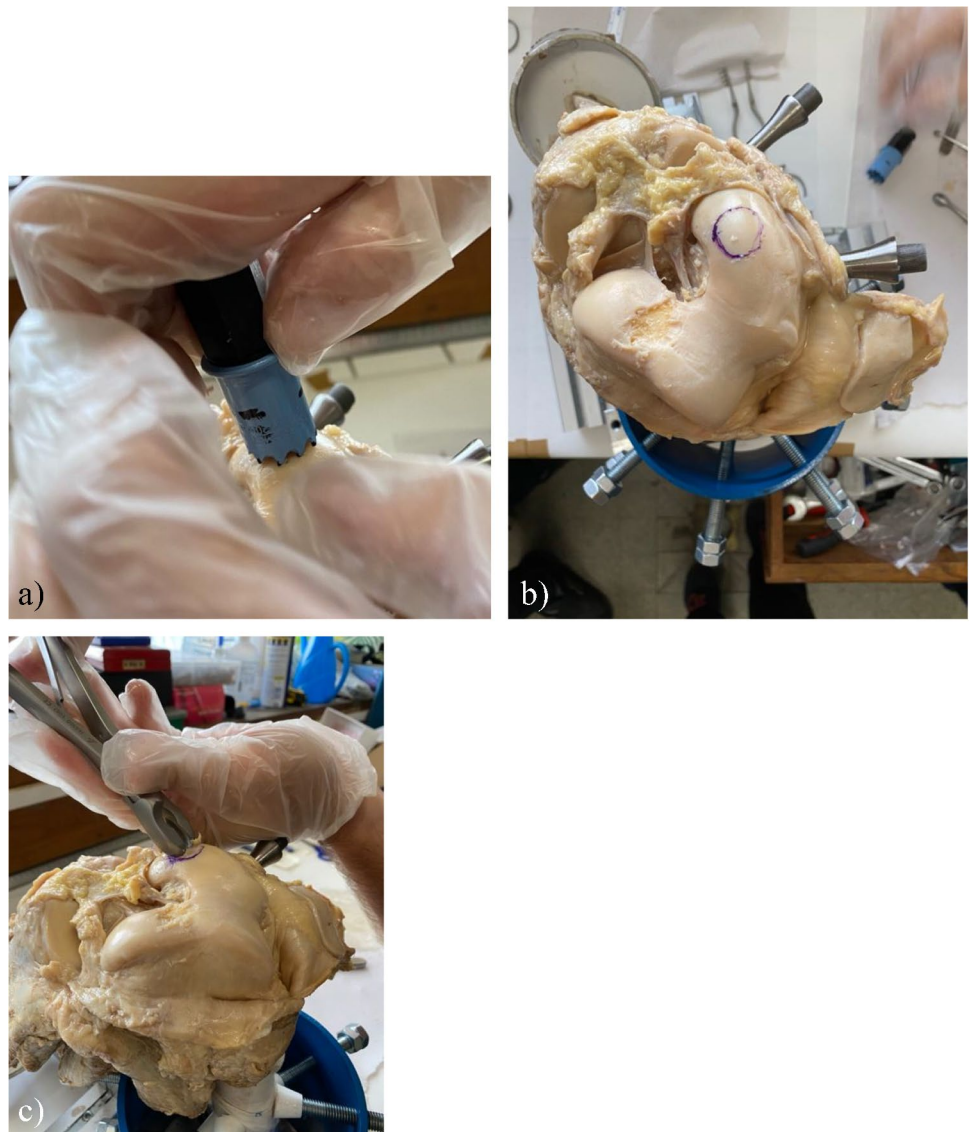


Surgical procedure of the osteochondral defect

For each knee, after checking the quality of the measurements recorded by the sheet during the first condition, the external femorotibial compartment was prepared. A cartilaginous defect 20 mm in diameter, corresponding to

a surface between 2 and 3 cm², was made on the external femoral condyle in the weight-bearing zone. This lesion was made using a 20 mm oval cutter and a surgical instrument to ensure reproducibility of the lesion for all specimens (Fig. 3). The lesion was made as far as the subchondral bone, thus making it possible to remove all

Fig. 3 Identification of the size of the defect (instrument of the same size, 20 mm) (**a** and **b**). Realization of the defect using a surgical instrument (**c**)



the cartilage. The compression test was again carried out with the defect.

Osteochondral autograft transplantation (OAT) procedure

The number and diameter of the grafts for filling the lesion were decided before the experiment. It was necessary to respect the diameters of the sampling kits available on the market. The COR® sampling kits (DePuy Mitek, Johnson & Johnson Company) made available by the laboratory were used for the manipulations. These kits allowed harvesting of grafts with a diameter of 4, 6, or 8 mm. Thus, the filling of the lesion was done with three plugs of 8 mm in diameter, four plugs of 6 mm in diameter, or six plugs of 4 mm in diameter.

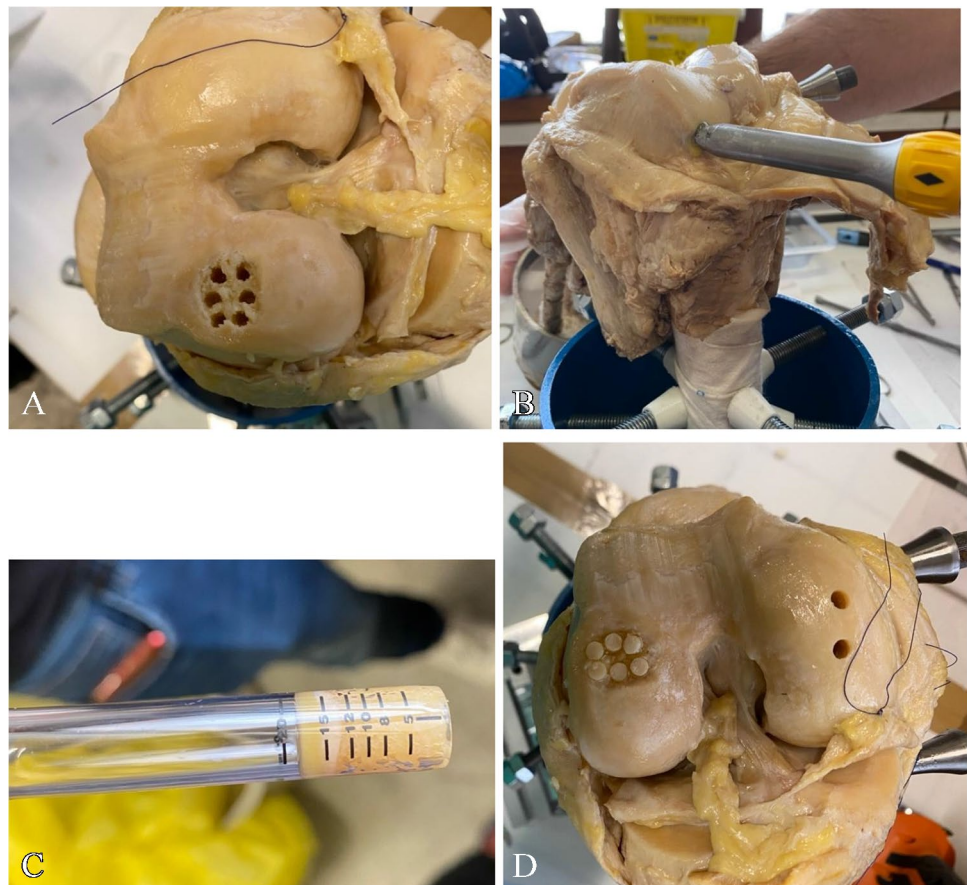
The surgical procedure respected the classic sequence with, first, the preparation of the defect. A sizer made it possible to imagine the layout of our plugs. The holes were prepared on the lesion using the specific drill provided in the ancillary kit, at a depth of 15 mm and remaining perpendicular to the joint surface. Then the osteochondral plugs were taken from the outer edge of the trochlea, respecting

the same length of 15 mm as that of our recipient tunnels. Once the graft was removed, it was inserted into the tunnel using specific instruments. It was necessary to check that the cartilage cap of the graft was flush with the cartilage so as to respect joint congruence (Fig. 4). The knee was then tested mechanically according to the same protocol as described in the other stages. For each category of filling, three knees were used, allowing three conditions to be achieved with the same number and the same diameter of plugs.

Parameters studied and statistical analysis

The results were exported and analysed using *Matlab 2020b* software. The written script made it possible to transform the video acquisitions into an intensity map per trial, calculated when the peak load was reached. It also made it possible to synthesise this state of maximum intensity into three quantities of interest: mean pressure exerted on the sensor (MPa), maximum pressure exerted on the sensor (MPa), and contact area (mm²). Statistics were performed using *Rstudio* software. Due to the small number of samples per group, the non-parametric Kruskal–Wallis test was used. Pair-to-pair comparisons were performed using Dunn’s test, adjusted by Bonferroni’s correction. When the values were normalised

Fig. 4 Surgical procedure. **A** Drilling of bone tunnels in the defect area. **B** Removal of grafts from the trochlea. **C** Osteochondral “plugs” in the sampling tool. **D** Result of filling the defect (6 plugs of 4 mm here)



to observe the intra-individual evolution, the non-parametric Wilcoxon test was used to compare our values with the null hypothesis $\mu=0$. The significance threshold was placed at 95%.

Results

Evolution of the parameters observed according to the different conditions

We analysed the effect of the three conditions (WD, D, and FD) on the three mechanical parameters. For this, all the data were grouped according to their conditions regardless of the number and diameter of the plugs used.

The first parameter observed concerns the contact area used during knee weight-bearing (Fig. 5a). No significant difference between the conditions was observed. However, we observed that the osteochondral defect (D) leads to an average reduction of 23% of the contact area compared with the normal condition (WD). The contact area decreased from 336 ± 97 to 260 ± 86 mm² for the WD and FD condition respectively. On the other hand, after filling the defect, an increase of 34% in the contact area was observed compared to the condition with defect (260 ± 86 mm² vs 349 ± 117 mm² for group WD and FD). The second parameter measured was the mean pressure under the different conditions (Fig. 5b). We found no significant difference between the conditions but a trend can be observed. If we look at the evolution of the mean pressure between the WD group and the D group, we notice an increase ranging from 0.72 ± 0.5 MPa for the WD group to 0.81 ± 0.5 MPa for the D group. This variation represents an increase of 13% of the mean pressure when the defect was created compared with the normal condition. Then, the mean pressure decreases to 0.65 ± 0.3 MPa for the FD condition, thus, showing that the filling of the defect (FD), leads to a decrease of 19% of the mean pressure

compared with the default condition (D). Finally, the maximum pressure was studied and no significant difference was observed (Fig. 5c).

Inter-group comparisons and influence of graft geometry

In this part, we analysed the effect of plug diameter and therefore the number of plugs used to fill the defect on the mechanical parameters previously described. The geometry and the number of plugs seem to have an impact on the contact area during loading, although no statistical differences were seen between groups. When 6-mm and 8-mm plugs were inserted, a decrease of 39% and 41% on the contact area was observed compared with the mean value obtained for 4 mm plugs (283.9 ± 20.5 mm² and 275.8 ± 69 mm² vs 465.6 ± 104 mm², for 6-, 8-, and 4-mm plugs, respectively) (Fig. 6a). It would appear that the insertion of 4 mm diameter plugs restores a larger contact area compared with two other diameter plugs.

We also measured the mean pressure obtained when using 4, 6, or 8 mm plugs. A trend can be seen, when using 4 mm plugs leading to a better distribution of loads on the lateral femorotibial compartment. The use of 6 mm plugs resulted in a 12% increase in mean pressure compared with the use of 4 mm plugs (0.565 ± 0.2 MPa vs 0.503 ± 0.2 MPa, for 6- and 4-mm plugs respectively). This effect was further increased when using 8 mm diameter plugs as the mean pressure values rose to 0.857 ± 0.5 MPa. This represented a 70% increase in mean pressure compared with using 4 mm plugs (Fig. 6b).

Finally, the same trends were observed for the maximum pressure (Fig. 6c). We observed an increase of 36% and 129% in the local maximum pressure when using a 6 mm and 8 mm plug respectively. In fact, the maximum pressure value obtained in the 4 mm condition was 2.89 ± 2.6 MPa while for the 6 mm and 8 mm condition the maximal pressures were 3.19 ± 0.02 MPa and 6.622 ± 4.9 MPa, respectively.

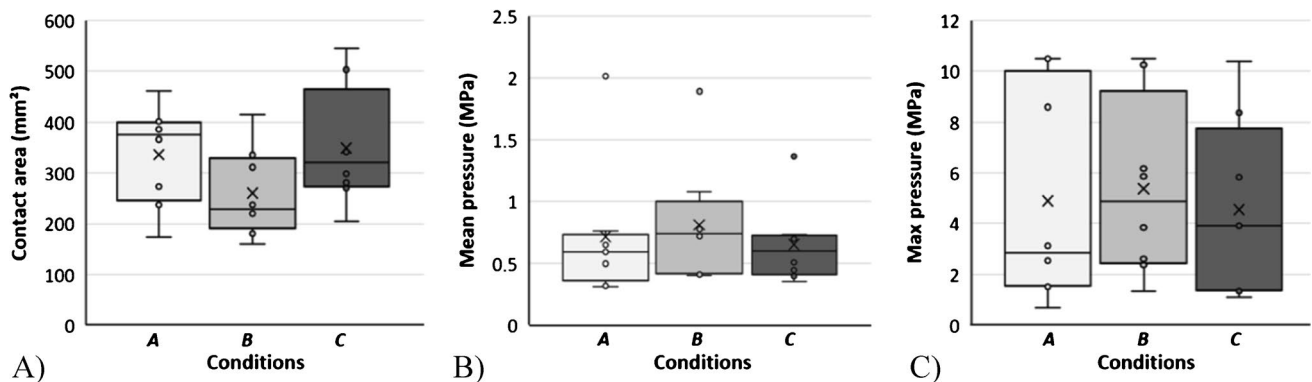


Fig. 5 The average values: (a) contact area (mm²); (b) average pressure (MPa); (c) maximal pressure (MPa) as a function of the three experimental conditions (A without defect (WD); B with defect (D); C after filling the defect (FD))

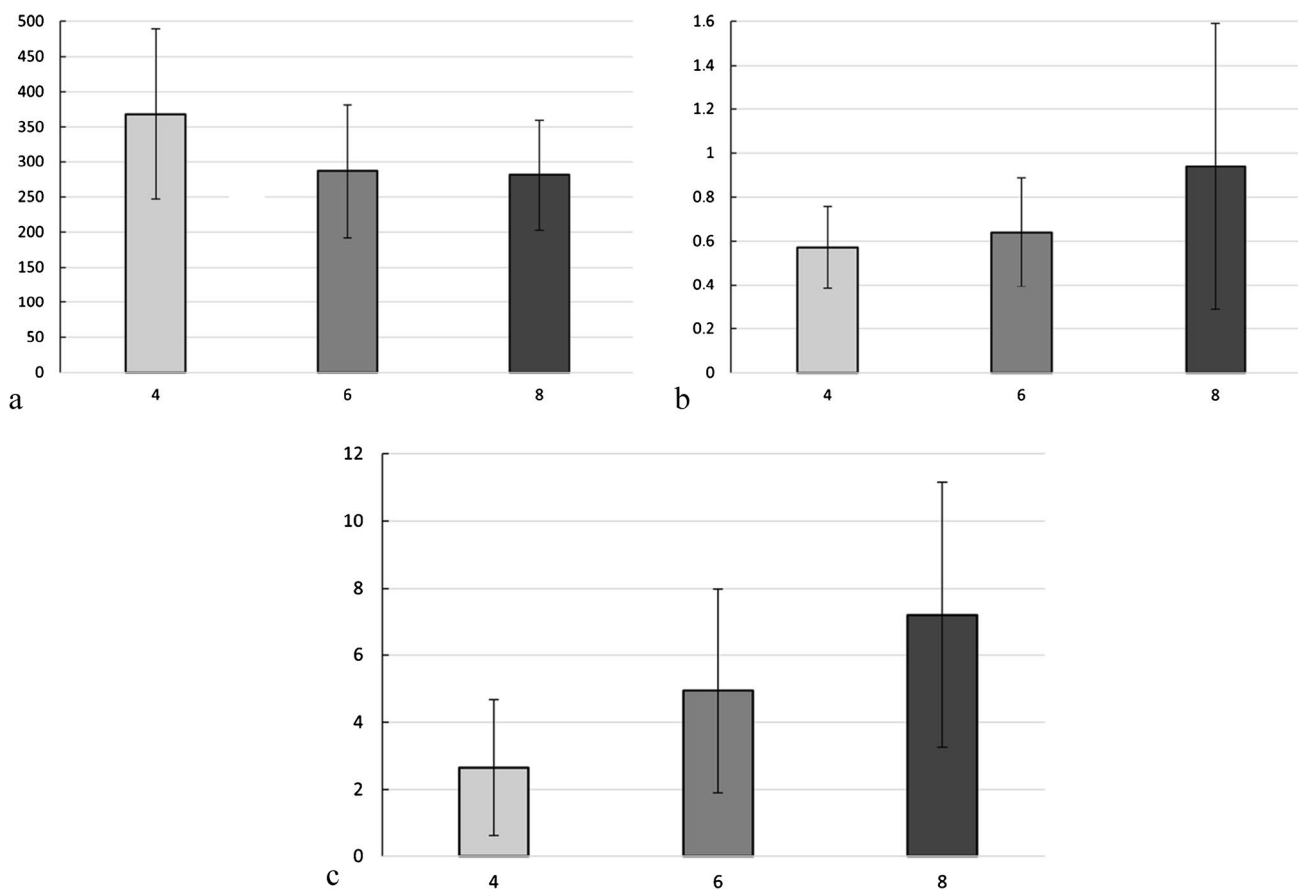


Fig. 6 Average values of contact area (mm²) (a), average pressure (MPa) (b), and maximum pressure recorded (MPa) (c) according to the diameter of the plugs

Discussion

The aim of our study was to compare the biomechanical effects of filling an osteochondral defect with plugs of different diameters. Our hypothesis could not be verified statistically. However, a trend could be found in favour of OAT using smaller-diameter plugs.

We analysed the biomechanical behaviours secondary to the filling of a 20 mm cartilage defect with cartilage damage down to the subchondral bone (stage 3 or 4 of the International Cartilage Repair Society [ICRS] classification). This corresponds on mean to lesions of 3 cm². It is accepted that for lesions of 2 to 4 cm², the cartilage repair procedure by mosaicplasty remains one of the reference surgeries, with satisfactory long-term results [4, 5, 14, 15]. It is also found to reduce the contact pressure exerted on the remaining healthy cartilage by 30% [3, 6]. In fact, Kock et al. [10] performed the test on a cartilage defect filled with three plugs. The diameter of the plugs was not specified, but the compression tests showed a decrease in pressure on the healthy cartilage, confirming the effective protection of the cartilage by this repair procedure. Our study seems to show results

going in the same direction, as filling the lesion increases the contact surface by 34% and decreases the mean pressure by 19%.

To our knowledge, only one study has compared the distribution of compression loads according to the diameter of plugs filling an osteochondral defect in the knee. Choung et al., study attempted to answer this question for defects located at the level of the talus [16]. An 8 × 12 mm defect was created on the medial part of the talus for ten cadaveric subjects. The experiment was carried out after filling the lesion with four plugs of 4 mm in diameter and with two plugs of 6 mm then the compression test was carried out with measurement by a pressure sensor. Grafts 4 mm in diameter restored 89.3% of the contact surface while those of 6 mm, only 67.7%. Our results support this analysis. Indeed, the three biomechanical parameters studied (contact area, mean pressure and maximum pressure) were more favourable to multiple grafts of 4 mm plugs compared with larger diameters. The restoration of a wider contact area may explain a better resistance to pressure. We find a difference of more than 71% in the reduction in mean pressure between the use of 8-mm plugs and 4-mm plugs.

The restoration of a larger contact surface with small diameter plugs may not be the only explanation. The importance of the articular congruence of the graft, allowing the restoration of the convexity of the condyle, has been demonstrated in the distribution of the compressive stresses on the healthy cartilage. Biomechanical studies [17–19] on this subject showed that a difference of 1 or 0.5 mm between the plumbness of the osteochondral graft and the surface of the cartilage significantly increased the pressure exerted compared with a graft reaching the level of the remaining healthy cartilage. Researchers also measured the dissipated energy (DE) as a friction parameter in a knee joint with local cartilage defects [20]. In this study, they investigated the effect of different types of OAT graph positioning. Four conditions were tested: even, deep (1 mm below the natural surface level), high (1 mm above the natural surface level), and defect (no plugs were used). They concluded that an enormous rise in friction appeared in the defect condition compared to the native one, as the DE values were three times higher (+ 165% compared with native) and in the high condition, they measured an increase of 22%. Thus, an osteochondral defect located in the weight-bearing zone, where the compression is the greatest, must be filled with plugs to restore the anatomy of the area as well as possible. We believe that smaller-sized grafts will provide the flexibility needed to best respond to the location, shape, and size of the chondral lesion. We do not have the same choices concerning the geometric arrangement of three plugs of 8 mm compared to six plugs of 4 mm for the filling of a spherical lesion.

It is currently accepted that the objective is to obtain coverage, by hyaline cartilage, of more than 70% of the loss of substance. It is recommended not to exceed six grafts. Robert. H recommends using fewer grafts but larger diameters to improve stability and coverage and also to simplify the surgical procedure [17]. Indeed, in addition to the morbidity of the donor site [18], there may be a risk of weakening the grafts. However, the stability of the grafts plays an important role in the protection of the remaining cartilage [19, 20]. During the experiment, we had more difficulty performing the 4-mm grafts, given the lesser thickness of the partitions in the recipient area, with greater fragility of the plugs.

It is the same problem in real life. Indeed, it is technically difficult to take and graft plugs of small sizes. In our practice, we prefer to harvest large-diameter grafts in order to increase primary stability and simplify the procedure. In case of confirmation of these results, perhaps the creation of specific instrumentation after planning the filling would be interesting.

We can note several limitations to our study. The lack of power to obtain statistically significant results was mainly related to too few samples and significant

intra- and inter-group variability. In addition, the selection of cadaveric knees made available for this study did not make it possible to represent the typical patient, rather young, active and without osteoarthritis presenting with these lesions and for whom this treatment will be applied. Another bias of the study is the inability to assess the contact mechanics of healed and fully embedded grafts in cadaver specimens. Instead, the grafts were assessed immediately after transplantation and their stability depended on sidewall friction along the borehole. Finally, it should be noted that the contact characteristics of the knee under dynamic loading or the effects of cartilage creep cannot be fully assessed through this medium. Shear forces cannot be measured with this type of pressure transducer.

Conclusion

It seems that biomechanically, filling our defect with smaller diameter plugs would be more effective in protecting healthy cartilage due to a better distribution of stresses. However, from a clinical point of view, it is more difficult to harvest small grafts due to their fragility. Thus, further studies should be conducted to support this idea.

Finally, the development of a more advanced reflection on these problems could benefit the improvement of existing surgical devices. The interest in developing specific instrumentation after planning the filling of an osteocartilaginous defect could also be considered.

Author contribution All authors contributed to the study's conception and design.

Material preparation, data collection, and analysis were performed by A. Caubère, F. Roseren, and G. Aullo-Rasser.

The first draft of the manuscript was written by A. Caubère and all authors commented on previous versions of the manuscript.

All authors read and approved the final manuscript.

Code availability Not applicable.

Data availability The data that support the findings of this study are available from the corresponding author.

Declarations

Ethics approval Approved by the Hospital and the Laboratory Ethics Committee.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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