Image-Guided Techniques Improve the Short-term Outcome of Autologous Osteochondral Cartilage Repair Surgeries - An Animal Trial

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Abstract

Mosaic arthroplasty is a valuable reconstruction option for cartilage repair, but the accuracy to harvest and deliver osteochondral grafts remains problematic. We investigated whether image-guided methods (optically-guided and template-guided) can improve the outcome of mosaic arthroplasty procedures.

Methods: Fifteen sheep were operated to create traumatic chondral injuries in each knee. After four months, the chondral defect in one knee was repaired using a: (A) conventional approach, (B) optically-guided method, or (C) template-guided method. For both image-guided groups (B, C) harvest and delivery sites were preoperatively planned using custom-made software. During optically-guided surgery, instrument position and orientation were tracked and superimposed onto the surgical plan. For the template-guided group, plastic templates were manufactured to allow an exact fit between template and the joint anatomy. Cylindrical holes within the template guided surgical tools according to the plan. Three months post-surgery, both knees were harvested and CT scanned to compare the reconstructed versus the native pre-injury joint surfaces. For each repaired defect, macroscopic (ICRS) and histological repair (ICRS II) scores were assessed. All results were statistically compared between the three surgical approaches using either non-parametric or parametric ANOVA tests.

Results: Three months after repair surgery, both image-guided surgical approaches resulted in significantly better histology scores compared to the conventional approach (improvement by 55%, $p=0.02$). Interestingly, there were no significant differences found in cartilage surface reconstruction and macroscopic scores between the image-guided and the conventional surgeries.

Conclusions: Our results suggest that image-guided systems can improve the clinical outcome of mosaic arthroplasty for the repair of cartilage defects.

Level of Evidence: Level 2

1 Background

Chondral and osteochondral lesions in the articular surface of the knee are injuries frequently encountered in clinical practice (1) (2). Due to the inadequate healing response of cartilage (3) (4), defects of a critical size may lead to osteoarthritis if untreated (5). Most commonly used treatment options for defects include microfracture (6) (7) (8) (9) (10), autologous chrondocyte implantation (ACI) (11) (12) (13) (14), and autologous osteochondral transplantation, also known as mosaic arthroplasty (15) (16) (17) (18) (19).

In a prospective randomized clinical study, Gudas *et al.* (20) found significantly better clinical outcomes and histology using mosaic arthroplasty compared to microfracture. The study found excellent or good postoperative results in 96% of the patients treated with mosaic arthroplasty compared to 52% of the patients treated by microfracture. Horas *et al.* (21) concluded from a study of 40 patients that mosaic arthroplasty resulted in a faster recovery than ACI. This result is in contrast to a study conducted by Bentley *et al.* (22) who found excellent or good results in 88% of the ACI patients compared to 69% for mosaic arthroplasty patients. Dozin *et al.* (23), on the other hand, found no difference between both techniques in a randomized trial. Recent reviews of randomized and controlled trials (24) (25) to compare the effectiveness of different cartilage repair methods concluded both that, at this point, there is insufficient evidence concerning the relative effectiveness of ACI or mosaic arthroplasty.

Various studies have demonstrated the importance of creating a congruent, continuous joint surface using mosaic arthroplasty to optimize outcomes (26) (27) (28). Donor sites accessibility and the variation in the radius of the femoral condyle curvature (29) make re-creation of a congruent joint surface challenging when using multiple small grafts. Sanders *et al.* (30) found in two-week postoperative MRI evaluations of 21 mosaic arthroplasty patients that only one patient had surface congruency, while 16 patients had mild, two patients moderate, and one patient marked surface incongruency over the defect. This raises the question of whether improved intraoperative methods that help the surgeon to achieve higher accuracy in harvesting and delivery of grafts might improve the outcome of mosaic arthroplasty procedures. Kaulalis *et al.* (31) compared the outcome of opto-electronically navigated procedures versus freehand mosaic arthroplasty procedures in three cadaveric knees and found improved accuracy in the navigated procedures for the perpendicularity of graft removal and placement, as well as for the depth of graft placement. A limitation of this study was due to the use of invitro specimens: the authors could not evaluate whether this improved accuracy influenced the clinical outcome.

While the use of opto-electronic technology for image-guided knee applications has had gratifying results, this technology has some drawbacks: additional technical equipment (optoelectronic camera, PC) is required in the operating theater and an intraoperative registration process is required to find the correspondence between the image data and the patient. To overcome these drawbacks, recent research in the area of image-guided surgeries has used patient-specific templates (32) (33) (34). The idea is to build custom surgical templates based on a three-dimensional reconstruction of the patients specific anatomical structures. In the trial presented here, we investigated the application of two image-guided systems for mosaic arthroplasty, one system using opto-electronic tracking and the other system using patient-specific templates, and compared the short-term clinical outcome for both systems with the conventional freehand method. The purpose of the study presented here was to investigate whether image-guided methods can help to improve the outcome of mosaic arthroplasty procedures.

2 Material and Methods

Fifteen mature sheep were randomly assigned to one of three treatment groups. For each sheep, one treatment and one control knee was randomly assigned. All sheep underwent an initial CT arthrogram (LightSpeed Plus (GE Healthcare, Waukesha, USA) in helical mode, with a slice thickness of 0.625mm at 140 kpV, followed by a procedure to create a traumaticallyinducted cartilage defect in the medial condyle of both knees (Cartilage Defect Surgery). During a second procedure four months later one of three repair procedures was performed (Cartilage Repair Surgery). Three months after the repair surgery, the sheep were euthanized. Both the treatment knee and the control knee were harvested and the outcomes were evaluated. All procedures were performed in accordance with the guidelines of the Canadian Council of Animal Care.

The cartilage defect surgery was performed through a 2 cm infrapatellar arthrotomy using spring loaded impactor to create chronic chondral defects on anterior central weight bearing region of the medial femoral condyles in both knees of each sheep as per previous reports (35). After routine closure of the athrotomy sheep were recovered and allowed exercise in large pens. These 4.5 mm diameter injuries increased in size over three months resulting in an irregularly shaped chondral lesion that was debrided to a circular 7mm diameter full thickness chondral defect in a second surgery four months later. Reconstruction was performed with one of the three following techniques: (A) conventional freehand technique, (B) optically-guided technique, and (C) template-guided technique. All surgeries were carried out by the same surgeon who was experienced in mosaic arthroplasty. The mosaic arthroplasty system from Smith and Nephew Endoscopy (Mosaicplasty, Andover, MA) was used for all surgeries. For all procedures, a medial parapatellar arthrotomy was performed and the patella was luxated laterally to expose the donor sites in the medial and lateral trochlear ridges as well as the medial femoral condyle recipient site.

2.1 Conventional Surgical Technique

The conventional osteochondral grafting technique was performed as described by Hangody and Kapati (36). During the surgery, 4.5mm osteochrondral grafts were harvested from the axial aspect of the medial trochlear ridge for transplantation into the medial condyle. The surgeon determined the location of donor and recipient site at the time of the surgery, optimizing the fit and congruency by eye.

2.2 Optically-guided technique

The optically-guided procedure consisted of preoperative planning and intraoperative guidance.

2.2.1 Preoperative Planning

Prior to the surgery, a CT arthrogram scan for the treatment knee was obtained. All scans were performed after the injection of an iodinated contrast material, and were obtained with a LightSpeed Plus (GE Healthcare, Waukesha, USA) in helical mode, with a slice thickness of 0.625mm at 140 kpV. Three-dimensional (3D) surface models for bone and cartilage were created using the commercial software package Amira (Visage Imaging Inc., Carlsbad, CA, USA).

Custom-made surgical planning software for osteochondral grafting was developed. The 3D surface models, as well as the CT dataset were loaded into the software and displayed (Figure 1a). The operator created a surgical plan consisting of a set of osteochondral grafts ("plugs") positioned over the defect site. The 3D position and orientation of each plug, as well as its shape (diameter, height, and surface slope), were chosen by the operator to best reconstruct the desired articular surface at the defect site (Figure 1b).

For each plug, a harvest location was chosen to best match the shape of the plug. The plugs could be rotated axially so that the sloped surface at the harvest site could be made to match the sloped surface at the defect site. The operator validated the surgical plan by superimposing the plugs on the 3D models and by superimposing the plugs on three orthogonal slices of the CT dataset (Figure 1a).

2.2.2 Intraoperative Procedure

A Polaris opto-electronic tracker (Northern Digital, Waterloo, Canada) was installed in the operating theatre (Figure 2a) and a tracking sensor was rigidly attached to the femur (Figure 2c).

Tracking sensors were attached to conventional harvest chisels and drill guides. A special retractable attachment was required for the harvest chisel because the heavy impacts made to the chisel would dislodge a conventionally-attached sensor (Figure 2d).

A registration was made between the sheep femur and the 3D bone model of the femur using a combined pair-point, and surface matching algorithm (37).

Using visual feedback from the computer-guidance system, the surgeon used a tracked pointing device to locate the planned harvest site of a plug and, using a sterile pen, marked an axial rotation

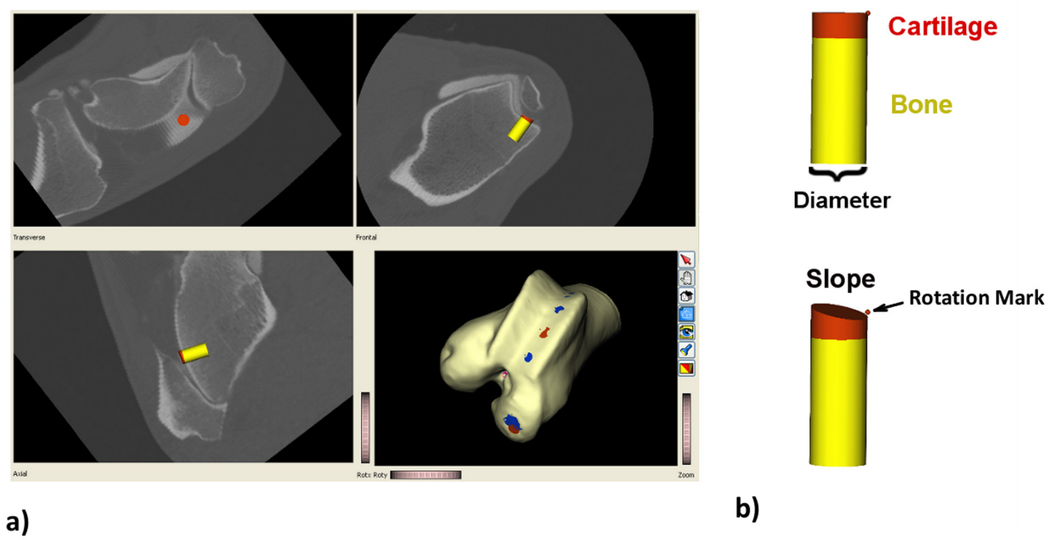

Figure 1: Preoperative Planning for Image-Guided Procedures: a) Planning of position and orientation of harvest and delivery site for virtual plug; b) Creation of virtual cartilage/bone plugs.

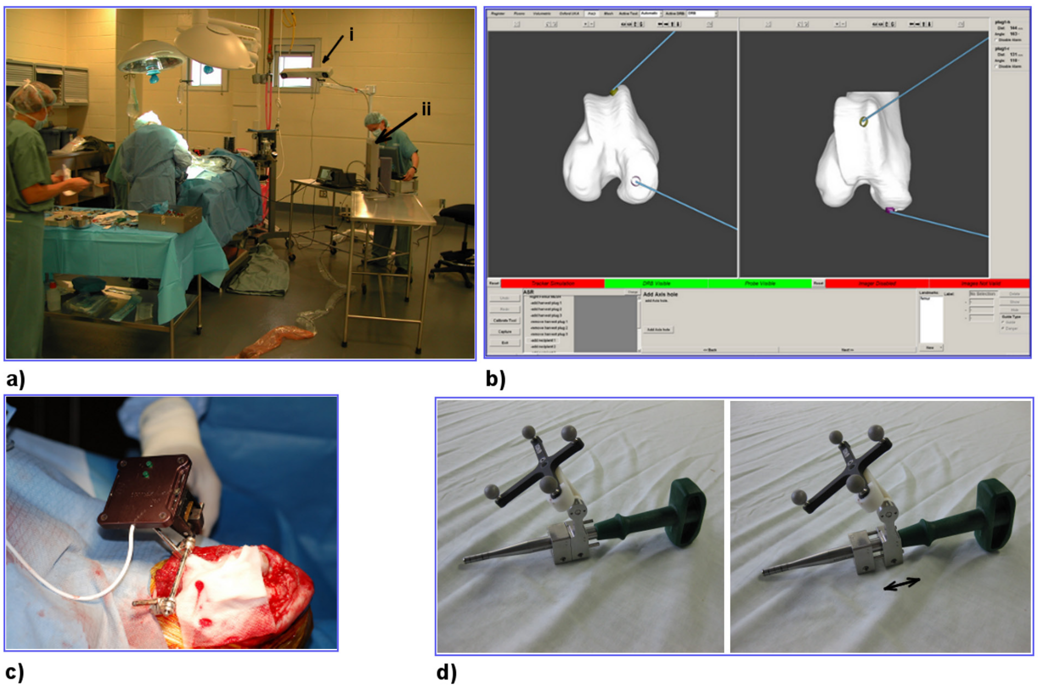

Figure 2: Optically-guided surgical technique. a) Installation of opto-electronic camera (i) and PC (ii) in operating room; b) Computer-guidance display for navigation of tools; c) Attachment of opto-electronic sensors to femur; d) Attachment of opto-electronic sensor to harvest chisel. The special designed attachment consisted of two pieces: one fixed to the chisel and one free to move from the fixed piece in a translation parallel to the chisel axis. Upon a blow to the chisel, the latter piece would briefly move away from the fixed piece, and then return to its original position as shown in the right image.

reference on the cartilage surface of this plug. This mark allowed the surgeon to keep track of the rotation of the plug between harvesting and delivery.

Using visual and numerical feedback on the display, the surgeon positioned and oriented the harvesting chisel on the cartilage according to the preoperative plan (Figure 2b). The surgeon then drove the chisel into the cartilage and bone until the guidance display indicated that the correct depth was reached. Then the graft was harvested.

After each graft was harvested the surgeon positioned and aligned, in a similar manner, the tracked drill guide over the planned recipient site and the recipient hole was drilled. The depth of the hole was navigated using the conventional depth indicator at the drill bit. The harvested plug was inserted into the drill guide in such a way that the rotation mark of the plug was aligned with the calibrated up-direction of the drill guide. Using the visual feedback of the guidance system, the drill guide was then axially rotated until the planned rotational position of the graft was reached and the graft was carefully inserted into the recipient hole. This procedure was repeated for each planned graft.

2.3 Template-Guided Technique

The template-guided procedure consisted of preoperative planning, template construction, and intraoperative guidance.

2.3.1 Preoperative Planning

The surgery was planned identically to the optically-guided procedure, as described in section B.1.

2.3.2 Template Construction

A set of individualized templates was built for each knee, containing one "marking guide", one "harvesting guide", and one "delivery guide" for each planned plug. The underside of each template was shaped to exactly match part of the surface of the knee (Figure 3), using the information from the pre-repair CT arthrogram. By this means, the planned position of the template could be correctly reproduced intraoperatively by adjusting the position of the template until an exact fit with the cartilage surface was achieved. Each template was built out of thermo-plastic acrylonitrile butadiene styrene (ABS) on a rapid prototyping machine (dimension SST; Statasys Inc., Eden Prairie, USA).

The marking guide was designed to fit into the femoral patella groove and contained, for each plug, a hole at the planned harvest site of the plug. Each hole had on its circumference a small indicator bump; the surgeon would draw a radial line on the cartilage surface at the location of the indicator. The line allowed the axial rotation of the plug to be tracked.

The harvesting guide was designed to fit into the femoral patella groove and contained, for each plug, a guidance cylinder for the harvesting chisel (Figure 3a). The height of each cylinder was chosen to stop the chisel after the chisel had been inserted to the planned depth (Figure 3c).

Each delivery guide fit to the medial femoral condyle at the location of the defect and contained a single guidance cylinder. The conventional drill guide fit into the guidance cylinder to guide the drill bit during drilling and to guide the plug during delivery.

Rotation marks at the guidance holes (Figure 3b) ensured that the harvested plug was delivered with the correct rotational alignment with respect to the plug axis.

2.3.3 Intraoperative Procedure

After the conventional incision was made, the marking guide was positioned on the knee and a rotation reference mark was made for each plug.

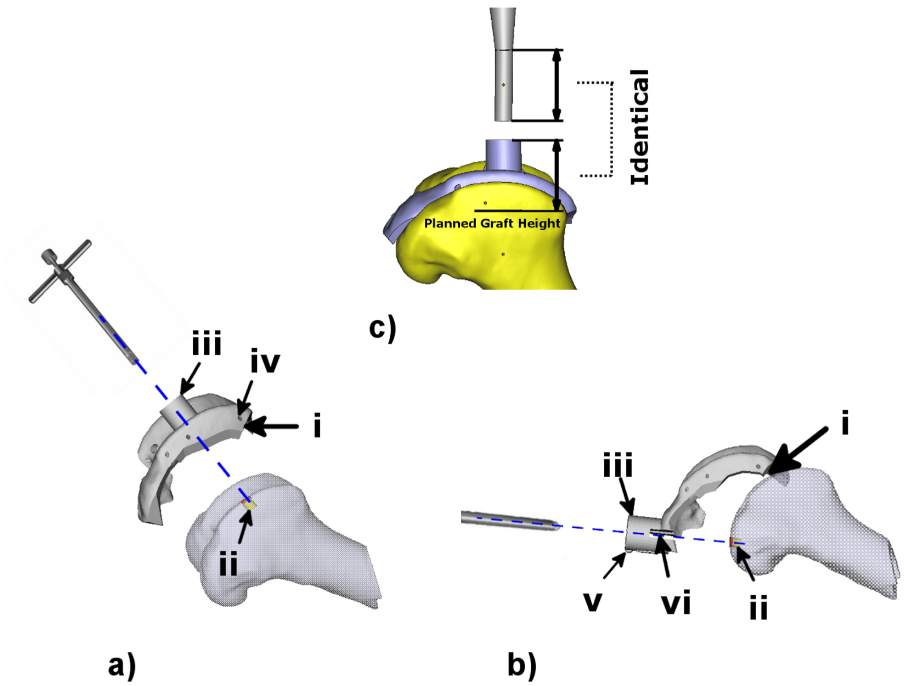

Figure 3: Patient-Specific Instrument Guides for harvesting graft (a) and delivery of graft (b). i Mirror image of cartilage surface allowed precise fit of guide to the articular surface. ii Planned position and orientation of harvest and delivery graft. iii Guidance cylinder for instrument. iv Pin holes to fixate guide to knee. v Rotation mark. vi Slots to irrigate the hole during drilling. To navigate depth of instrument insertion, length of the guidance cylinder was defined based on planned graft height (c).

Figure 4: Intra-operative use of patient-specific instrument guide. Left: The harvesting guide was placed on the knee and harvest chisel inserted; Right: The recipient guide was placed on the knee and the drill guide was inserted.

The harvesting guide was placed on the knee and fixated with two 2 mm Kirscher wires. Using the guidance cylinders, all plugs were harvested and stored in numbered containers (Figure 4a). For each plug, the length of the plug was verified using a conventional ruler. The harvesting guide was removed.

For each plug in sequence, one delivery guide was placed on the knee (Figure 4b). The delivery hole was drilled. The depth marking on the Mosaic arthroplasty drill bit was used to determine the depth of the hole. Then the plug was inserted into the drill sleeve and the rotation mark on the plug aligned with a corresponding rotation mark at the guidance cylinder. Finally, the plug was pushed through the drill sleeve into the delivery hole and the delivery guide for that plug was removed.

2.4 Measurements Taken

All sheep were recovered from anesthesia and had restricted exercise in small pens for 3 weeks followed by unrestricted movement in larger pens for the 3 month recovery period. At the end of the study the sheep were euthanized with an overdose of pentobarbital and the hind limbs harvested for assessments. CT arthrograms were repeated in the reconstructed joints. The joints were then dissected carefully and photodocumented. The following criteria were recorded from each joint:

- Shape of Articular Surface Reconstruction

Immediately after the surgery, the surgeon documented the result in surgical notes, describing the congruency of each plug to the surrounding surface at four points on the circumference of the plug.

- Weight, Pain and Lameness

  After the surgery, each sheep was followed daily for three months. Weight, pain and lameness were documented. Pain was graded on a scale of 1 to 3 as a combination of lameness, respiration, attitude, and appetite. Lameness was graded on a scale of 1 to 5, with 1 being "weight bearing but slight limp" and 5 being "not weight bearing, leg lifted or cannot get up".

- Macroscopic ICRS Score after Healing

  All sheep were euthanized three months postoperatively and both knees were harvested and dissected. The joints were photographed and examined macroscopically using the ICRS (International Cartilage Repair Society) Macroscopic Score (38). The scoring was done by one observer who was blinded to the treatment method used for repair.

- Shape of Articular Surface after Healing

  Three dimensional models for bone and for cartilage were created from CT images before injury and 3 months post-reconstruction using the commercial software package Mimics (Materialise, Leuven, Belgium). Using the Iterative Closest Point algorithm (39), the post-healing bone model was registered to the pre-defect bone model. The resulting transformation was applied to align the post-healing cartilage model with the pristine articular surface of the pre-defect scan. The Root Mean Square (RMS) error between both surfaces over the defect was calculated.

- Subchondral Bone Cyst Formation after Healing

  After harvesting the treatment knee, a MicroCT (GE LOCUS Explore) with a voxel size of 0.095mm3 was performed. Using the Mimics software, the cysts in the medial condyle were segmented and the volume of these cysts determined.

- Histological Measures after Healing

  Immediately after harvesting, imaging, and macroscopic evaluation of the knees, the following tissue samples were obtained for histological evaluation: Synovial membrane intercondylar area, medial aspect; osteochondral blocks from the medial femoral condyle, the tibia plateau, and the medial trochlea. All samples were stored in formalin, decalcified in formic acid, and embedded in paraffin blocks from which six micron thick sections were created. Sections were stained with hematoxylin and eosin (H&E) and safranin-O/fast green. Sections from the repair site were examined by two independent reviewers using the ICRS II histological scoring system consisting of 14 parameters scored using a visual analogue scale of 0-100 (40). This system is an integrated evaluation of tissue and cell morphology with emphasis on restoration of normal cartilage and subchondral bone plate architecture as well as integration of the grafts and intergraft repair tissue with the surrounding host tissue.

3 Statistical Methods

Statistical analysis was performed using the software package Analyse-It (Analyse-It Software Ltd., Leeds, UK). A non-paired Student t test was used to evaluate significant differences between all three groups for parametric tests. For nonparametric score results, differences were evaluated by the Mann-Whitney U test. For all tests, $p<0.05$ was considered statistically significant.

4 Results

For all 15 sheep, the cartilage defect and cartilage repair surgery was successfully performed. There was one case of superficial wound infection in the conventional group after the reconstructive surgery,

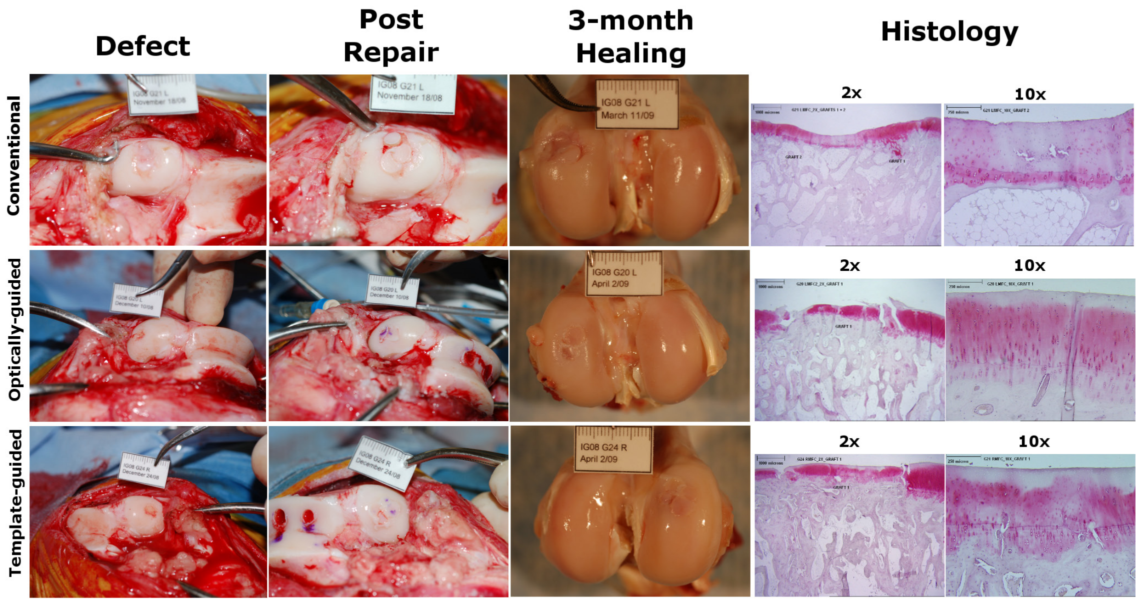

Figure 5: Examples for outcomes for conventional technique (top row), optically-guided technique (middle row), and template-guided technique (bottom row). For each technique, four images demonstrate the state at different points in the study. The left column shows the defect before the repair surgery; the second column shows the area over the defect direct after the repair surgery; the third column shows the articular surface three-months post-healing after harvesting of the knee; and the last column shows the stained histology image.

which was treated successfully with antibiotics. For one sheep in the optically-guided group, a mechanical lameness due to an intermittently luxated patella was diagnosed one week following the cartilage repair surgery.

Figure 5 shows photographs for three knees (one from each group) during different steps of our study and evaluation.

All results are presented as "average ± standard deviation" (unless stated otherwise in the figures as a 95% confidence interval).

- Shape of Articular Surface Reconstruction

  Figure 6 shows the percentage of recessed and proud plug surface for all three groups, as determined from the intraoperative notes immediately after surgery.

  The percentage of **proud** surface was significantly smaller (p=0.018) for the template-guided group (1.4 ± 3.1 %) compared to the conventional group (31.2 ± 22.4 %). The difference between the optically-guided group (7.8 ± 7.8 %) and the conventional group was not significant (p=0.06), but the borderline p value suggested a trend toward smaller values for the optically-guided group.

  The percentage of **recessed** surface had no significant differences between conventional (0.0 ± 0.0 %), optically-guided (27.1 ± 23.1 %), and template-guided (6.2 ± 13.9 %).

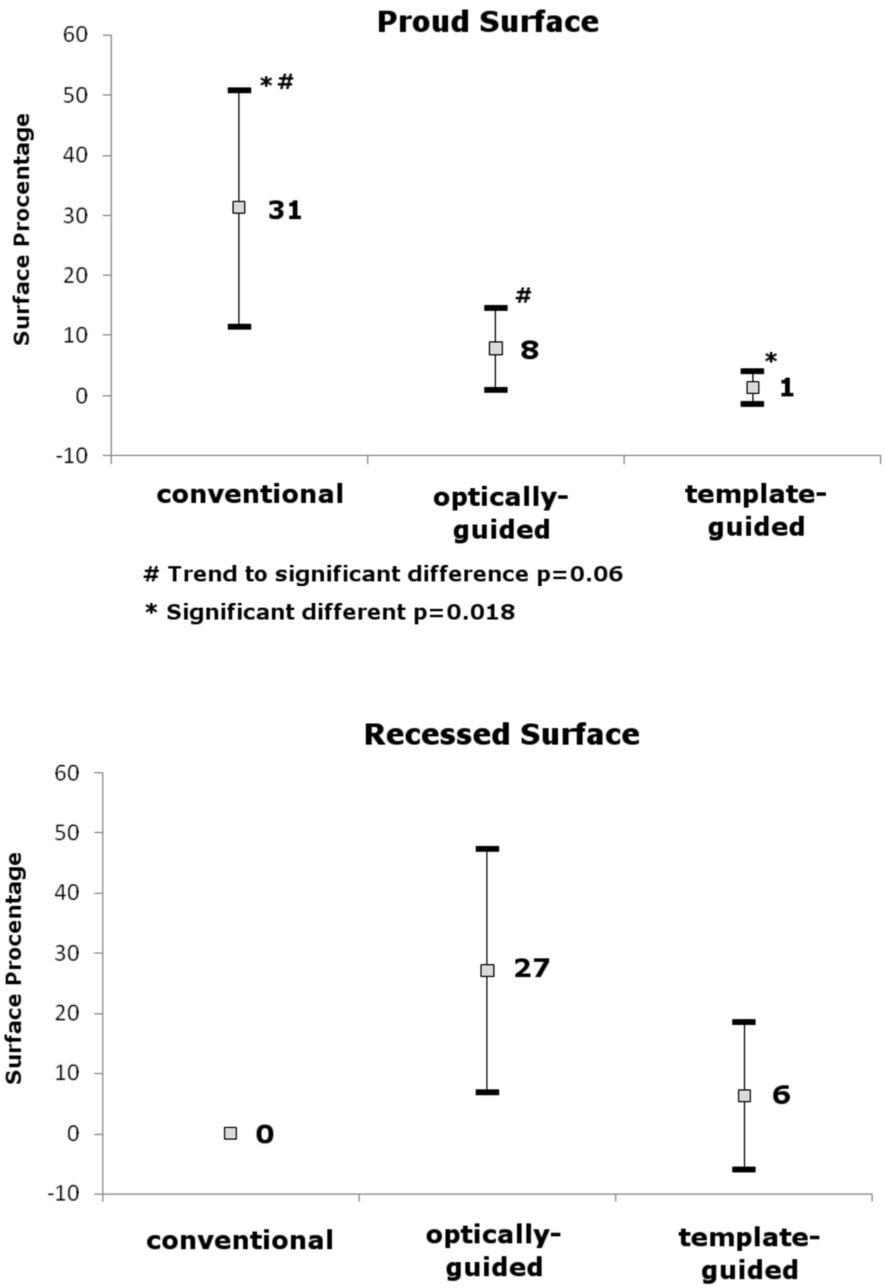

Figure 6: Results for surface congruency of articular surface post-repair. Values are displayed as average and 95% CI.

- Weight, Pain and Lameness

  There was no significant difference in weight, pain, or lameness between the conventional group and the computer-assisted groups.

  But, within the computer-assisted groups, the average duration of pain was significantly greater (p=0.039) for the template-guided group (6.2 ± 2.6 days) compared to the optically-guided group (2.4 ± 2.3 days). The conventional group pain duration was 4.0 ± 4.1 days.

  The intensity of the pain for the template-guided group (2.6 ± 1.4) was significantly greater (p=0.034) than that of the optically-guided group (1.0 ± 0.8). The conventional group pain intensity was 2.0 ± 2.1.

- Macroscopic ICRS Score after Healing

  No significant difference was found between any groups in the three-month post-repair macroscopic evaluation. Table 1 shows the macroscopic scores.

Table 1: Three-month postoperative macroscopic scores (mean ± standard deviation).

	Conventional	Optically guided	Template guided
ICRS repair score	6.0 ± 2.7	5.0 ± 1.8	8.0 ± 1.8
Treatment effect whole joint quantititve assessment score	1.5 ± 7.1	9.0 ± 5.8	11.0 ± 6.2

- Shape of Articular Surface after Healing

  The articular surface over the defect in the post-healing CT scan was compared to the corresponding (pristine) articular surface in the pre-defect scan. We found an RMS error of 0.33 ± 0.10 mm for the conventional group, 0.44 ± 0.14 mm for the optically-guided group, and 0.29 ± 0.25 mm for the template-guided group. No significant differences between the three groups were found.

- Subchondral Bone Cyst Formation after Healing

  Figure 7 shows the cyst volumes in the medial condyle three months post-healing. The cyst volume for the template-guided group (51 ± 47 mm^3) was significant smaller (p=0.015) than that of the conventional group (173 ± 76 mm^3). No significant difference was found with the optically-guided group (98 ± 144 mm^3).

- Histological Measures after Healing

  Figure 8 shows the histology scores for three areas (the medial condyle, the tibial plateau, and the surrounding tissue) and for the three groups. Error bars show the 95% confidence interval.

  For the medial condyle, the treatment effect was significant better (p=0.016) in the optically-guided group than in the conventional group. Also, the treatment effect in the template-guided group was significant better (p=0.008) than in the conventional group.

  For the tibial condyle, the treatment effect was significantly better (p=0.032) in the template-guided group than in the conventional group.

  No significant differences were found for the histology score of the surrounding tissue for all three groups.

  A significant linear correlation was found (linearity fit p=0.0033) between the ICRS II treatment effect for the medial condyle and the intraoperative estimated percentage of proud reconstructed articular surface for all 15 sheep. Figure 9 displays this correlation.

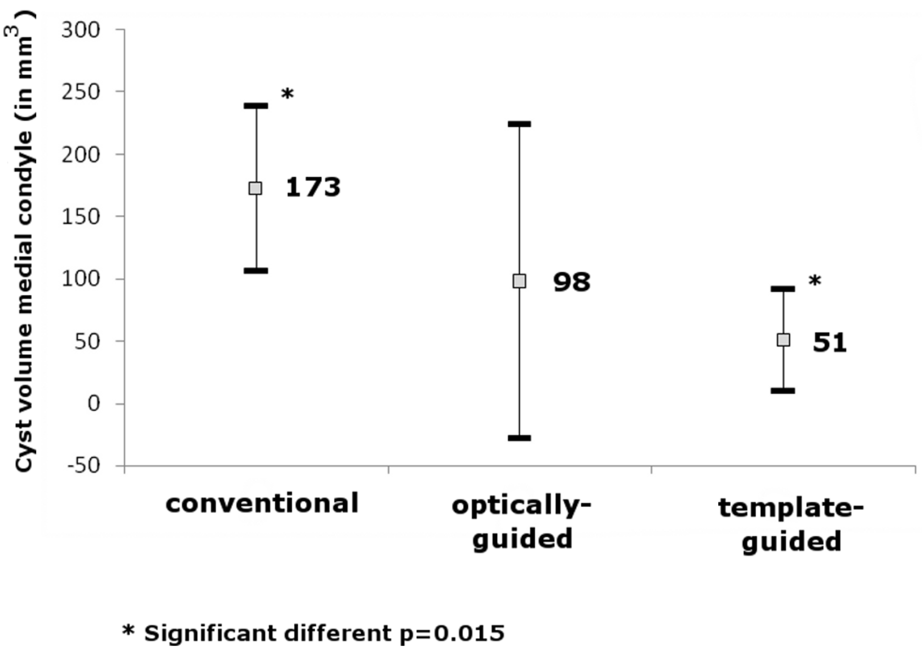

Figure 7: Results for cysts volume in medial condyle three-month post-surgery. Values are displayed as average and 95% CI.

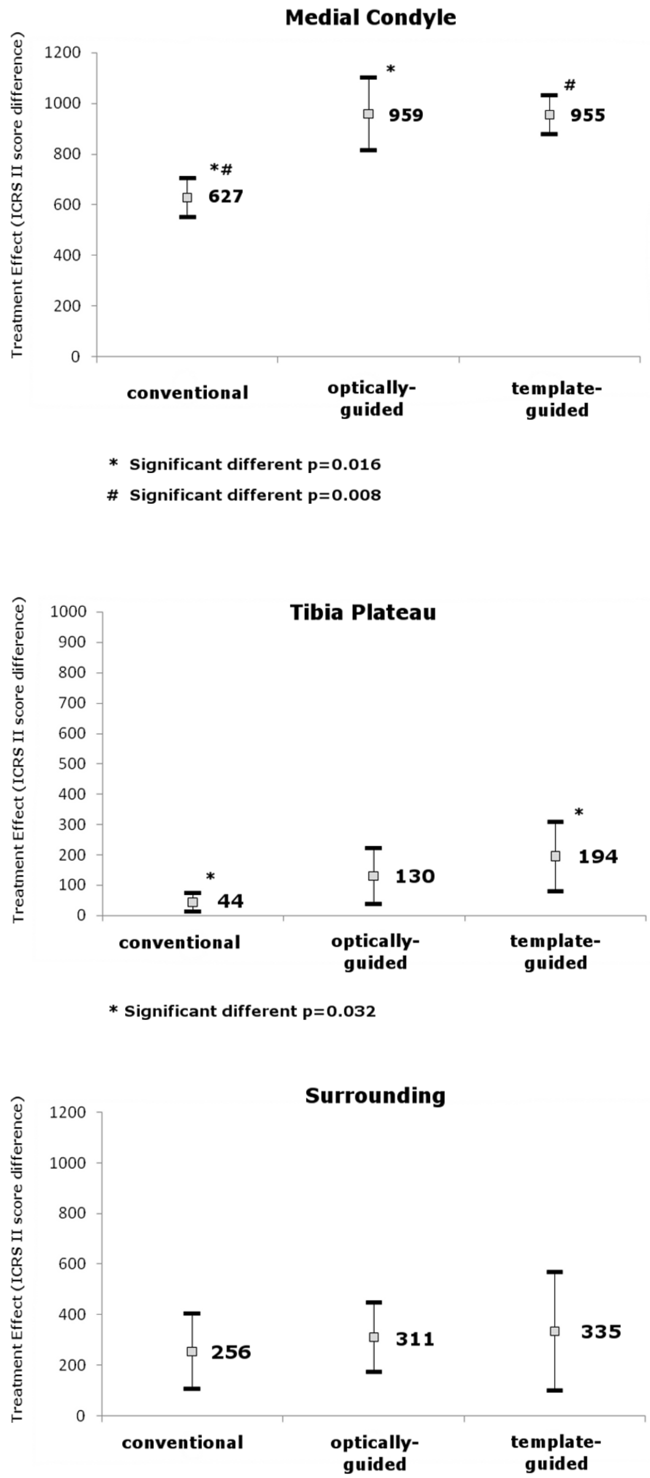

Figure 8: Results for treatment effect using the ICRS II histology score three-month postsurgery. Values are displayed as average and 95% CI.

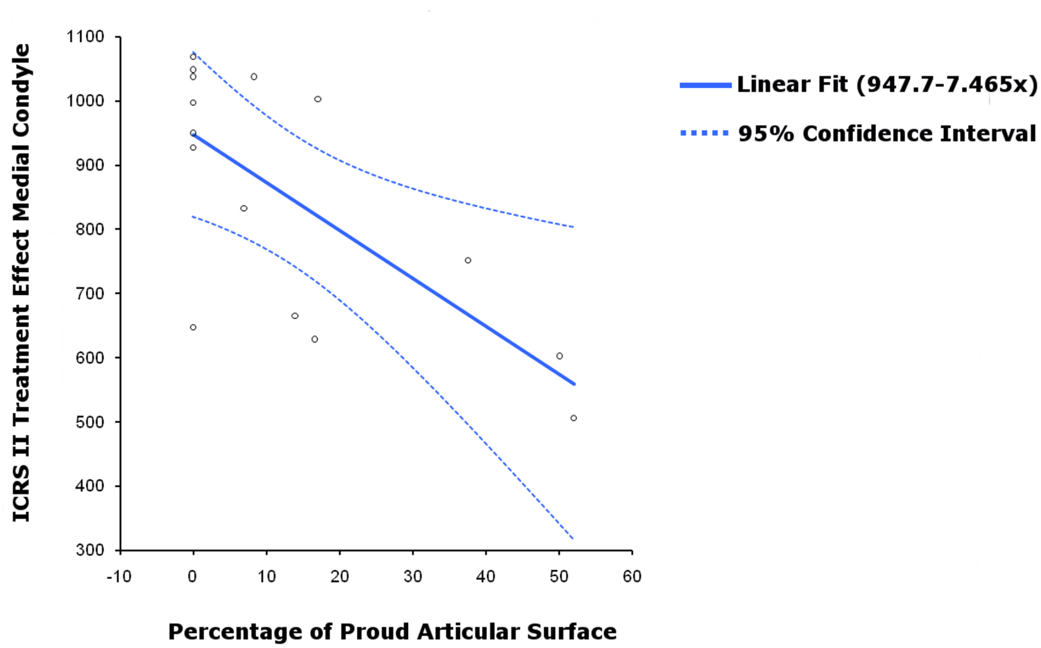

Figure 9: Linear correlation between the percentage of reconstructed articular surface which was proud and the ICRS II treatment effect for the medial condyle for all 15 sheep.

5 Discussion

The primary finding was that both image-guided techniques had a significantly better treatment effect than did the conventional surgical technique.

Surface Congruency

The template-guided technique resulted in significantly better surface congruency than the conventional technique. We also saw a trend towards better surface congruency using the optically-guided method compared to conventional technique.

Interestingly, our results did *not* show a correlation between the articular surface congruency immediately after the operation and the macroscopic appearance of the cartilage at three months postoperatively. Similarly, no correlation was found between the articular surface congruency immediately after the operation and the surface congruency measured on the CT scan taken three months postoperatively. The lack of correlation suggests that **a remodeling process occurred: proud plugs subsided and recessed plugs filled in**. This is consistent with observations from other studies (28).

Healing Quality

A secondary finding is the significant correlation between the articular surface congruency immediately after the operation and the histology of the cartilage three-months postoperatively. The results showed that **proud plugs are associated with poorer healing** in the short term. The poorer healing could be the effect of peak pressure on these grafts. Koh *et al.* (27) observed in an invitro study striking increase in peak pressures when the plug was proud. This increased pressure may cause overload in the tissue and may damage the cartilage.

Our results did not show a correlation between recessed plugs and short-term cartilage healing. This is in agreement with a study conducted with rabbits (42) in which marginally recessed plugs did not adversely affect outcomes. Also, during a sheep study (43) it was observed that plugs recessed up to 1 mm had a good survival rate. However, our healing results are limited to a short-term period; the longer-term effects of recessed plugs were not studied.

Optical Guidance or Template Guidance

The surgeon found that it was difficult to hold the position and orientation of the tool according to the opto-electronically guided computer display during impacts. This was likely because the hardness of the sheep bone required more manipulation to harvest osteochondral plugs than would be necessary in normal human bone.

On the other hand, the template-guided technique provided mechanical support to the surgical tools because the template was stabilized in the registered position using wires. This might explain the better surface reconstruction for the template-guided group. We speculate that the problem of holding the optically-guided chisel will not arise in human patients unless the subchondral bone was sclerotic.

We did not find any significant differences in ICRS-II score in the surrounding cartilage between the template-guided and conventional techniques, which suggests that the placement and fixation of the templates did not have a negative effect on the tissue in the first three months postoperatively.

Cysts

The three month post-reconstruction micro-CT images revealed a significantly **larger cyst volume in the conventional group than in the template-guided group**. Subchondral cysts can result in serious complications, such as a collapse of the graft into the recipient hole. Cyst creation during healing might be larger for the conventional technique due to the significantly higher percentage of proud plugs found in the conventional technique. This is consistent with results from Pearce *et al.* (28), who observed in a study significantly more cyst creation with plugs placed proud with respect to the articular surface than with flush placed plugs. Those authors suggested that micromotion of the plugs could lead to synovial fluid penetrating normal subchondral bone, which in turn might predispose the development of subchondral cysts. Tytherleigh-Strong *et al.* (41) also discussed the possibility of synovial fluid penetration into the gap between the graft and the surrounding, normal subchondral bone to create subchondral cysts.

The template-guided technique may provide a more tightly fitting plug, reducing the penetration of synovial fluid, because the drill guide is held more rigidly inside the template during the preparation of the recipient site. With the conventional and opto-electronically guided techniques, the tools are handheld, without external support, and can result in a hole that is less cylindrical.

Pain, Lameness, and Macroscopic Scores

We found no significant difference in measures of pain, lameness, weight, and macroscopic scores after healing between the optically-guided and conventional techniques. This suggests that the invasive attachment of the sensors to the femur was well tolerated.

However, we found a significant increase of the length and intensity of postoperative pain in the template-guided group compared to the optically-guided group. This difference might be explained by the reduced invasiveness of the optically-guided technique: While the arthotomies in both groups were the same, the insertion of the template required more soft tissue retraction which could have caused more capulitis and synovitis.

Summary

The small number of sheep limited the statistical power of the measures obtained from the study. Nonetheless, statistical significance was found for a number of important measures. This is, to our knowledge, the first in-vivo study to investigate the clinical outcome of image guided mosaic arthroplasty in comparison to the conventional surgical method. The planning for the image-guided techniques required that an operator use a computer interface to place virtual plugs on a model of the patient's bone and cartilage. The planning process took 30 to 45 minutes per procedure and required that the surgeon estimate, on the computer screen, the desired 3D articular cartilage surface over the defect. To improve the planning process, we developed, subsequent to this study, fully automatic planning methods.

In conclusion, this in-vivo animal study has shown that image-guided techniques produce better morphological and healing outcomes for mosaic arthroplasty compared to conventional surgical techniques. Further studies are necessary to confirm that this short-term improvement will translates to a better long-term clinical outcome.

Acknowledgments

This research was supported by grant STPGP 336779 from the Natural Sciences and Engineering Council of Canada. The authors are grateful to Karen Lowerison and Nicole Kudo for their help with data collection, Paul St John for his technical support, and Emily Bishop, David Wright, John Li, Tamara Redwood, and Jerome Grondin-Lazzazzera for their valuable help with segmenting the data.

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