Primary stability of osteochondral grafts in mosaicplasty

Short thesis

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Introduction

Focal chondropathies in weight bearing joints present a significant problem for orthopaedic surgeons. Little is known about the natural history of these lesions and their long term effects on joint function. Since hyalin cartilage has a very limited healing potential spontaneous regeneration of these defects cannot be expected. Partial thickness lesions show minimal regeneration and full thickness ones may “heal” by fibrocartilagenous repair from multipotent cells of the subchondral bone. (Buckwalter) Focal chondropathies occur very often in the young and active – not infrequently in sportsmen – therefore the treatment should aim at maintaining long term activity levels. In the last 15 years new techniques have been developed for the treatment of the previously generally ignored focal chondropathies. (Steadman, Hangody, Brittberg). These techniques are used in cases with ICRS grade III-IV chondropathies and osteochondral defects. Most authors recommend these methods for patients younger than 40-45 years which accounts for 5-7% of all knee arthroscopies in epidemiologic studies. (Hjelle, Widuchowski, Curl) This is a significant number considering the several million arthroscopies performed each year world wide.

Several techniques have been described for the treatment of chondral defects, but the ideal one is yet to come. Since a lot of patients become symptom free for a significant period of time after debridement this simple, low risk treatment is one of the first line treatments especially in small lesions. (Hubbard, Dozin) Experimental studies and clinical data have shown that patients with chondral lesions measuring more than 1 cm in diameter may benefit from cartilage repair since in these case increased contact pressure and shear forces may result in degenerative changes. (Güttler)

After bone marrow stimulating techniques multipotent cells from bone marrow and blood clot fill the cartilage defect. Through proper rehabilitation this clot matures into fibrocartilage in a few weeks time. The most advanced of these methods is the microfracture technique. (Steadman) The mechanical properties of fibrocartilage are inferior to the intact hyalin cartilage but may be suitable for small defects (Coletti, Franke) Cell based techniques involve removing a small amount of intact cartilage, cultivation in vitro than reimplantation into the defect area. The chondrocyte suspension
can be injected under a periosteum flap (Brittberg), or resorbable membrane (Caplan) In second generation chondrocyte transplantation a preformed matrix is seeded with the cells and implanted into the defect. (Marcacci) This method results in a hyalin-like repair tissue with most components of normal articular cartilage. The techniques used in clinical practice have not been successful in reproducing the highly organized collagen structure of native hyalin cartilage.

The mosaicplasty technique was developed in the early 1990s and introduced into clinical practice in 1992. Since then it has become a popular method of focal chondral and osteochondral defects. (Biró, Bobic, Buckwalter, Berlet, Laprell, Chow)

Mosaicplasty is indicated in full thickness cartilage defects not greater than 4 cm². The maximal size of the lesion is limited by donor site morbidity. (Hangody)

The procedure can be performed arthroscopically, through a mini incision or open depending on the size and location of the defect as well as on experience. Mosaicplasty involves harvesting of osteochondral grafts from the less weight-bearing periphery of the patello-femoral joint into the defect on the weight-bearing surface. The gaps between the grafts will be filled by fibrocartilage producing a hyalin-fibrocartilage composite surface.

Weight-bearing is restricted for 4-8 weeks postoperatively depending on the location and size of the lesion. Full range of motion exercises may be commenced on 1 postoperative day.

Clinical results of the technique are encouraging. In the largest series good and excellent results were found to be between 78-94% depending on the site of the lesion. The best results were achieved on the talar dome and the worse in the patello-femoral joint. (Hangody) Independent authors published similar results in smaller series with shorter follow-ups. (Kreuz, Jakob, Ozturk, Marcacci)

Chondrocyte survival and graft-host integration has been confirmed in both animal studies and on human specimens. (Chow, Nam, Harman, Hangody)

Along with the widespread use of the technique biomechanical investigations has been initiated aiming at improvement of the operative technique and achieving better results. These studies include investigations on donor site morbidity, congruency, the effect of harvesting and implantation techniques, graft sizing and positioning, biomechanical
properties of the transplanted cartilage and primary stability. (Duchow, Whiteside, Koh, Huntley, Pearce)

The latter is of paramount importance, since press-fit primary stability ensures that grafts remain flush with the surrounding cartilage surface and integration occurs in this position.

It has been shown in animal studies that sunk grafts will be covered by biomechanically inferior fibrocartilage. (Coletti, Franke)

Wu used a finite element model, while others showed in animal studies that inadequate positioning of the grafts results in abnormal stress and strain distribution in the transplanted cartilage and prompts degenerative changes. (Wu, Koh, Pearce, Huang)

Osteochondral grafts may be subjected to significant stress during insertion. There is no agreement in the literature regarding the level of stress that causes irreversible damage to the cartilage. (Repo, Torzilli, Borelli) Whiteside found logarithmical relationship between the single impact energy and the depth of cell death. Quinn saw chondrocyte damage at 7 Mpa stress at all investigated strain rate. Borazjani found significant cell death on fresh frozen human femora after an average of 13.3 Mpa stress during graft insertion. (Whiteside, Quinn, Borazjani) The above studies suggest that push-in forces and strain rates should be kept at a minimum.

Objectives

Maintaining congruency after mosaicplasty depends on the primary stability of the grafts until bony integration occurs between the graft and the recipient drill-hole. Until union is complete weight-bearing should be restricted. The length of this period is usually between 4-8 weeks depending on the site and size of the grafted area. (Hangody) Mosaicplasty patients are young and active, some of them are professional athletes who wish to return to their activities and training without delay. It would be therefore of significant clinical importance to improve the operative technique and produce primarily stable grafts withstanding physiologic loads reliably. Improving primary stability at the expense of increased insertion forces should however be avoided because this may damage the transplanted cartilage.
Prior to our series one paper had been published on the primary stability of osteochondral grafts. Duchow et al. studied pull-out forces on a porcine model. They found lower pull-out strength for smaller diameter and shorter grafts less than for larger diameter and longer grafts. Repeated insertion and levering of the tubular chisel during harvesting resulted in decreased pull-out strength.

Having reviewed the relevant literature the following objectives were set:

1. Developing a sensitive and reproducible method for testing the push-in forces during the insertion of osteochondral grafts.

2. Primary stability is influenced by the following variables:
   
   1. Graft diameter
   2. Dilation length
   3. Relation between graft and recipient hole length
   4. Number of transplanted grafts

The aim of our studies was to determine the effect of the above variables on the primary stability of the osteochondral grafts used in mosaicplasty.

3. On the basis of our results suggestions should be made regarding the necessary changes in the operative technique to improve primary stability.

4.2 Materials and methods

Testing was performed on a computer controlled universal testing machine used in mechanical experiments. The graft was pushed in with an indentor of corresponding diameter at a rate of 2mm/min. The graft was first pushed in level with the surrounding cartilage, then after 10 seconds it was pushed 3mm below cartilage level. The load curve was recorded.
In our model, we used porcine femurs, since its elastic modulus is comparable to that of human bone and is widely used in biomechanical experiments.

One 15mm long osteochondral graft, 4.5mm in diameter was taken from the central portion of the medial trochlea and transplanted to the weight-bearing surface of the lateral condyle. The place of implantation was standardized. In case of multiple grafting three 15mm long osteochondral grafts, 4.5mm in diameter were harvested from the medial trochlea and transplanted to the weight-bearing surface of the lateral condyle in a row or in circular fashion. The third graft was always taken from the central portion of the trochlea in order to ensure standard bone quality. In case of implantation in a row the last graft was inserted in the middle position. The graft, whose stability was measured, was inserted in such a way that it was 7mm proud of the surrounding cartilage surface. We used the MosaicPlasty™ instruments (Acufex, Smith & Nephew Inc. MA, USA).

The effect of graft diameter and dilation were studied in three series:

Group 1: one 4.5mm graft was inserted into a 20mm long drill-hole, dilated 20mm long (n=13).
Group 2: one 6.5mm graft was inserted into a 20mm long drill-hole, dilated 20mm long (n=14).
Group 3: one 4.5mm graft was inserted into a 20mm long drill-hole, dilated 15mm long (n=12).

The effect of drill-hole length was measured in two series:

Group 4.: 4.5mm grafts, 15mm in length inserted into 12mm long drill-holes (n=9)
Group 5.: 4.5mm grafts, 15mm in length inserted into 15mm long drill-holes (n=10)
Group 3. was used as control.

The effect of multiple grafting was studied in 3 groups:
Group 6.: three 4.5mm grafts were inserted into 20mm long drill-holes, dilated 20mm long in a row (n=7).
Group 7.: three 4.5mm grafts were inserted into 20mm long drill-holes, dilated 20mm long in circular fashion (n=9).

Group 8.: (control group for multiple grafting): one 4.5mm graft, was inserted into a 20mm long drill-hole, dilated 20mm long (n=9).

Student’s two tailed, two-sample t-test was used to determine the differences between groups. Data are shown as mean±SD. Significance was set at p≤0.05.

Results

Push-in forces for 6.5mm grafts were significantly higher at all levels compared to 4.5mm grafts.
The effect of dilation on push-in forces

15mm vs. 20mm dilation length resulted in increased push-in forces at 3mm level only.

The effect of drill-hole length on push-in forces

12mm drill hole length resulted in significantly increased push-in forces at all levels, while using 15mm drill-hole length push-in forces increased at 2 and 3mm levels only.
Level push-in forces were similar for single and multiple grafts, but significant decrease was measured at 1-3mm levels in multiple grafting series.
<table>
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<th>Level push-in (N)</th>
<th>1mm (N)</th>
<th>2mm (N)</th>
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<td></td>
<td>43.46±15.50</td>
<td>69.38±19.72</td>
<td>79.94±20.93</td>
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|                | 20mm dilation    |              |              |              |
|                | 43.46±15.50      | 69.38±19.72  | 79.94±20.93  | 92.54±22.07  |
| **15mm dilation**|                  |              |              |              |
|                | 36.58±10.40      | 67.93±17.46  | 92.07±14.52  | 122.50±12.04 |
| **p**          |                  |              |              |              |
|                | 0.2277           | 0.8537       | 0.1228       | 0.0006       |

|                | Row              |              |              |              |
|                | 31.80±8.09       | 38.92±8.49   | 45.69±6.00   | 52.17±10.25  |
| **Circle**     |                  |              |              |              |
|                | 30.44±9.36       | 34.40±9.36   | 45.52±10.47  | 54.33±9.14   |
| **Control (single graft)** |            |              |              |              |
|                | 38.67±7.59       | 63.79±13.48  | 73.12±12.13  | 86.78±14.22  |
| **p (row/circle)** | 0.7865         | 0.2569       | 0.9738       | 0.6967       |
| **p (row/single)** | 0.1454         | 0.0025       | 0.0004       | 0.0004       |
| **p (circle/single)** | 0.0715       | 0.0001       | 0.0002       | 0.0001       |

Summary of push-in forces and significance data.

Discussion

Primary stability is crucial in the maintenance of congruency after osteochondral grafting. Integration of the graft and recipient hole starts off at the end the first week after transplantation and is completed by the end of the 4th week according to animal studies. Currently it is suggested that grafts should be inserted into approximately 5mm longer drill-holes. Shorter grafts leave a cavity at the bottom of the holes, thus graft fixation relies exclusively on press-fit stability.

Rehabilitation protocol suggests that patients should restrict weight bearing for 4-8 weeks postoperatively but open chain exercises and active flexion are encouraged. These latter produce significant joint reaction forces both in the patello-femoral and
the femoro-tibial joint. (Lutz, Wilk) As a consequence non-weight bearing without adequate primary stability may not prevent graft subsidence.

Our results suggest that grafts of larger diameter (6.5mm) using the same dilation length resist higher push-in forces than smaller grafts (4.5mm). These results are consistent with that of Duchow’s. This can be explained by the larger total surface area resulting in stronger press-fit stability.

Our data on push-in forces are in the same range as that of Kock’s, found in his later study on human bone. This confirms that porcine bone is suitable model for biomechanical testing of mosaicplasty.

Since the surface area of a 6.5mm graft is more than twice as great, as that of a 4.5mm graft (0.16 vs. 0.33 cm²), the compressive force acting on the 6.5mm graft is also more than twice as great provided the pressure is constant across the joint surface (Force = Pressure *Area). Our results showed that 6.5mm grafts resist more than 1.3 times more force than 4.5mm grafts, but since at constant pressure the force per unit area for 6.5mm grafts is more than twice as much, 4.5mm grafts would be 1.54-times more stable than 6.5mm grafts.

Push-in forces were expected to increase with shorter dilation length since the bottom of the drill-hole remains narrower. This occurred at 3mm level only in our series. Shorter dilation length may result in significantly increased push-in forces, but this remains to be investigated.

Drill-hole length relative to graft length has a significant impact on primary stability. Push-in forces were significantly higher at all levels when grafts 15mm in length were inserted into 12mm drill-holes, while using same graft and drill-hole length (15mm) significant difference was recorded at 2-3mm levels only. Same graft and drill-hole length resulted in better primary stability without increased level push-in forces.

In our series the mean level push-in force for 4.5mm graft was 43N, corresponding 2.7Mpa stress. For 6.5mm grafts the same values were 76N and 2.3Mpa. These data suggest that during the Acufex mosaicplasty procedure push-in forces are within physiologic ranges and therefore no damage to the cartilage cup is expected. Manual graft insertion instead of using a mallet strain rate remains low further decreasing the risk of cartilage damage.
Although in practice the shape of the lesion dictates the configuration of the mosaicplasty, we used the row and the circle as two basic patterns of transplantation. Primary stability has even more important role after multiple grafting since the larger the grafted area the less are the grafts protected by the surrounding cartilage surface. Intraoperative estimate of primary stability is more difficult at the same time, since grafts abut at the bottom and dilation of the drill-hole and insertion of further grafts also have an impact on stability. Our results suggest that multiple grafting results in decreased primary stability compared to single grafting. Since there is a gap between the bottom of the drill-holes and the bottom of the graft, after subsidence, below cartilage level the graft gradually loses contact with neighbouring grafts and push-in forces become significantly smaller, compared to single grafts. Our results cannot be transformed directly into human practice, but can be compared to it, since elastic modulus of human and porcine bone is in the same range and others have measured similar data on human bone. (Kock) According to data from the literature the mean femoro-tibial contact pressure at 70kg body weight is 3.65Mpa. (Kusters, Morrison) Compressive forces are directly related with the surface area of the grafts so 4.5mm grafts would see a mean of 58.3N while 6.5mm grafts a mean of 120.3N. These data are in the range found by us in our experimental setting. Therefore, it seems to be realistic that by adjusting the operative technique full weight-bearing could be commenced immediately after mosaicplasty. Limitations of our study involve the lack of information on the changes in primary stability with time. Some bone resorption occurs in fracture healing and this may result in decreased press-fit stability on the graft-hole interface although its extent remains to be investigated. Direct clinical use of our data is further limited by the fact that grafts will be subject to cyclic loading in vivo which is significantly different from the static pressure used in our experimental setting and may have a bearing on the results gained.

New findings
1. We developed a sensitive and reliable method for the measurement of push-in forces of osteochondral grafts. Our data is in the same range as others’ measured on human cadaveric bone.

2. We quantified the primary stability of 4.5mm and 6.5mm grafts against compression. 6.5mm grafts were found to be resist 1.3 more compressive force than 4.5mm grafts.

3. The effect of dilation on the primary stability was measured. 15mm vs. 20mm dilation length was found to increase push-in forces by 1.3 times at 3mm level, while no difference was measured at flush and 1-2mm levels.

4. The effect of different drill-hole lengths on primary stability were measured. Inserting 4.5mm grafts into 12mm drill holes resulted in significantly increased push-in forces at all levels compared to the 20mm control drill hole. Using 15mm grafts and 15mm drill-holes no difference was seen at flush and 1mm level, but significantly increased push-in forces were found at 2-3mm levels.

5. Our results showed that multiple grafting results in decreased primary stability.

6. Our data show that push-in forces are in physiologic ranges for the human knee joint.

Clinical relevance

1. Restriction of weight-bearing is recommended for many weeks after mosaicplasty to avoid graft subsidence until bony integration occurs. Significant joint reaction forces during rehabilitation may also result in graft subsidence. Improved operative technique resulting in better primary stability
could - in theory – shorten the period non weight-bearing or even render it unnecessary.

2. Improved primary stability without increased insertion forces should secure the survival of the grafted cartilage and good long term results.

Recommended changes in operative technique:

1. From a biomechanical point of view we suggest the use of smaller diameter grafts since their primary stability is better relative to the compressive forces seen in vivo. Other studies showed that better congruency can be achieved by smaller grafts and defects can also be filled more completely.

2. We suggest that grafts and drill-holes should be of the same length improving primary stability without increasing level push-in forces. We did not find significant difference at flush and 1mm level and this suggests that graft length can exceed drill-hole length by 1mm without increase in level push-in force.

3. The effect of dilation on primary stability is difficult to judge intraoperative. Shorter dilation length may result in improved primary stability at the expense of increased push-in forces. We suggest that primary stability should not be improved by shorter dilation length.

4. Multiple grafting results in decreased primary stability therefore we recommend the use of equal graft and drill-hole lengths to avoid subsidence.

Areas of further research

Changes of primary stability in time should be investigated in an in vivo animal model. Further research needed to investigate the effect of cyclic loading on the stability of osteochondral grafts. Once the necessary primary stability is quantified intraoperative measurements could guide the surgeon to decide on postoperative
rehabilitation.
Publications

1. Mozaikplasztika: az osteochondralis graftok primer stabilitása
Kordás, G.; Szabó, J.; Hangody, L.
Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet 2003;46(2):147-153

2. Géza Kordás, MD; Jenő S. Szabó; László Hangody, MD, PhD, DSc
The Effect of Drill-Hole Length on the Primary Stability of Osteochondral Grafts in Mosaicplasty
Orthopedics, 2005; 28:401-404. IF.: 0.46

3. Géza Kordás, MD; Jenő S. Szabó; László Hangody, MD, PhD, DSc
Primary stability of osteochondral grafts used in mosaicplasty.

Mozaikplasztika: Többszörös osteochondralis graftok primer stabilitása
Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet 2006;49(4):315-321

5. G. Kordas, J.S. Szabo, and L. Hangody
Primary stability of osteochondral grafts used in mosaicplasty.

6. Géza Kordás
The role of primary stability in mosaicplasty. Review of the literature
Joint Diseases and Related Surgery
Submitted for publication