Histologic Analysis of 2 Alternative Donor Sites of the Ipsilateral Elbow in the Treatment of Capitellar Osteochondritis Dissecans

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Purpose: To compare the histologic features of the cartilage from the capitellum with 2 proposed alternative donor sites from the ipsilateral elbow in the treatment of capitellar osteochondritis dissecans (OCD): the nonarticulating part of the radial head and the nonarticulating lateral side of the olecranon tip. **Methods:** Ten human cadaveric elbow specimens with macroscopically normal articular surfaces were used to obtain 5-mm osteochondral grafts: 10 from the capitellum (60° anteriorly relative to the humeral shaft), 10 from the radial head (nonarticulating part at 80°), and 4 from the olecranon (lateral side of the olecranon tip). Grafts were fixated in formalin (4% formaldehyde), decalcified, and processed into standard 8-μm-thick hematoxylin and eosin–and Toluidine Blue–stained sections. These were assessed for cartilage thickness, shape of articular surface, and 13 histologic parameters of the International Cartilage Repair Society II. Olecranon scores were excluded from statistical analysis. **Results:** Mean cartilage thickness was 1.5 ± 0.22 mm at the capitellum; 1.3 ± 0.34 mm at the radial head; and 1.9 ± 1.0 mm at the olecranon. There was no difference in cartilage thickness between the capitellum and radial head ($P = .062$). All grafts demonstrated a convex articular surface. International Cartilage Repair Society II scores ranged from 82 to 100 for the capitellum, from 81 to 100 for the radial head, and from 67 to 87 for the olecranon tip. There was less chondrocyte clustering at the capitellum (84 ± 14) than in the radial head (94 ± 3.2; $P = .019$). Mid/deep zone assessment of the capitellum scored higher (97 ± 6.7) than the radial head (91 ± 4.6; $P = .038$). **Conclusions:** This study demonstrates appropriate histologic similarities between the cartilage from the capitellum and 2 alternative donor sites of the ipsilateral elbow in the treatment of capitellar OCD: the nonarticulating part of the radial head and the nonarticulating lateral side of the olecranon tip. **Clinical Relevance:** From an histologic point of view, there seem to be no obstacles to use grafts from these alternative donor sites for reconstruction of the capitellum when performing osteochondral autologous transplantation.

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Introduction

The osteochondral autologous transplantation system (OATS) has become a popular treatment option for advanced osteochondritis dissecans (OCD) of the capitellum or in case of failed bone marrow procedures.[1-4] In OATS, single or multiple osteochondral

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grafts are harvested from the less-weightbearing parts of the femoral condyle or costal—osteochondral junction. These cylindrical grafts are then perpendicularly transplanted into the defect area at the capitellum.[1-3] Several factors need to be taken into account for a proper match between the donor graft and the recipient site, including the curvature of the articular surface and cartilage thickness.[5-8] Ideally, the curvature of a donor graft is similar to that of the recipient site to maintain the biomechanical properties of the elbow joint.[9-11] Cartilage thickness should also be taken into account because plugs heal to the subchondral and deeper bone and not along the cartilage surface.[5,12]

Promising outcomes in terms of pain relief, elbow function, and return to sporting activities have been reported after capitellar OATS.[1-3,13] However, donor-site morbidity remains a problem and the subject of ongoing debate.[14,15] A systematic review performed by our research group demonstrated considerable donor-site morbidity: 7.8% after harvesting from the knee (mainly knee pain during activities) and 1.6% after harvesting from the rib (1 pneumothorax that required insertion of a chest tube).[15] To eliminate the risk for donor-site morbidity of an asymptomatic knee or rib area in a young athlete, we hypothesized 2 alternative donor sites within the affected elbow joint as a potential source for graft harvesting: the nonarticulating part of the radial head and the nonarticulating lateral side of the olecranon tip. Three-dimensional computed tomography (CT) analysis has demonstrated that the articular surfaces of both donor sites provide an appropriate topographic match to that of the capitellum.[8] It is yet unknown if the articular surface of the capitellum matches these alternative donor sites in terms of histologic features (e.g., cartilage thickness, cell and matrix morphologies).

As a result, the purpose of this study was to compare the histologic features of the cartilage from the capitellum with 2 proposed alternative donor sites of the ipsilateral elbow in the treatment of capitellar OCD: the nonarticulating part of the radial head and the nonarticulating lateral side of the olecranon tip. We hypothesized that there would be no difference in terms of histologic features between the cartilage from the capitellum and the 2 donor sites.

Methods

This study was waived for review by the medical ethics committee of our institution because of its study design.

Ten human cadaveric elbow specimens, frozen within 48 hours of death, were collected (N.F.J.H.). The distal humerus and radius were available for all 10 specimens. A matching ulna was available in 4 specimens. The remaining 6 ulna had already been used for other research purposes. Included in this investigation were specimens that showed a macroscopically normal articular surface. Specimens were excluded if they showed abnormal osseous anatomy (congenital or post-traumatic deformities). All elbow specimens showed macroscopically normal articular surfaces (N.F.J.H.) and thus were included in this study. The sex and age of the elbow specimen donors were unknown.

The nonarticulating part of the radial head was marked by using an osteotome (N.F.J.H.). This zone extends 65° anterior to and 45° posterior to the bisecting reference mark made with the forearm in neutral rotation.[16] A disposable standard plug harvesting system (Arthrex, Naples, FL) was used to obtain osteochondral grafts with a diameter of 5 mm orthogonal to the joint surface from the capitellum, the nonarticulating part of the radial head, and the nonarticulating lateral side of the olecranon tip. The graft depth was 10 mm. Capitellar grafts were harvested from the posterolateral zone, 60° anteriorly relative to the shaft of the humerus, which is the most commonly affected zone in capitellar OCD (Fig 1A).[17] From the radial head, grafts were obtained at 80°, which is the site where the nonarticulating zone is divided into 2 equal parts (Fig 1B). The superior edge of the radial head was not included. Olecranon grafts were harvested from the lateral side of the nonarticulating part of the olecranon tip (Fig 1C).

The obtained grafts were immediately fixated in formalin (4% formaldehyde) and stored refrigerated.[18] After at least overnight fixation, the biopsy specimens were cut in half, perpendicular to the chondral surface, and fixed for an additional 24 hours. The fixed specimens were subsequently decalcified[19] and processed into standard paraffin-embedded tissue blocks. These blocks were used to produce standard 8-μm-thick hematoxylin and eosin (HE)- and Toluidine Blue (TB)-stained sections.

Histologic Parameters

The following parameters were included based on the current literature and the experience of 2 senior authors (D.E. and D.S-H.): cartilage thickness (in tenths of millimeters),[5,7,20,21] shape of the articular surface (convex or concave),[6,7] and 13 parameters of the International Cartilage Repair Society (ICRS) II (Table 1).[22,23] The ICRS II is a commonly used and reliable histologic scoring system for cartilage repair.[22-24] One parameter, basal integration, was excluded from assessment because basal integration is only applicable in the assessment of transplanted cartilage.

All parameters were assessed during blinded microscopic slide assessment, which was performed twice by an histopathologist (H.d.B.) under the supervision of a

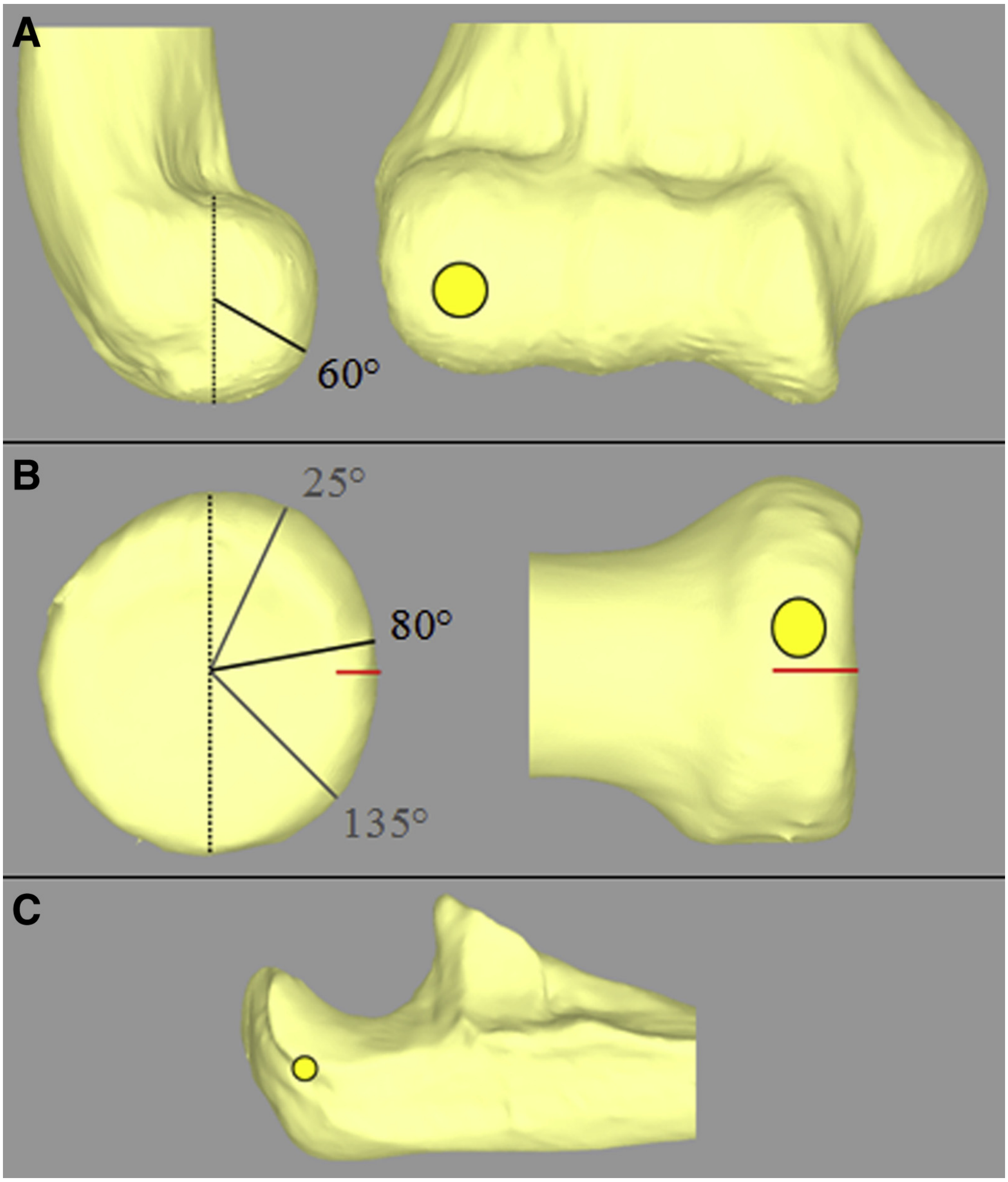

Fig 1. (A) Lateral and anterior view of a right distal humerus. Capitellar grafts were harvested from the posterolateral zone of the capitellum (60° anteriorly relative to the shaft of the distal humerus), which is the most commonly affected zone in capitellar OCD. (B) Radial head grafts of a right elbow were obtained at 80°, which is within the nonarticulating zone of the radial head. (C) Olecranon grafts of a right elbow were harvested from the lateral side of the nonarticulating part of the olecranon tip.

senior pathologist (D.S-H.), both of whom have specialized experience in bone and cartilage histology. Total cartilage thickness was assessed with the use of a micrometer. Cartilage thickness was also assessed for each of 3 zones separately: the superficial zone, where the collagen orientation is parallel to the joint surface and chondrocytes are flattened; the transitional zone, where the collagen orientation is oblique or random and chondrocytes are round; the deep/radial zone, where the collagen orientation is perpendicular and round chondrocytes are arranged in columns. The included ICRS parameters were assessed qualitatively and subsequently converted into an estimated percent value, according to Table 1.[22] The average score of both assessments was averaged.

Statistical Analysis

Baseline characteristics were summarized as means with standard deviations for continuous variables. A Wilcoxon-Mann-Whitney test was performed to detect any differences between the recipient (capitellum) and the radial head for each histologic parameter. Because only 4 olecranon specimens were included, these were excluded from statistical analysis. A P value of $< .05$ was considered significant.

Table 1. International Cartilage Repair Society II Parameters[22]

Parameter	Score (Range, 0-100)
1. Tissue morphology	0%: full-thickness collagen fibers 100%: normal cartilage birefringence
2. Matrix staining (metachromasia)	0%: no staining 100%: full metachromasia
3. Cell morphology	0%: no round/oval cells 100%: mostly round/oval cells
4. Chondrocyte clustering (4 or more grouped cells)	0%: present 100%: absent
5. Surface architecture	0%: delamination, or major irregularity 100%: smooth surface
6. Formation of a tidemark	0%: no calcification front 100%: tidemark
7. Subchondral bone abnormalities/marrow fibrosis	0%: abnormal 100%: normal subchondral bone/bone marrow
8. Inflammation	0%: present 100%: absent
9. Abnormal calcification/ossification	0%: present 100%: absent
10. Vascularization	0%: present 100%: absent
11. Overall surface/superficial assessment (upper third of the cartilage tissue)	0%: total loss or complete disruption 100%: resembles intact articular cartilage
12. Overall mid/deep zone assessment (lower two thirds of the cartilage tissue)	0%: fibrous tissue 100%: normal hyaline cartilage
13. Overall assessment	0%: bad (fibrous tissue) 100%: good (hyaline cartilage)

Intraobserver variation was assessed for cartilage thickness and all 10 ICRS parameters by calculating the intraclass correlation coefficient. A value of ≥0.80 was chosen to indicate substantial agreement.[25] Statistical analysis was performed with the use of Stata (version 13.0; StataCorp, College Station, TX).

Results

Mean cartilage thickness was 1.5 ± 0.22 mm at the capitellum, 1.3 ± 0.34 mm at the nonarticulating part of the radial head, and 1.9 ± 1.0 mm at the lateral side of the nonarticulating olecranon tip (Table 2). There was no significant difference in cartilage thickness between the capitellum and the radial head ($P = .062$).

All capitella and both donor sites (radial head and olecranon tip) demonstrated a convex articular surface (Table 2).

For the capitellum, mean scores among the parameters ranged from 82 to 100; for the radial head, from 81 to 100; and for the olecranon tip, from 67 to 87 (Table 3). There was less chondrocyte clustering at the capitellum (84 ± 14) than in the radial head (94 ± 3.2; $P = .019$). Also, mid/deep zone assessment (lower two thirds of the cartilage tissue) of the capitellum scored higher (97 ± 6.7) than the radial head (91 ± 4.6; $P = .038$). No differences were seen in the remaining parameters ($P > .05$). Two micrographs of a decalcified biopsy specimen, stained with TB and HE,[22] are shown in Figs 2 and 3.

The mean intraobserver reliability was substantial (intraclass correlation coefficient = 0.90; range, 0.81 to 0.99).

Discussion

Overall, the results of this study demonstrate appropriate histologic similarities between the capitellum and 2 alternative donor sites of the ipsilateral elbow, with regard to cartilage thickness, shape of the articular

Table 2. Histological Outcomes: Cartilage Thickness and Shape of Articular Surface

Parameter	Capitellum Score (n = 10)	Radial Head Score (n = 10)	Olecranon Score (n = 4)
1. Total cartilage thickness ±SD, mm	1.5 ± 0.22	1.3 ± 0.34	1.9 ± 1.0
Thickness superficial zone ±SD, mm	0.52 ± 0.67	0.27 ± 0.13	0.27 ± 0.058
Thickness transitional zone ±SD, mm	0.68 ± 0.13	0.62 ± 0.13	1.2 ± 0.90
Thickness deep/radial zone ±SD, mm	0.44 ± 0.16	0.4 ± 0.16	0.53 ± 0.31
2. Shape of articular surface (convex vs concave)	Convex	Convex	Convex

SD, standard deviation.

Table 3. Outcomes: International Cartilage Repair Society II Parameter Scores

Parameter (Score, 0 to 100)	Capitellum Score (n = 10)	Radial Head Score (n = 10)	Olecranon Score (n = 4)
1. Tissue morphology ±SD	97 ± 6.7	91 ± 10	70 ± 26
2. Matrix staining ±SD	82 ± 15	81 ± 11	87 ± 5.8
3. Cell morphology ±SD	96 ± 10	94 ± 6.3	85 ± 13
4. Chondrocyte clustering ±SD	84 ± 14*	94 ± 3.2*	83 ± 2.9
5. Surface architecture ±SD	87 ± 13	88 ± 7.5	67 ± 32
6. Formation of a tidemark ±SD	92 ± 18	87 ± 16	70 ± 35
7. Subchondral bone abnormalities/marrow fibrosis ±SD	100 ± 0	100 ± 0	100 ± 0
8. Inflammation ±SD	100 ± 0	100 ± 0	100 ± 0
9. Abnormal calcification/ossification ±SD	100 ± 0	100 ± 0	100 ± 0
10. Vascularization ±SD	100 ± 0	100 ± 0	100 ± 0
11. Surface/superficial assessment ±SD	84 ± 21	87 ± 7.9	70 ± 0
12. Mid/deep zone assessment ±SD	97 ± 6.7*	93 ± 4.2*	93 ± 5.8
13. Overall assessment ±SD,	93 ± 10	91 ± 4.6	72 ± 19

SD, standard deviation.
*Significant difference between capitellum score and radial head score.

surface, and cell and matrix morphology. Mean difference in cartilage thickness between the capitellum and radial head was 0.2 mm; mean difference between the capitellum and olecranon tip was 0.4 mm. All recipient and donor sites revealed a convex articular surface. At the level of cell and matrix morphologies, the present results revealed uniform cartilage tissue features for the capitellum and both donor sites, including tissue and cell morphologies, proteoglycan content, and surface architecture, among others.

The findings of this investigation demonstrate small differences in cartilage thickness between the capitellum and both donor sites. The mean cartilage thickness of the capitellum in our investigation is consistent with prior studies investigating cartilage features to optimize knee-to-elbow matching for capitellar OATS.[5,7] Schub et al.[5] used magnetic resonance imaging to assess cartilage thickness of commonly used donor and recipient sites of the femoral condyle and capitellum. Based on 94 elbow magnetic resonance images of adolescents, the mean cartilage thickness of the capitellum was 1.3 ± 0.31 mm, which is comparable to our finding of 1.5 ± 0.22 mm. They reported a difference in cartilage thickness of 0.5 mm of the most congruent match between the capitellum and the femoral condyle.[5] In a similar study, Vezeridis and Bae[7]

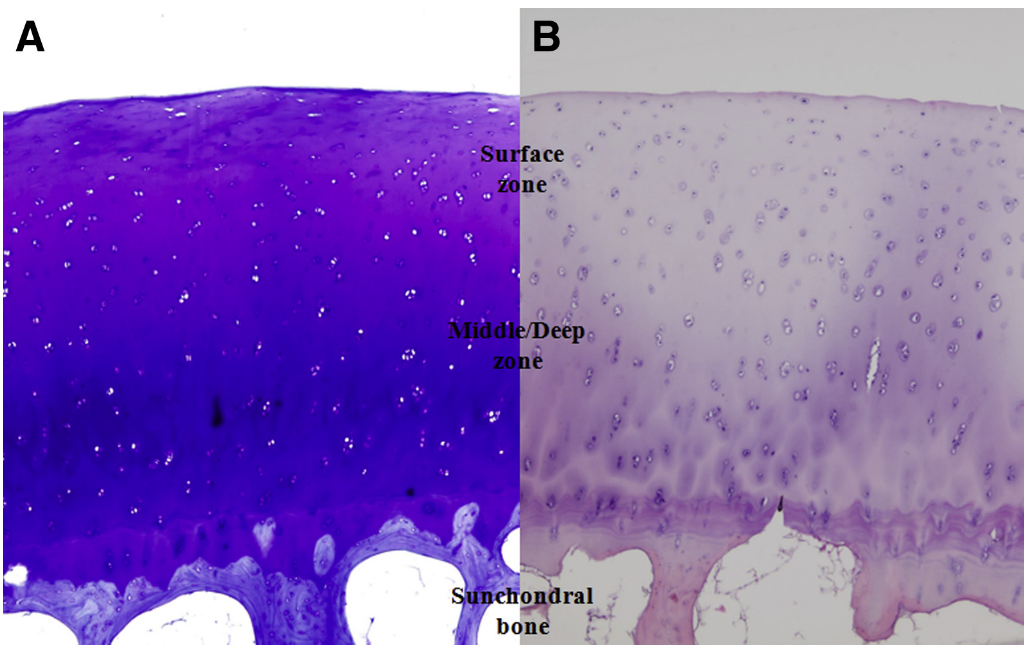

Fig 2. Micrographs of a decalcified biopsy-specimen of cartilage and subchondral bone, stained with Toluidine Blue (A) and Haematoxylin and Eosin (B), in line with the recommendations of Mainil-Verlat and colleagues[22] in their paper on the ICRS II scoring system. Magnification ratio: 50x.

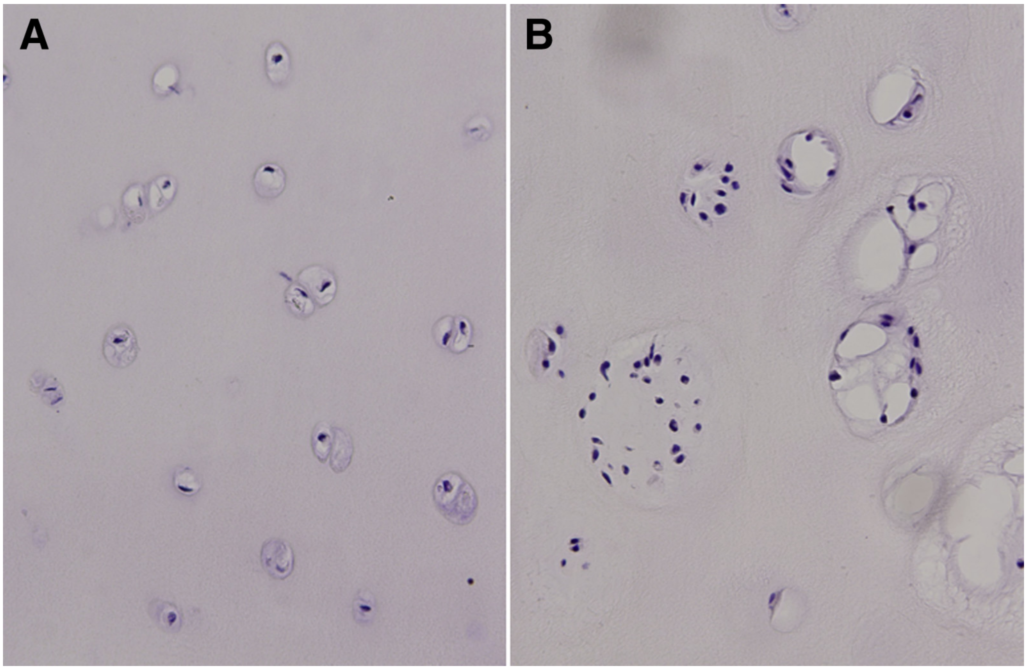

Fig 3. Micrographs of Haematoxylin and Eosin stained sections with A) the cytonuclear details of unremarkable, solitary chondrocytes with small pycnotic nuclei and B) a focus of more elongated/flattened and clustered chondrocytes. Magnification ratio: 400x.

reported a mean difference in cartilage thickness between the capitellum and 5 femoral donor sites of 0.6 mm. Interestingly, the aforementioned differences in cartilage thickness are slightly larger than the differences we found between the capitellum and both donor sites (radial head, 0.2 mm; olecranon tip, 0.4 mm). This suggests that, when performing OATS in the treatment of capitellar OCD, harvesting grafts from the ipsilateral elbow may hypothetically lead to greater bone-to-bone contact between the donor plug and the surrounding recipient tissue, thereby expediting the incorporation of the graft into the capitellum. As previously theorized by multiple authors, this would lead to minimized stress between donor plug and recipient, thereby prolonging donor plug viability.[5,12]

All specimens showed a convex articular surface. Although this does not say anything about the radius of convexity in different directions, it suggests that either donor site may potentially lead to a congruent articular surface match with the capitellum. This is supported by a recent study conducted by our research group, based on 3-dimensional quantitative computed tomography analysis, that revealed an appropriate topographic surface match between the capitellum and both alternative donor sites.[8] Two studies have investigated knee-to-elbow matching in a quantitative way as opposed to our qualitative assessment.[6,7] Vezeridis and Bae[7] reported <1 mm of articular incongruity when a 10-mm graft was harvested from the anterior non-weightbearing part of the femoral condyle. Shin et al.[6] found a smaller difference (<0.6 mm) in articular surface match between the capitellum and the femoral condyle.

Overall, the specimen showed articular hyaline cartilage with minimal collagen fibers (i.e., fibrocartilage), indicating normal healthy, nonscarred chondral tissue. Matrix staining with TB indicated similar proteoglycan content for all specimens, which suggests similar load-bearing qualities of the cartilage.[26,27] There was more chondrocyte clustering at the capitellum than at the radial head, but the significance of this finding is not fully understood. In osteoarthritic tissue, clustering of chondrocytes is associated with degeneration, but their presence in developing or immature cartilage may suggest cartilage remodeling during the healing process.[28,29] The cause and possible effect of this small difference therefore remain currently unknown. A small difference in the mid/deep zone assessment of the cartilage was observed between the capitellum and the radial head. However, both scored almost 100%, indicating good overall cartilage quality, and the effect is therefore expected to be minimal.

This study should be considered as a pilot study in which we demonstrated that both alternative donor sites of the ipsilateral elbow show appropriate similarities to the capitellum in terms of cartilage thickness, articular surface shape, and cell and matrix morphologies. From an histologic point of view, there seem to be no obstacles to use grafts from these donor sites for reconstruction of the capitellum. In addition to our previous study, in which we reported a similar topographic 3-dimensional match between the capitellum and both donor sites,[8] this study has laid the foundation to develop harvest techniques from the ipsilateral elbow when performing OATS for capitellar OCD.[30] Reconstruction of the capitellum by means of OATS may be indicated in symptomatic OCD lesions of 10 mm in diameter (78.5 mm^2) or larger.[31,32] Hypothetically, when obtaining 3 grafts from the radial head and 3 grafts from the olecranon, lesions up to 117.6 mm^2 (6 grafts $\times$ 19.6 mm^2) could be treated. In lesions that are larger, one may not be able to obtain enough grafts from the ipsilateral elbow. For these cases, the femoral condyle or costal—osteochondral junction may be more suitable.[31,33-35] Avoiding the risk of donor site morbidity of the knee or rib area would be beneficial for the adolescent athlete.[15] However, before proceeding to in vivo studies, further research is needed to indicate whether these grafts are appropriate in the clinical setting[30] and to find out if harvesting from the ipsilateral elbow affects elbow function in a negative way.

Limitations

The findings of this study should be interpreted by taking into account some limitations. First, the number of included specimens was relatively small. In addition, because we were able to include only 4 olecranon specimen, these were excluded from the statistical analyses. The inclusion of more (olecranon) specimens would be needed to corroborate the findings of our small survey. Second, we solely investigated donor sites within the ipsilateral elbow joint. Assessment of matching knee specimen was not possible because of the study design, so no direct comparison with knee-to-elbow matching was possible. Third, although the findings of this investigation are encouraging, there is no direct knowledge on the correlation between the used histologic parameters and the *performance* of these donor sites in the clinical setting. For example, compression and shear loads alter chondrocyte metabolism in human articular cartilage.[36] It is not yet known if the chondrocyte metabolism of nonarticulating cartilage (e.g., of the radial head or olecranon tip), which is hypothetically exposed to different types of loads, would *perform* when transplanted to an articulating part of the joint. However, the histologic parameters we used are seen as general determinants of cartilage health.[22]

Conclusions

This study demonstrates appropriate histologic similarities between the cartilage from the capitellum and 2 alternative donor sites of the ipsilateral elbow in the treatment of capitellar OCD: the nonarticulating part of the radial head and the nonarticulating lateral side of the olecranon tip.

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