

Press-fit stability of an osteochondral autograft

Influence of different plug length and perfect depth alignment

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Submitted 05-07-18. Accepted 05-12-23

Background Osteochondral autologous transplantation is used for the treatment of full-thickness articular cartilage lesions of a joint. Press-fit stability is an important factor for good survival of the transplanted plugs.

Material and methods 36 plugs of three different lengths were transplanted in fresh-frozen human knees. On one condyle, 3 plugs were exactly matched to the depth of the recipient site (“bottomed” plugs) and on the opposite condyle 3 plugs were 5 mm shorter than the depth of the recipient site (“unbottomed” plugs). Plugs were left protruding and then pushed in until flush, and then to 2 mm below flush level, using a loading apparatus.

Results Longer plugs needed higher forces to begin displacement. At flush level, bottomed plugs needed significantly higher forces than unbottomed plugs to become displaced below flush level (mean forces of 404 N and 131 N, respectively). Shorter bottomed plugs required higher forces than longer bottomed ones.

Interpretation Bottomed plugs generally provide much more stability than unbottomed ones. Short bottomed plugs are more stable than long bottomed plugs. Thus, in clinical practice it is advisable to use short bottomed plugs. If, however, unbottomed plugs are still chosen, the longer the plug the higher the resulting stability will be because of higher frictional forces.

In the past decade, osteochondral autologous transplantation has gained popularity for the treatment of full-thickness articular cartilage defects. Intrinsic stability has been shown to be an important factor for optimal in-growth of the transplanted plugs (Pearce et al. 2001, Makino et al. 2002) and thus appears to be correlated with a successful outcome. It seems plausible that the longer the plugs the greater the stability—because of higher frictional forces that hold the plugs in place. It also seems to be obvious that placing the plug directly on the bottom of the defect (rather than leaving a void underneath the plug) should result in a more stable situation.

Some authors have reported that protrusion of plugs results in higher contact pressures, which may damage the transplanted hyaline cartilage (Pearce et al. 2001, Wu et al. 2002, Koh et al. 2004). In practice, the surgeon often creates a deeper recipient site defect than the length of the harvested plug (unbottomed). In this way, the procedure is less time-consuming but—more importantly—the surgeon can make sure that the plug(s) will not protrude. By doing so, the surgeon is assuming that the frictional forces alone will provide enough stability for a plug not to become displaced below flush level.

We assessed the effect of length and depth alignment of the bone plug on its stability.

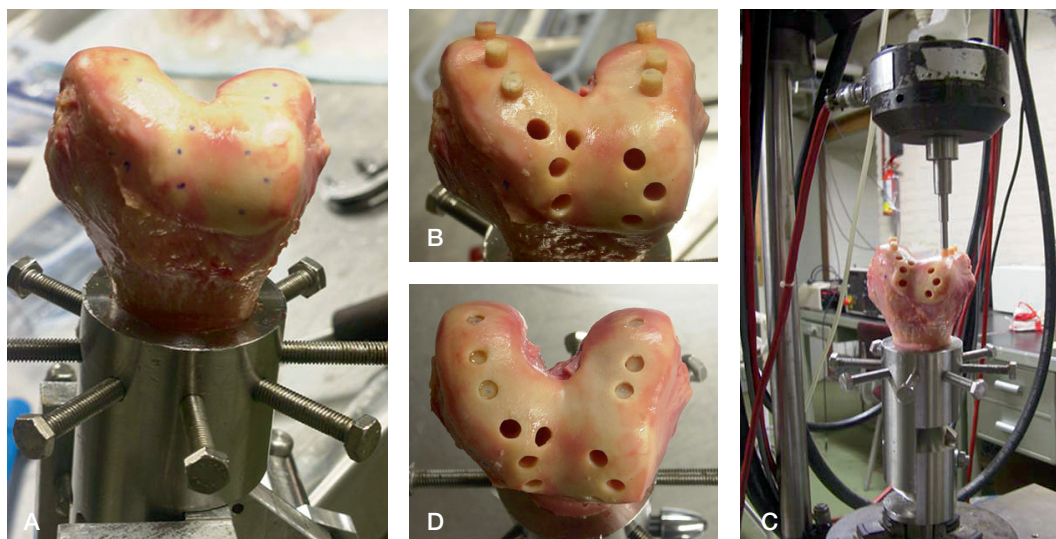


Figure 1.

A. The distal femur fixated in a steel container. Blue dots indicate locations for plug harvesting.

B. Femoral condyles after partial mosaicplasty. Plugs are placed approximately 5 mm above flush level.

C. Specimen under loading apparatus.

D. Specimen after the experiment was fully completed. Plugs are approximately 2 mm under flush level. Left side bottomed, right side unbottomed.

Material and methods

Material

We used 3 pairs of human distal femora. Specimens were freshly frozen and thawed at room temperature overnight before testing.

Preparations

The femoral side of a specimen was positioned in a steel container, in which it was fixated with screws and acrylic cement. Each condyle was marked with 3 permanent dots at the sites where the plugs were to be transplanted. The same procedure was carried out for the donor sites at the trochlear regions (Figure 1). Orientation and location of the plugs were selected such that they would not interact in the subchondral bone regions.

Plug locations were as follows. Every femoral condyle received 3 transplanted plugs of different lengths (8, 12 and 16 mm, respectively), alternating in position. Trochlear locations (donor sites) were treated in the same manner. If in one knee the plugs for the medial condyle were “bottomed”, the plugs of the lateral condyle were placed in a recipient site defect, 5 mm deeper than the plug length, and so these plugs were “unbottomed” (Figure 2). In the contralateral knee of the same patient, bot-

toming was performed in the opposite condyle, to rule out possible differences between lateral and medial condyles.

Bone plug transfer and testing

For the osteochondral transplantation we used a disposable 6-mm Osteochondral Autograft Transfer System (OATS) (Somas, Sint Anthonis, the Netherlands). When an osteochondral plug was to be bottomed, the bottom of the defect was tampered and measured for its depth. The plug harvested from the donor site was matched for this measured depth by removing some subchondral bone with surgical bone-nibbling pliers. The harvested plugs were then tampered in place until about 5 mm from flush with the recipient site cartilage surface (Figure 1), and this height was carefully measured.

After finishing one knee, the steel container was clamped on top of a tilting platform, so that tilting was possible in two opposite directions. The surface of one plug was placed horizontal in two planes and positioned under a plunger connected to a loading apparatus (Figure 1). This plunger had a diameter of 5.5 mm and was thus slightly smaller in diameter than the plugs, so that the edges of the surrounding host cartilage were not touched when the plunger pressed through flush level. The

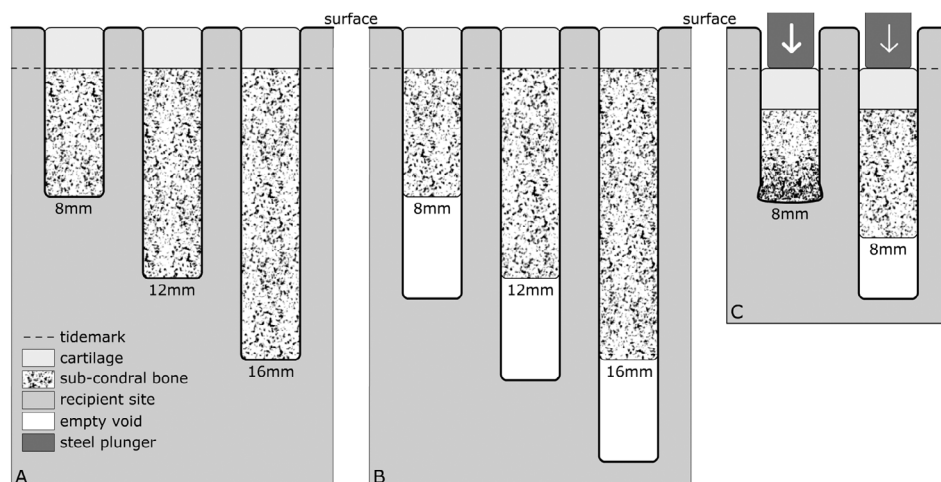


Figure 2.

- A. 3 bottomed plugs of different lengths (8–16 mm). The cartilage of the plugs is nicely flush with the surface of the recipient site, and the bottoms of the plugs are exactly positioned at the bottom of the defect.
- B. 3 unbottomed plugs of same lengths as in a. The cartilage of the plugs is also nicely flush but the bottoms of the plugs “float” about 5 mm above the bottom of the recipient site defect.
- C. 2 short plugs of 8 mm, after being pushed 2 mm below flush level by the plunger. The left plug is bottomed and the right plug is unbottomed. Notice the compression of subchondral bone at the bottom of the bottomed plug. The thicker white arrow represents the fact that more force is needed to displace the bottomed plug.

machine was set at displacement control with a rate of 0.5 mm per sec, and both the displacement and the force generated were recorded at a rate of 20 samples per sec. Following the previously measured plug height (approximately 5 mm above the joint surface), the machine was then set to move the plug until flush level was obtained, to stop for three seconds (to mimic the steady position of a plug after a normal OATS procedure) and to press further to 2 mm below flush level. The end result after testing is shown in Figure 1.

Evaluation of variables

Each of 6 knees provided 6 plugs, 2 of each length, of which 1 was bottomed and 1 un-bottomed. Thus, there were 36 plugs in total: 12 of 8 mm, 12 of 12 mm and 12 of 16 mm, half of them bottomed and half unbottomed (Table 1).

3 general groups were created for statistical evaluation: (1) the whole group of all plugs (bottomed and unbottomed combined), (2) a group with only bottomed plugs, and (3) one with only unbottomed plugs.

Statistics

Differences for plug lengths, bottomed versus

unbottomed, patient, left or right knee, medial or lateral condyle and location on condyle were examined within and throughout the groups. For statistical analysis, we used SPSS 9.0 for Windows. Groups were not normally distributed and the general linear model for multiple variances was used, to evaluate the difference in influence of plug length and perfect depth alignment. For testing of significance, we used the Tukey, equal variances assumed, post-hoc test. P-values less than 0.05 were considered to be statistically significant.

Results

Force-time curves showed some typical characteristics (Figure 3). The following were visible in all plots: the force required to start the initial displacement of the plug (a), the relatively constant increasing force to displace the plug until flush (b), then a waiting period of 3 seconds (c) during which a slightly reduced force was maintained. The second starting force from flush level (d) and the push-through force (e) were also visible.

The maximum force measured (in Newtons, N)—seen at individual stages a, b, d and e—was

Figure 3. Schematic graph showing force and displacement in time for both a bottomed and an unbottomed plug of 16 mm. Stage a. shows the force needed to start the initial displacement from approximately 5 mm above flush level. Stage b. shows the maximum force needed to get the plug flush. Stage c. is a three-second waiting period. Stage d. is the second starting point from flush level. Stage e. is the force required to push the plug 2 mm below flush level.

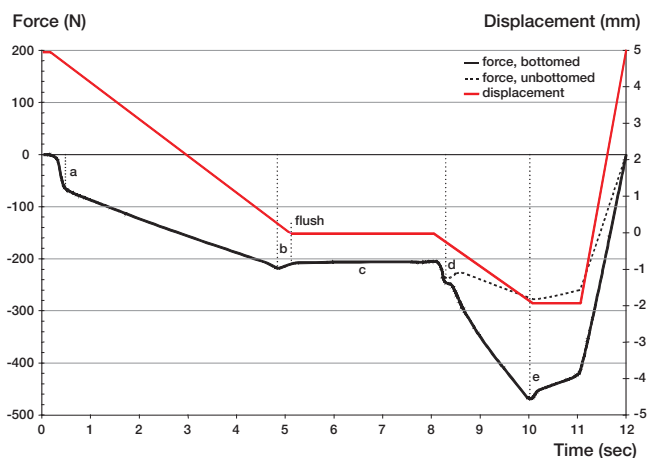


Table 2. Mean forces (SD) and significant p-values

Stage ^a	Plug length (mm)	Whole group (N)	P-value	Bottomed (N)	P-value	Unbottomed (N)	P-value bottomed vs unbottomed
a	8	27 (10)	(8 vs 12) 0.01				
	12	47 (21)	(8 vs 16) 0.02				
	16	45 (16)					
b	8	143 (45)					
	12	150 (70)					
	16	138 (59)					
flush level							
d	8			161 (48)		135 (40)	
	12			187 (76)		145 (52)	
	16			150 (69)		153 (61)	
e	8			528 (69)	(8 vs 12) 0.03	123 (58)	< 0.001
	12			384 (76)	(8 vs 16) 0.001	171 (43)	< 0.001
	16			294 (105)	(12 vs 16) 0.12	151 (69)	0.02

^a See Figure 2

used for the evaluation, except for stage e in the unbottomed group, where forces often diminished after motion (stage d) was obtained, so in that case the endpoint of this stage was used.

Statistics

No significant or apparent differences between specimens for sex, knee side, condyle side or condyle locations were found.

Stage a. In the whole group, the 12-mm and 16-mm plugs showed higher forces (Table 2) when compared to 8-mm plugs ($p = 0.01$ and $p = 0.02$, respectively). For the 12-mm and 16-mm plugs,

forces were similar. The bottomed group and unbottomed group were not reviewed separately, because at this stage all plugs were in fact still unbottomed.

Stage b. No apparent tendencies or significant differences were found in any of the groups.

Stage d. In the unbottomed group, there was a trend showing a relationship between longer plugs and higher forces, but no statistically significant significance was found. For the whole group and the bottomed group, no apparent tendencies in the relationship between plug length and force were found.

Stage e. A clear difference was found between bottomed and unbottomed plugs; forces needed to push the plugs below flush level were greater for bottomed plugs. In the 8-mm group, mean forces were 528 N and 123 N, respectively ($p < 0.001$). In the 12-mm group, mean forces were 384 N and 171 N, respectively, ($p < 0.001$) and in the 16 mm group the corresponding values were 294 N and 151 N ($p = 0.02$).

Within the bottomed group, the 12-mm and 16-mm plugs showed lower mean forces, 384 N and 294 N respectively, than 8-mm plugs ($p = 0.03$ and $p = 0.001$, respectively) where the mean force was 528 N. No significant difference in mean force was found between 12-mm and 16-mm plugs ($p = 0.1$), although there was a similar trend.

Discussion

Osteochondral autologous transplantation is a relatively simple method for directly placing healthy hyaline cartilage into full-thickness articular cartilage defects of the weight-bearing area of the knee. Although short-term and mid-term outcome results are promising (Jakob et al. 2002, Bentley et al. 2003, Hangody and Fules 2003, Horas et al. 2003), there are some problems such as donor site morbidity (Feczko et al. 2003, van Susante et al. 2003), cartilage integration and survival (Evans et al. 2004, Kock et al. 2004, Tibesku et al. 2004), and cyst formation in the subchondral bone (Pearce et al. 2001). Lack of cartilage integration between plug and surrounding cartilage is still an unsolved problem. Damage to cartilage can mainly be attributed to higher contact pressures generated from surface irregularities and height misalignment of the plugs with their surrounding cartilage. Healthy and thus well-integrated subchondral bone, from which chondrocytes receive their nutrition, is also important for survival of the hyaline cartilage. Cyst formation has mainly been ascribed to instability of the plugs and the possibility of synovial fluid entering subchondral bone locations. Whiteside et al. (2003) have already reported that the initial stability after plug transfer becomes reduced by more than 50% after 1 week. These factors emphasize the necessity to provide as much stability as possible to the plugs during osteochondral transplantation.

Interpretation of results

We found that when displacing unbottomed plugs, higher forces are needed when using longer plugs because of higher frictional forces (Figure 3: stages a and d; Figure 2b). For a plug to become displaced from its steady position, static friction must be overcome (stages a and d). This is generally higher than dynamic friction, which must be overcome when the plug has already gained motion (stages b and e). This explains why stage a shows a much steeper curve, meaning higher forces per displacement unit, than stage b (as also with stage e in comparison to stage d in the unbottomed group). Perhaps this relatively low dynamic friction—combined with the small number of plugs per group ($n = 6$) and possible inter-plug variance—also accounts for the fact that no obvious associations were found in stage b.

When pushing bottomed plugs past flush level (stage e and Figure 2c), we found an association between plug length and displacement forces. When using longer plugs, lower forces were needed. Hence, when plugs are bottomed they are more stable if they are shorter. It seems that the intact, still fully integrated trabecular system of the (subchondral) bone supporting a plug is more stable than a long column of subchondral bone in a harvested plug; thus, longer plugs are more easy to compress than shorter ones. Even so, when plugs are being bottomed, regardless of length, this always results in a more stable situation at flush level than when plugs are unbottomed (Figure 2).

We realize that this experiment has been conducted *ex vivo*, and thus represents clinical reality only to a limited extent. However, by using fresh-frozen human knees, we believe we have approximated a clinical situation as well as possible. The displacement of the plunger was a relatively slow and continuous motion. This differs considerably from the clinical setting, in which the plugs are tampered into position. The plunger displacement as prescribed in this study provided optimal reproducibility, however. Furthermore, we realize that we used only one single plug and therefore did not perform an actual mosaicplasty, where other factors play a dominant role in maintaining a stable position, such as inter-plug and plug-host incongruencies, surface curvature and differences in contact pressures. Also, in comparing donor

plugs and their recipient site, cartilage layer thickness was not equal; however, this risk is the same in clinical practice. Tidemarks will often not be at the same level, but for a successful outcome we believe that it is more important that the cartilage surfaces are flush.

Stability

Duchow et al. (2000) performed some tests on the use of different plug lengths and diameters and found significant differences, but they only tested the pull-out strength of the plugs, which—clinically—seems to us to be of less importance than the push-through force. More recently, Kordas et al. (2005) reported that bottomed plugs were more stable than unbottomed ones, but only a few groups were compared. They also suggested that if plugs were bottomed, a recipient site would result in higher impaction forces to get the (relatively longer) plug at flush level. As discussed earlier, protrusion of a plug will most likely result in failure, especially when a plug is bottomed and there is no possibility of subsidence of the plug. So when placing a plug that is longer than its recipient site, this risk is a real one; therefore, this test seems hardly contributable to clinical practice.

In most biomechanical studies, including ours, only stability in the sagittal direction has been addressed. In general, longer plugs generate higher frictional forces and are therefore more difficult to displace. In our opinion, even an almost bottomed plug, irrespective of length, can be considered to be unbottomed. The little void underneath the plug initially results in a less stable situation, with a greater risk of the plug subsiding below flush level (and thus more risk of failure) than when the plug is bottomed exactly. As stated before, shorter bottomed plugs appeared to be more stable than longer bottomed ones, but whether this leads to improved clinical performance remains to be investigated.

Cartilage survival

If longer plugs produce higher retention strengths (in a push-through configuration), it would also require a higher force to tamper the longer plugs in place. These forces could potentially become so high that the viability of the cartilage cap might be compromised. While impacting articular cartilage, Repo and Finlay (1977) found a threshold of

25 Mpa, below which chondrocyte death or structural damage was seen. Torzilli et al. (1999) also reported that this force should not exceed 15–20 Mpa, to prevent cartilage degeneration. If one takes the lowest acceptable compression stress as 15 MPa, in our setting, with a plunger size of 5.5 mm diameter, this would mean a compression force of 356 N. This threshold reflects a single impact force and is probably best approximated by the maximum force we found to get the plug at flush level, though the plunger was smoothly moved instead of tampered. Maximum measured force was 247 N (mean 144 N) and therefore this threshold was not reached, but in clinical practice multiple tampering is actually necessary to get the plugs in place. Nabavi-Trabrizi et al. (2002) described cartilage damage following plug transfer by means of consecutive tampering with either a plastic or steel hammer, while tampering was limited to 5 times. We have found no reports on the influence of force repetition on cartilage viability and on whether the repetitive forces must be combined, or that the cartilage can recover between impacts. In our study, the fact that this critical force was not reached is probably best ascribed to the fact that only one-time static friction had to be overcome, while in the case of consecutive tampering this force has to be overcome several times. It remains to be shown whether the use of shorter plugs and a more continuous motion for displacement of the plugs will prohibit damage to the cartilage cap.

Clinical relevance

Bottoming of plugs generally provides greatest stability. When using unbottomed plugs, longer plugs result in higher stability and are thus advisable in clinical practice. When there are few harvest locations and/or harvesting of long plugs is prohibited because of interaction in the subchondral bone regions, the use of short, bottomed plugs may help to overcome this problem—and may even provide the most stable reconstruction.

Contributions of authors

NK practical execution and writing of article. JvS orthopedic aspects and manuscript correction. PB biological aspects and manuscript correction. AvK orthopedic aspects and manuscript correction. NV biomechanical aspects and manuscript correction.

No competing interests declared.

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