Eklem Hastalıkları ve Cerrahisi
Joint Diseases and Related Surgery

Review / ***Derleme***

Joint Dis Rel Surg
2007;18(3):150-155

The role of primary stability in mosaicplasty: a review of the literature

Mozaikplastide primer stabilitenin rolü: Literatür değerlendirmesi

Géza Kordás, M.D.

Department of Orthopaedics and Trauma, Great Western Hospital

Mosaicplasty was introduced into clinical practice 15 years ago and since then it has gained increasing popularity in the treatment of small- and medium-sized cartilage defects. Survival of the transplanted cartilage and integration of the grafts have been shown both in animal studies and humans. Short- and mid-term results are now available and seem promising. Along with the widespread use of the technique, biomechanical investigations have been launched aiming at improvement of the operative technique and achieving better results. These studies are concerned with donor site morbidity, congruency, the effect of harvesting and implantation techniques, and primary stability. The latter is of paramount importance, since press-fit primary stability ensures that grafts remain flush with the surrounding cartilage surface, in which position integration occurs. A better understanding of the biomechanics of the mosaicplasty technique should improve the outcomes of the procedure. This paper summarizes the results of the biomechanical studies on primary stability in mosaicplasty and puts their conclusions into perspective.

Key words: Biomechanics; cartilage, articular/injuries/transplantation; chondrocytes/transplantation; knee injuries/surgery; stress, mechanical; transplantation, autologous.

Mozaikplasti klinik uygulamaya 15 yıl önce girmiştir ve o zamandan bu yana küçük ve orta büyüklükte kıkırdak defektlerinin tedavisinde giderek artan bir yaygınlığa ulaşmıştır. Nakledilen kıkırdağın canlı kaldığı ve greftlerin ortamla bütünleştiği hem havyan çalışmalarında hem de insanda gösterilmiştir. Bu çalışmaların alınmaya başlanan kısa ve orta dönem sonuçları ümit vericidir. Tekniğin yaygınlık kazanmasıyla birlikte, ameliyat tekniğini iyileştirmeyi ve daha iyi sonuçlar almayı hedefleyen biyomekanik çalışmalar da başlatılmış bulunmaktadır. Bu çalışmaların başlıca konuları verici alan morbiditesi, yüzey uyumluluğu, greft elde etme ve uygulama tekniklerinin etkileri ve primer stabilitedir. Bunlar arasında primer stabilitenin önemi çok büyüktür, çünkü, pres-fit primer stabilite greftlerin çevre kıkırdak yüzeyiyle aynı hizada olmasını, dolayısıyla bütünleşmeyi sağlar. Mozaikplasti tekniğinin biyomekaniğinin daha iyi anlaşılması işlemin başarılarını da artıracaktır. Bu derlemede, mozaikplastide primer stabilite üzerine yapılan biyomekanik çalışmalar özetlendi ve bunların sonuçları değerlendirildi.

Anahtar sözcükler: Biyomekanik; kıkırdak, eklem/yaralanma/transplantasyon; kondrosit/transplantasyon; diz yaralanması/cerrahi; stres, mekanik; transplantasyon, otolog.

Over the past decade autologous osteochondral grafting has gained increasing popularity in the treatment of focal chondral and osteochondral defects of weight-bearing joints. The survival of the chondrocytes, maintenance of hyalin matrix properties, and integration of bone of the recipient area and the grafts have already been shown in animal models and in humans.[1,2] Short- and medium-term results achieved by several authors are promising.[3-6] In the last seven years, a number of biomechanical investigations have been published, the common aim of which is to give a better understanding of what happens to the grafts during and after the procedure and its possible bearing on outcome. Various studies cover several issues from donor site morbidity, congruency, and contact pressure to harvesting and implantation techniques. Primary stability is of major concern since the reconstruction and maintenance of a congruent gliding surface is of paramount importance for good outcomes. On the other hand, excessive insertion forces may damage the transplanted cartilage. The studies on primary stability reviewed in this paper may

---

- *Received: August 28, 2007 Accepted: October 30, 2007*

- Correspondence: Géza Kordás, MD. Department of Orthopaedics and Trauma, Marlborough Road, Swindon SN3 6BB, UK.
  Tel: +44 790 861 27 32 *Fax:* +44 179 360 49 17 *e-mail:* kordas@index.hu

help improve our operative technique as well as the instrumentation, both of which should contribute to better outcomes.

Congruency

Achieving a congruent surface after mosaicplasty is paramount to the clinical outcome. If the grafts are inserted in an oblique fashion or sink below the surrounding articular surface, the gaps will be filled with fibrocartilage. It has been shown that fibrocartilage is biomechanically inferior to normal hyalin cartilage[7,8] and, therefore, the articular surface area covered by it should be minimized.

In a finite element study Wu et al.[9] showed that inadequate placement of the osteochondral plugs produced abnormal stress and strain distribution within the cartilage. This may lead to degeneration of the transplanted grafts.

Koh et al. studied the effect of height mismatch[10] and angled grafting[11] in a porcine model and demonstrated that normal contact pressure could be restored by osteochondral grafts inserted flush, but plugs inserted higher or higher and angled resulted in significantly higher contact pressures.

Huang et al.[12] investigated the effect of small incongruities in a sheep model after osteochondral grafting. Their results showed that, in grafts sunk less than 1 mm, the cartilage thickened through chondrocyte hyperplasia and tidemark advancement, whereas cartilage necrosis and fibrous overgrowth were observed in grafts countersunk 2 mm.

There is certainly limited experience in humans due to the ethical issues regarding control arthroscopies. In a small series of five patients with protruding and sunk grafts, Nakagawa et al.[13] saw no short-term problems with depressed grafts, but patients experienced catching with protruding grafts.

Primary stability

Having achieved a congruent repair surface, maintenance of this congruency is vital. This relies on the primary stability of the grafts until bony union occurs with the recipient area providing secure anchorage for the grafts. To prevent graft subsidence, patients are instructed to remain non-weight bearing for many weeks after surgery, making rehabilitation rather long. However, young and active mosaicplasty patients – not infrequently athletes – want to return to normal activities and training without delay. It would be therefore of significant clinical importance to improve the operative technique and produce primarily stable grafts that would withstand physiologic loads reliably.

Furthermore, Makino et al.[14] found that primary stability contributed to the maintenance of histologic properties of the transplanted cartilage. In a rabbit model, loose grafts showed signs of degeneration, while stable ones maintained their normal hyalin appearance.

Instrumentations developed for osteochondral grafting provide a degree of press-fit primary stability for the grafts. Usually a graft of larger diameter is inserted into a recipient hole of smaller diameter with or without dilating the latter. The strength of this primary stability depends on multiple factors, some of which have been studied in animal models and on human bone.

Duchow et al.[15] were the first to investigate the effect of graft diameter and length, repeated insertions and harvesting technique on the primary stability of osteochondral grafts. They used the osteochondral allograft transfer system (OATS) on fresh frozen porcine femurs. A 2-mm screw was inserted in the middle of the grafts before harvest and pull-out strength was measured on a mechanical testing machine. They found that failure loads of the 10-mm long grafts were significantly lower than those of the 15-mm or 20-mm long ones. Reinsertion of a 15-mm long graft reduced the mean failure loads by more than 50% after the first reinsertion and by about 65% after the second one. Failure loads of 8-mm diameter grafts were significantly lower than those of 11-mm grafts. Levering the tubular chisel resulted in about 40% reduction in failure loads compared with just turning the chisel during graft harvest.

On the basis of their results, they suggested using longer or larger diameter grafts if primary stability was to be improved and avoiding both repeated insertion and levering the tubular chisel during graft harvest.

Later studies has also confirmed that longer grafts and grafts of larger diameter resist more push-in force than shorter or smaller grafts and it is now generally accepted that this is the result of a larger surface area and higher frictional forces. Repeated insertion seems to decrease primary stability, but no explanation of the mechanism was offered in their paper. It is speculative, but probably realistic to say that moving the graft in the recipient hole results in a more even surface on both sides, decreasing frictional forces. Levering the chisel during harvest was also found to decrease primary stability and the authors suggested that this might be caused by the grafts breaking off in an oblique fashion, thus reducing the surface area. No data was included regarding the difference between the length of the levered and not levered grafts or an estimate about the difference in the total surface area. The mechanism leading to decreased stability after levering is therefore not yet clear.

The authors used pull-out testing, because it is a commonly used technique to test fixation strength of orthopedic implants like interference screws in anterior cruciate ligament reconstruction. The main difference is that interference screws should resist pull-out *in vivo* as well; however, osteochondral grafts are subject to mainly compressive forces.

There was also a tenfold variation in the pull-out forces within groups, which was not seen in later experiments measuring push-in forces. This may reflect an internal error of the testing method, probably related to the placement of the screw in the graft. In a later study, Whiteside et al.[16] found that pull-out strength was consistently lower than push-in strength after osteochondral grafting.

Whiteside et al.[16] studied the push-in and pull-out strengths of osteochondral grafts immediately after and one week following transplantation. The authors used the Soft Delivery System to transplant 6.3-mm grafts to fresh porcine femurs. Push-in and pull-out forces were found to be 44% less on average after one week incubation in culture medium. Indentation testing was performed to ensure that mechanical properties did not change during a week period and eventually no significant difference was found in the elastic modulus of the donor or the recipient bone. Cell necrosis due to surgical trauma and press-fit pressure are the suspected causes of decreasing stability. Limitations of this study include the lack of circulation and presence of cellular, humoral, and mechanical factors which are known to have role in fracture healing.

It has been shown in dogs that bone resorption at the graft-recipient interface does occur after mosaicplasty; thus, a decrease in primary stability is very likely.[1]

In our first experiment, we studied the effect of drill-hole length on primary stability after mosaicplasty.[17] We used the Acufex MosaicPlasty system and fresh porcine femurs. A single 15-mm long graft was harvested from the trochlea and inserted into 20-, 15-, and 12-mm long drill-holes in the lateral femoral condyle. Specimens were mounted on a universal testing machine and push-in forces were recorded from 7 mm proud to flush and then 3 mm further (Fig. 1). Level push-in forces were not significantly different in the unbottomed and bottomed groups and similarly we found no difference at 1-mm level. However, at 2-mm level bottomed-out grafts needed about 30% more force than unbottomed ones and this difference increased to 50% at 3-mm level. In the third group where 15-mm grafts were inserted into 12-mm long holes, push-in forces were significantly higher at all levels than those in the first two groups.

These results suggest that, with similar push-in forces at flush level, bottomed grafts are more stable than unbottomed ones. However, even flush push-in forces increase significantly when grafts are 3 mm longer than recipient holes.

In our second series of experiments, we investigated the effect of graft diameter, dilation length, and multiple grafting on primary stability.[18] We again used the Acufex MosaicPlasty instruments. In the first series, single osteochondral grafts, 4.5 and 6.5 mm in diameter were transplanted from the trochlea of porcine femurs to the weight-bearing area of the lateral femoral condyle. In the second series, 4.5-mm grafts were transplanted into drill holes dilated to 15 mm and 20 mm in length.

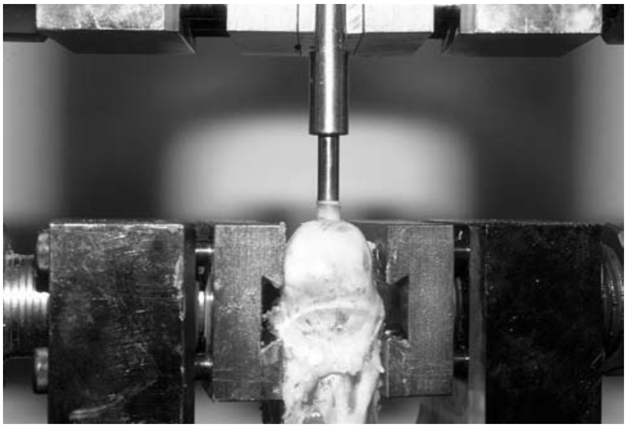

Fig. 1. Specimen in the testing machine. Porcine femurs were mounted on the testing machine with the grafts 7 mm proud. The medial condyle was removed.

In the multiple grafting series, three grafts 4.5 mm in diameter were transplanted either in a row or in a circular fashion. All grafts were unbottomed. Similar to the previous experiment, the grafts were left proud and first pushed in level with the surrounding cartilage surface, then they were pushed further 3 mm below the cartilage level. The push-in forces were measured.

We found that 6.5-mm grafts resisted significantly greater push-in forces at all levels compared to 4.5-mm grafts. Push-in forces that 4.5-mm grafts resisted decreased by 43%, 42%, 33%, and 24% at flush level, and at 1-mm, 2-mm, and 3-mm levels, respectively. Comparisons between 15-mm and 20-mm dilation lengths showed no significant differences at flush, 1-mm and 2-mm levels, but push-in forces increased by 25% in the 15-mm dilation series at 3-mm level. Multiple grafting of three 4.5-mm grafts either in a row or in a circular fashion resulted in similar primary stability. Level push-in forces were similar to the single control series, but stability decreased by 43% at 1-mm, and 39% at 2- and 3-mm levels. These data suggest that grafts of greater diameter resist greater push-in forces, a result consistent with that reported by Duchow et al.[15] Stability may be increased by a shorter dilation length, while level push-in forces do not increase significantly, but this was evident only at 3-mm level in our setting. There is no difference in primary stability between grafts implanted in a row or in a circular fashion and multiple grafts are not as stable as single ones using unbottomed grafts.

Kock et al.[19] investigated the effect of plug and drill-hole length on the primary stability of osteochondral grafts. They used the OATS instruments for transplantation of grafts, 6 mm in diameter, from the trochlea to the medial and lateral femoral condyles of fresh-frozen human femurs. Level push-in forces for 12-mm and 16-mm plugs were similar and consistently higher than for 8-mm plugs. For pushing further, 2-mm "bottomed-out" grafts needed significantly higher forces than "unbottomed" grafts of any length. On the other hand, 8-mm bottomed grafts needed significantly higher forces than 12-mm or 16-mm grafts and similar trend was observed between 12-mm and 16-mm grafts.

This study again confirms what has already been shown in porcine models that longer grafts result in better primary stability if unbottoming and bottoming out increase push-in resistance.

A new finding of this study was, however, that 8-mm grafts proved to be more stable than longer grafts if bottomed-out. This can be explained by the more compact subchondral bone on both the donor and recipient sides of shorter grafts. After bottoming-out, the bottom of the graft or the recipient hole, or both need to be compressed for further displacement and this is easier in the case of longer grafts with less compact bone on both sides.

Without ignoring the fact that the statistical power of their findings might have been affected by the use of only three pairs of femurs, it is noteworthy that they found no differences in push-in forces between medial or lateral condyles or condyle locations. Bearing in mind that contact pressures are significantly higher in the medial compartment of the intact knee,[20] this finding may have clinical implications.

One limitation of animal model studies is that, although porcine bone is very similar to human in biomechanical properties, absolute values of stability cannot be used directly in human practice.

Furthermore, primary stability may well decrease with time as Whiteside et al.[16] suggest, but the extent and time course *in vivo* are still unknown. Finally, the grafts will be subjected to cyclic loads rather than a single impact as in all the experiments mentioned above, and stability under these circumstances may be very different from that measured here.

It is, however, clear that maximizing primary stability by increasing the press-fit effect will certainly result in higher push-in forces during graft insertion. There is no consistency in the literature on a threshold above which irreparable cartilage damage occurs. Repo and Finlay[21] reported this threshold to be around 25 MPa detected by autoradiography, light and electron microscopy in fresh human tibias. Torzilli et al.[22] found 15-20 MPa to cause chondrocyte death and collagen fibre damage in porcine cartilage. Borelli et al.[23] found no cartilage damage in rabbits after 2, 6, and 12 weeks following a single impact of 55.5 MPa.

Borazjani at al.[24] found that the use of the OATS instruments to insert 15-mm grafts, 10 mm in length, resulted in an average of 13.3 MPa of stress in fresh human distal femoral cartilage. This was enough to cause 21% chondrocyte cell death at the superficial 0.5-mm level at 1 hour after transplantation, and 47% death after 48 hours.

Whiteside et al.[25] suggested that there was a logarithmic relationship between the single impact energy and depth of cell death in bovine and porcine cartilage. Furthermore, they found that the mean force of impact predicted the depth of chondrocyte death more strongly than the number of impacts.

In conclusion, based on the above studies push-in forces should be reduced during graft insertion and ideally kept in the physiologic range. A sound means of improving primary stability is inserting grafts into recipient holes of the same length and adding the "bottoming-out" effect to press-fit. This, although looks simple, is not easy to perform. The bottom of the graft is rarely regular flat and also the bottom of the hole may well be irregular if not drilled, but prepared using a tubular chisel. Our study showed that flush and 1-mm below level push-in forces in the unbottomed and bottomed groups did not differ significantly, but further push-in forces were higher in the bottomed group. Harvesting grafts a few millimeters longer than the recipient hole and cutting its bottom flat leaving it 1 mm longer than the recipient hole could ensure exact graft length and geometry. The recipient hole should not be drilled or chiselled to the definitive length, but 1 mm shorter. A tamp can then be used to reach the desired length and produce a flat and somewhat compressed surface on the bottom of the recipient hole. Further studies should confirm the usefulness of this technique.

Repeated insertion should also be avoided. It may be reasonable to reinsert the graft into a new drill hole using the "bottom-out" technique.

The relationship between graft size and *in vivo* primary stability is not obvious. Although the above studies show that grafts of larger diameter resist greater push-in or pull-out forces, *in vivo* larger grafts will be exposed to larger compressive forces than smaller ones owing to their larger surface area. In our study, a 6.5-mm graft resisted 1.3 times greater push-in force than a 4.5-mm graft did. However, the surface area of a 6.5-mm graft is more than twice, making the force per unit area more than double at any contact pressure level.

Further studies should elucidate the time course of changes in primary stability and the effect of cyclic load. Once we agree on the strength of primary stability to be achieved, instruments capable of intraoperative pressure measurements can be developed to help fine-tune our operative technique, which may possibly allow early full weight-bearing after mosaicplasty.

REFERENCES

1. Hangody L, Kish G. Karpati Z, Szerb I, Udvarhelyi I, Toth J, et al. Autogenous osteochondral graft technique for replacing knee cartilage defects in dogs. Orthop Int 1997;5:175-81.
2. Harman BD, Weeden SH, Lichota DK, Brindley GW. Osteochondral autograft transplantation in the porcine knee. Am J Sports Med 2006;34:913-8.
3. Jakob RP, Franz T, Gautier E, Mainil-Varlet P. Autologous osteochondral grafting in the knee: indication, results, and reflections. Clin Orthop Relat Res 2002;(401):170-84.
4. Marcacci M, Kon E, Zaffagnini S, Iacono F, Neri MP, Vascellari A, et al. Multiple osteochondral arthroscopic grafting (mosaicplasty) for cartilage defects of the knee: prospective study results at 2-year follow-up. Arthroscopy 2005;21:462-70.
5. Kreuz PC, Steinwachs M, Erggelet C, Lahm A, Henle P, Niemeyer P. Mosaicplasty with autogenous talar autograft for osteochondral lesions of the talus after failed primary arthroscopic management: a prospective study with a 4-year follow-up. Am J Sports Med 2006;34:55-63.
6. Szerb I, Hangody L, Duska Z, Kaposi NP. Mosaicplasty: long-term follow-up. Bull Hosp Jt Dis 2005;63:54-62.
7. Coletti JM Jr, Akeson WH, Woo SL. A comparison of the physical behavior of normal articular cartilage and the arthroplasty surface. J Bone Joint Surg [Am] 1972; 54:147-60.
8. Franke O, Durst K, Maier V, Goken M, Birkholz T, Schneider H, et al. Mechanical properties of hyaline and repair cartilage studied by nanoindentation. Acta Biomater 2007;3:873-81.
9. Wu JZ, Herzog W, Hasler EM. Inadequate placement of osteochondral plugs may induce abnormal stress-strain distributions in articular cartilage-finite element simulations. Med Eng Phys 2002;24:85-97.
10. Koh JL, Wirsing K, Lautenschlager E, Zhang LO. The effect of graft height mismatch on contact pressure following osteochondral grafting: a biomechanical study. Am J Sports Med 2004;32:317-20.
11. Koh JL, Kowalski A, Lautenschlager E. The effect of angled osteochondral grafting on contact pressure: a biomechanical study. Am J Sports Med 2006;34:116-9.
12. Huang FS, Simonian PT, Norman AG, Clark JM. Effects of small incongruities in a sheep model of osteochondral autografting. Am J Sports Med 2004; 32:1842-8.
13. Nakagawa Y, Suzuki T, Kuroki H, Kobayashi M, Okamoto Y, Nakamura T. The effect of surface incongruity of grafted plugs in osteochondral grafting: a report of

five cases. Knee Surg Sports Traumatol Arthrosc 2007; 15:591-6.

14. Makino T, Fujioka H, Terukina M, Yoshiya S, Matsui N, Kurosaka M. The effect of graft sizing on osteochondral transplantation. Arthroscopy 2004;20:837-40.
15. Duchow J, Hess T, Kohn D. Primary stability of press-fit-implanted osteochondral grafts. Influence of graft size, repeated insertion, and harvesting technique. Am J Sports Med 2000;28:24-7.
16. Whiteside RA, Bryant JT, Jakob RP, Mainil-Varlet P, Wyss UP. Short-term load bearing capacity of osteochondral autografts implanted by the mosaicplasty technique: an in vitro porcine model. J Biomech 2003;36:1203-8.
17. Kordas G, Szabo JS, Hangody L. The effect of drill-hole length on the primary stability of osteochondral grafts in mosaicplasty. Orthopedics 2005;28:401-4.
18. Kordas G, Szabo JS, Hangody L. Primary stability of osteochondral grafts used in mosaicplasty. Arthroscopy 2006;22:414-21.
19. Kock NB, Van Susante JL, Buma P, Van Kampen A, Verdonschot N. Press-fit stability of an osteochondral autograft: Influence of different plug length and perfect depth alignment. Acta Orthop 2006;77:422-8.
20. Bruns J, Volkmer M, Luessenhop S. Pressure distribution at the knee joint. Influence of varus and valgus deviation without and with ligament dissection. Arch Orthop Trauma Surg 1993;113:12-9.
21. Repo RU, Finlay JB. Survival of articular cartilage after controlled impact. J Bone Joint Surg [Am] 1977; 59:1068-76.
22. Torzilli PA, Grigiene R, Borrelli J Jr, Helfet DL. Effect of impact load on articular cartilage: cell metabolism and viability, and matrix water content. J Biomech Eng 1999;121:433-41.
23. Borrelli J Jr, Zhu Y, Burns M, Sandell L, Silva MJ. Cartilage tolerates single impact loads of as much as half the joint fracture threshold. Clin Orthop Relat Res 2004;(426):266-73.
24. Borazjani BH, Chen AC, Bae WC, Patil S, Sah RL, Firestein GS, et al. Effect of impact on chondrocyte viability during insertion of human osteochondral grafts. J Bone Joint Surg [Am] 2006;88:1934-43.
25. Whiteside RA, Jakob RP, Wyss UP, Mainil-Varlet P. Impact loading of articular cartilage during transplantation of osteochondral autograft. J Bone Joint Surg [Br] 2005;87:1285-91.