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Morrey Award 2023: radial head donor plug for capitellum osteochondral autograft transfer: a cadaveric biomechanical analysis

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A R T I C L E I N F O

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Level of evidence: Basic Science Study; Biomechanics

Background: Limitations to using the knee as donor cartilage include cartilage thickness mismatch and donor site morbidity. Using the radial head as donor autograft for capitellar lesions may allow for local graft harvest without distant donor site morbidity. The purpose of this study is to demonstrate the feasibility of performing local osteochondral autograft transfer from the nonarticular cartilaginous rim of the radial head to the capitellum. Additionally, we sought to determine the load to failure of the radial head after harvest.
Methods: Sixteen matched cadaveric elbows were used. A Kaplan approach was performed in half of the specimens and an extensor digitorum communis split in the other half. 6-mm and 8-mm capitellar cartilage defects were created. A donor plug was harvested from the rim of the radial head and transferred to the capitellum. In half of the specimens, the donor site was backfilled with autograft from the recipient plug. The other half was backfilled with calcium phosphate cement. The radial head was removed from the specimen and biomechanical analysis performed.
Results: Both surgical approaches had adequate exposure to access the lateral two-third capitellar lesions in all specimens. The medial third of the capitellum was less accessible in extensor digitorum communis split approaches (1/8) compared to the Kaplan approach (6/8; $P = .01$). The average cartilage thickness of the peripheral rim of the radial head and capitellum was 2.5 mm (range 1.8-3.2, standard deviation 0.4) and 2.2 mm (range 1.8-3, standard deviation 0.3), respectively. During the procedure, 2 of 8 radial heads fractured in the 8-mm plug group. No radial heads fractured in the 6-mm group ($P = .47$). Biomechanical testing demonstrated a mean load to failure of 1993N with no difference between groups when stratified by donor plug size or type of backfill.
Conclusion: This study demonstrates that the nonarticulating peripheral cartilaginous rim of the radial head could be a local harvest site for osteochondral autograft transfer for capitellar lesions up to 8 mm in diameter. The cartilage thickness of the radial head closely approximates the capitellum. Biomechanical analysis did not demonstrate a significant difference in load to fracture when backfilling the radial head harvest site with autograft bone or calcium phosphate cement. After harvest, the radial head could withstand forces much greater than those seen across the elbow when nonweight-bearing. Further investigation is needed to determine how to mitigate the risk of iatrogenic fracture with this operation.

Capitellar cartilage defects are seen in several settings to include overuse, osteochondritis dissecans, radial head fractures, capitellum fractures, elbow dislocations, and post-traumatic osteoarthritis.[13,17,26,29] Management of focal cartilage lesions of the capitellum varies greatly and may include nonoperative management, arthroscopic débridement, chondroplasty, fragment excision, fragment fixation, microfracture, transosseous drilling, bone grafting, osteotomy, osteochondral autograft transfer (OATS), osteochondral

This study was exempt from institutional review board approval as it is a cadaveric biomechanical study.
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Figure 1 Extensor digitorum communis split approach.

allograft transfer, and arthroplasty.[7,8,10,13,17,21,23,24,26,29,42] Management of cartilage defects associated with osteochondritis dissecans has been extensively studied.[8,16,21,22,25,39,40,42] Currently, OATS is considered a more durable surgical option when compared to débridement and microfracture, especially for larger lesions.[1,4,19] The most common donor site used for OATS is the nonweight-bearing portion of the knee.[20] The benefit of taking graft from the knee is the ability to harvest multiple grafts as large as 10 mm from the nonweight-bearing portion of the lateral or medial femoral condyle.[20,28] However, there are several limitations to this technique to include radius of curvature mismatch, cartilage thickness mismatch, and donor site morbidity.[11,26,31,32,41]

The cartilaginous end of the rib has been used as another graft harvest site with lower rates of donor site morbidity rates when compared to the knee.[30,35] However, this graft harvest requires an exposure unfamiliar to most elbow surgeons, is used less commonly, and carries the additional risk of iatrogenic pneumothorax.[5]

Several studies looking to predict radial head prosthesis size have demonstrated anatomic similarities in the dimensions of the radial head and capitellum.[6,9,34] Bexkens et al demonstrated less than 0.2 mm variance in subchondral bone topography on 3-dimensional computed tomography (CT) between the capitellum and radial head with similar cartilage thickness on histologic analysis.[2,12] A magnetic resonance imaging (MRI) study by Griswold et al showed an average of 0.3 mm difference in the radius of curvature of the convex peripheral cartilaginous rim of the radial head when compared to the radius of curvature of the capitellum.[12] Furthermore, 94% of these elbows had a radius of curvature difference less than 1 mm.[12] Using the nonarticulating portion of the radial head as osteochondral autograft for osteochondral lesions of the capitellum may have several advantages over other graft options to include local graft harvest without additional skin incisions, no additional knee donor site morbidity, and a closer radius of curvature match.

The purpose of this study was to demonstrate the feasibility of performing local OATS from the nonarticular peripheral cartilaginous rim of the radial head to the capitellum through standard surgical approaches. Additionally, we sought to determine the load to failure of the radial head after osteochondral autograft harvest and backfilling. We hypothesized (1) that the radial head OATS to the capitellum would be surgically feasible through standard approaches to the elbow and (2) that the radial head would be able to withstand loading expected during the postoperative period following autograft harvest and backfilling.

Figure 2 Capitellum defect preparation.

Methods

Sixteen matched elbows were harvested from 8 fresh frozen cadaveric specimens. Baseline dual x-ray absorptiometry studies were obtained on each elbow. A Kaplan approach was performed in 8 specimens and an extensor digitorum communis (EDC) split approach was performed in 8 specimens to expose the radiocapitellar joint. The Kaplan approach was performed in the interval between the extensor carpi radialis brevis and EDC. The EDC split was performed by dividing the common extensor tendon in its central portion (Fig. 1). After exposure, the coronal diameter of the capitellum was measured at its widest portion from the lateral cartilaginous edge of the capitellum to the beginning of the trochlear ridge. Measurements were recorded using a digital caliper (FWT Precision Digital Caliper; FWT GmbH, Bingen, Germany). The cartilage thickness of the capitellum was measured by inserting a needle through the cartilage to subchondral bone, marking the depth on the needle and measuring the depth with the caliper. This was performed at 3 separate points at the anterior, middle, and lateral thirds of the capitellum. Similarly, the cartilage thickness of the nonarticulating peripheral rim of the radial head was measured at 3 separate points separated by 3 mm at the 90° anatomic safe zone of the proximal radial head rim. To evaluate surgical access to lesions on the capitellum by surgical approach, the total diameter of the capitellum was measured, and then divided into 3 zones. The OATS harvester was brought in through the selected surgical approach. If the surgeon was able to get the OATS harvester perpendicular to the articular surface, that zone was categorized as accessible. If the OATS harvester could not be placed perpendicular to the articular surface, that zone was categorized as inaccessible. In the sagittal plane, accessibility was evaluated according to the clockface described by Johnson et al.[15] Assessment of access with more posterior approaches such as an anconeus split or Kocher approach was not performed due to the short lever arm and stiffness of the cadaveric specimens that limited elbow flexion beyond 100°.

After measurements were recorded, capitellar osteochondral lesions were simulated at the inferolateral aspect of the anterior capitellum using the OATS recipient plug harvester (Autograft OATS Kit 2.0; Arthrex, Naples, FL, USA, Fig. 2). A 6-mm diameter defect was created in half of the specimens and an 8-mm defect was created in the other half. A new harvesting kit was used after

Figure 3 Radial head donor plug harvest.

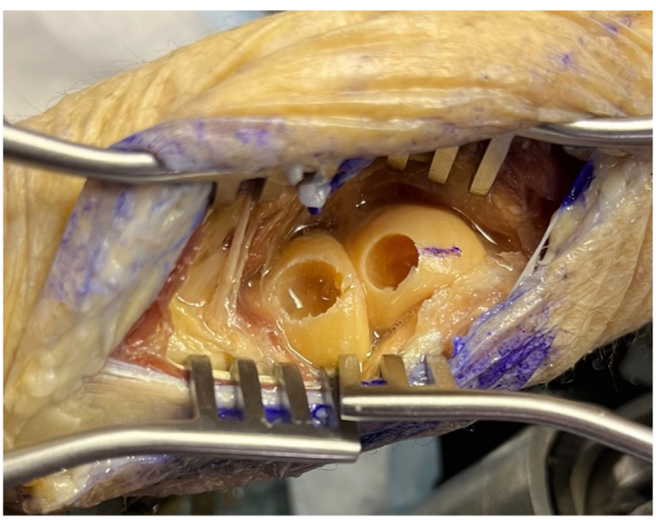

Figure 4 Donor site radial head (*Left*) and recipient site on capitellum (*Right*).

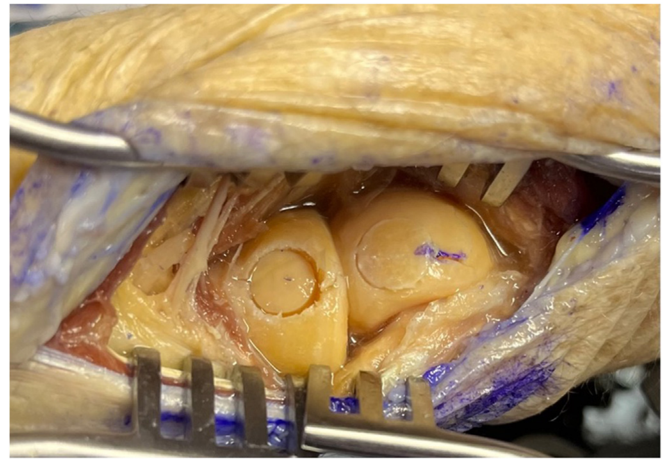

Figure 5 Completed osteochondral autograft transfer with corticocancellous autograft backfill in radial head.

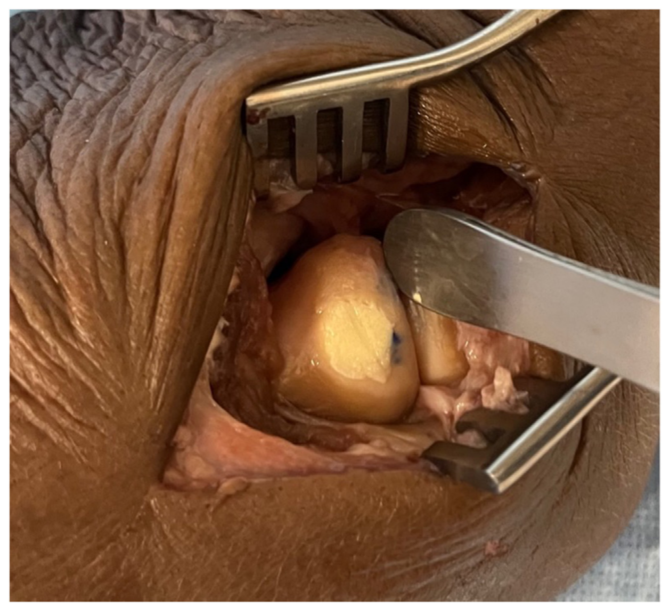

Figure 6 Calcium phosphate putty backfill in radial head.

performing 4 harvests. The forearm was placed in neutral rotation and the anatomic "safe zone" was defined on the radial head as the 90° arc between Lister's tubercle and the radial styloid. Additionally, the safe zone was confirmed by palpation and direct visualization through the incision during forearm pronation and supination, confirming that the area of planned harvest would not articulate with the proximal radial ulnar joint. The OATS plug harvester was placed on the nonarticulating peripheral cartilaginous rim of the radial head, just distal to the superior aspect of the radial head (Fig. 3). After the initial iatrogenic fractures, the harvester was tilted 5° distally to avoid penetration of the articular dish of the radial head. The OATS harvester was impacted to a depth of 8-9 mm, twisted and removed to extract the donor plug (Fig. 4). If excess bone was removed, it was trimmed off the donor plug to match the depth of the recipient site. Then, the donor plug was inserted into the recipient site on the capitellum (Fig. 5).

In 8 specimens, the plug from the original recipient site was used to backfill the radial head harvest site to simulate application of cancellous bone graft to the harvest site. In the other 8 specimens, a fast-setting calcium phosphate bone putty that resists compressive loads (Montage Bone Putty; Abryx, Stamford, CT, USA) was used to backfill the radial head harvest site (Fig. 6). This calcium phosphate was chosen due to its immediate hardening and structural support. The radial head was removed from the specimen and biomechanical analysis performed to assess load to fracture (Fig. 7).

Biomechanical analysis

After completion of the procedure, the radial head and shaft from the specimens were isolated and potted (Bondo Body Filler and Fiberglass Resin) up to the distal aspect of the radial tuberosity. Specimens were loaded to failure using an MTS 858 MiniBionix II System (MTS Systems Corporation, Eden Prairie, MN, USA). A 25-mm aluminum ball, which was of a similar size to the average diameter of a human capitellum, was centered in the articular dish of the radial head and loaded against the radial head at 0.25 mm/s. The ultimate load to failure was recorded at a point of an abrupt

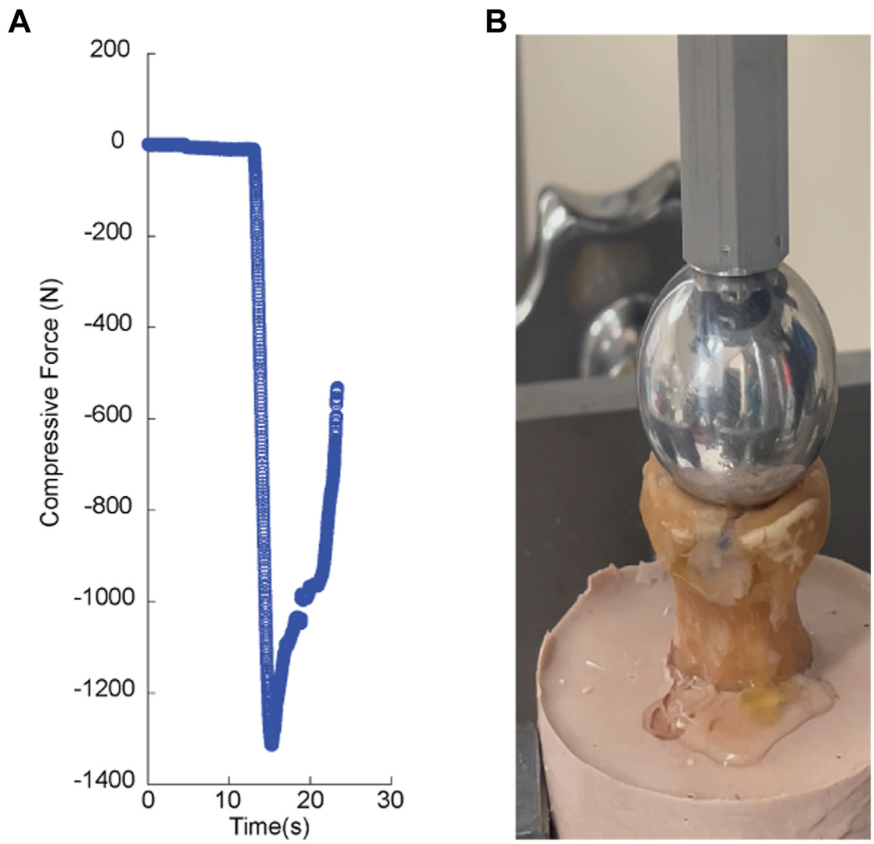

Figure 7 Biomechanical testing of radial head after donor plug harvest and corticocancellous autograft backfill. (**A**) An example of compressive load profile of load to failure. (**B**) The corresponding subchondral failure.

Table I
Load to fracture in radial head specimens backfilled with corticocancellous autograft vs. calcium phosphate putty.

Specimen	Corticocancellous autograft (N)	Calcium phosphate (N)	*P* value
1	3047	2218	
2	680	997	
3	2727	3498	
4	1314	1712	
5	1674	1785	
6	2889	3563	
7	786	1229	
8	Not tested due to fracture	1458	
Average	1907	2058	.11

drop on the load/displacement curve in Newtons (N). An additional 8 native radial heads were tested for a control comparison.

Statistical analysis

Categorical data (accessibility based on approach) were analyzed and compared using contingency tables and chi-square analysis. Cartilage thickness was analyzed with unpaired *t*-test analysis and load to failure was analyzed with paired *t*-test analysis with significance set at $P < .05$ (MedCalc; MedCalc Software Ltd., Flanders, Belgium).

Results

The average age of the specimens was 78.25 (63-93) years. No specimens had osteophytes or full-thickness chondral lesions upon gross inspection. Average bone density of the cadaveric specimens was 0.58 g/cm^3 with no significant difference between matched elbow specimens. Kaplan and EDC split approaches had adequate exposure to access the lateral two-thirds of the capitellum in all 16 specimens. The medial third of the capitellum was less accessible in the EDC split approach (1/8) compared to the Kaplan approach (6/8; $P = .01$). This was due to limited visualization of the muscle and tendon anterior to the split. Both Kaplan and EDC split approaches allowed access to the anterior capitellum from 12 o'clock to 5 o'clock in all specimens. Average diameters of the radial head and capitellum were 23.8 mm (range 18-24, standard deviation [SD] 2.0) and 19.6 mm (range 20-31 mm, SD 3.1), respectively. The average cartilage thickness of the peripheral rim of the radial head and capitellum was 2.5 mm (range 1.8-3.2, SD 0.4) and 2.2 mm (range 1.8-3, SD 0.3), respectively. During the procedure, 2 of 8 radial heads fractured in the 8-mm plug group. Both fractures had a donor plug harvest starting less than 3 mm from the superior rim of the radial head and were in the first of 3 harvested radial heads. One fractured specimen had a radial head diameter of 22 mm and the other was 23 mm. One fracture occurred in the Kaplan approach and the other in the EDC split approach. No additional fractures occurred after these two. Zero of 8 radial heads fractured in the 6-mm group ($P = .47$). Biomechanical testing demonstrated an average load to fracture of 1993N with no significant difference between groups when stratified by autograft or calcium phosphate cement backfill (1907N vs. 2058N, $P = .11$, Table I). No significant difference in load to fracture was seen in 6 mm or 8 mm plug size (2107N vs. 2313N, $P = .58$, Table II). There was no significant difference in load to fracture in the intact native radial compared to the radial head after graft harvest (2168N vs. 1993N, $P = .63$).

Table II
Load to fracture in radial head specimens with 6-mm and 8-mm donor plugs.

	6-mm plug (N)	8-mm plug (N)	*P* value
	2218	2727	
	3047	3498	
	680	1314	
	997	1712	
	1674	Fractured	
	1785	1458	
	2889	786	
	3563	1229	
Average (N)	2107	2313	.58

Discussion

The primary findings of this study are that an osteochondral plug up to 8 mm can be harvested from the "safe zone" of the peripheral cartilaginous rim of the radial head and transplanted into a capitellar osteochondral defect. The cadaveric analysis also demonstrated that the nonarticulating convex peripheral rim of the radial head and capitellum have similar cartilage thickness making it a suitable graft.

Although the knee is a robust source of osteochondral autograft for management of capitellar osteochondral lesions, donor site morbidity can persist when taking osteochondral autograft from the knee. Studies reporting the incidence of knee donor site morbidity vary widely with rates described as low as 0% to as high as 54%.[5,20,31,32,37,41] Additionally, there are concerns regarding the differences in cartilage thickness and radius of curvature between the distal femur and capitellum.[11,36,38,41] In a CT study evaluating distal femur OATS for capitellar lesions, the average radius of curvature of the capitellar lesion was 9.79 mm and the average radius of curvature of the distal femur harvest site was 15 mm.[11] In their study, only 15% of grafts had "good fit," which was defined as less than 3 mm difference in radius of curvature.[11] Another CT-based study reported conflicting results with less than 0.1 mm difference in surface topography of the distal femur and capitellum.[38]

Previous studies have shown consistent similarities in the radius of curvature and cartilage thickness of the capitellum and peripheral convex rim of the radial head.[2,3,12] Griswold et al performed an MRI study of 83 patients with normal elbow MRIs assessing the radius of curvature of the peripheral convex rim of the radial head and capitellum.[12] They found that 94% of patients in the study had less than 1 mm difference in radius of curvature between the radial head and capitellum. This study suggested that the peripheral cartilaginous rim of the radial head may be a novel local robust osteochondral autograft for reconstruction of complex capitellar bone and cartilage injuries.[12] Additionally, Bexkens et al performed a topographic 3-dimensional CT study of the capitellar subchondral bone compared to the subchondral bone of the nonarticular portion of the radial head and found less than 0.2 mm difference in subchondral topography.[3] Bexkens et al also analyzed the histology of the capitellum and radial head cartilaginous surfaces and found no significant difference between their cartilage thickness and their International Cartilage Repair Society scores.[2]

The similarities in radius of curvature between the nonarticular portion of the radial head and capitellum make it an attractive autograft option given that it is local to the surgical site and knee donor site morbidity can be avoided. Furthermore, our present study showed similar cartilage thickness between the radial head donor site and capitellum, with an average difference of 0.3 mm between the radial head and capitellum. However, the amount of graft available for harvest at the radial head is a concern. All iatrogenic fractures in our study occurred when using an 8-mm OATS harvester less than 3 mm from the most superior edge of the radial head. No fractures were seen when using the 6-mm OATS harvester. Further cadaveric studies are needed to optimize the harvest technique and determine the safety of using an 8-mm osteochondral plug.

The average size of lesions associated with osteochondritis dissecans has been reported to be 10 mm medial to lateral and 5 mm anterior to posterior.[15] The amount of graft available at the radial head is a limitation to this technique because we were only able to harvest a maximum plug diameter of 8 mm. Future studies may evaluate the clinical result of incomplete filling of the defect with an autograft OATS plug and the biomechanical effect of taking 2 osteochondral plugs from the radial head. Furthermore, oblong harvest plugs may be another suitable option which may provide increased length of graft harvest with smaller width.

In the radial head specimens that underwent biomechanical testing, the average load to fracture after osteochondral plug harvest was 1993N. A cadaveric study assessing the biomechanical load seen across the radiocapitellar joint demonstrated a maximum load of 40N with resting muscle tension.[27] The maximum load to fracture in our study was much greater than 40N, suggesting that the risk of radial head fracture after successful autograft OATS harvest would be low. We did not observe a statistically significant difference in load to fracture when comparing specimens backfilled with corticocancellous autograft vs. calcium phosphate putty. Prior studies have shown trochlear donor sites less than 10 mm in diameter may not need backfilling.[33] While load to failure indicates the strength of a single loading cycle, future studies should evaluate the effect of long-term cyclic loading on the radial head after donor plug harvest.

Capitellar osteochondral defect location is critical when planning the surgical approach to address the defect. Defects associated with simple elbow dislocations are most frequently seen at the posterolateral aspect of the capitellum.[18] Lesions associated with osteochondritis dissecans are most often found anteriorly between 3 and 5 o'clock.[15] In a cadaveric study evaluating access to capitellar lesions, investigators performed anconeus split, lateral collateral ligament (LCL) preserving and LCL-sacrificing approaches and placed wires at the peripheral points of the approach that allowed perpendicular access for the OATS harvester.[14] They found that the anconeus split approach afforded access to capitellar lesions ranging from 3 o'clock (anterior) to 7 o'clock (posterior), the LCL-preserving approach allowed access from 12 o'clock to 4 o'clock anteriorly, and the LCL-sacrificing approach allowed access from 12 o'clock to 5 o'clock anteriorly.[14] In our cadaveric study, we found similar results with the Kaplan and EDC split approaches allowing anterior access from 12 to 5 o'clock. Additionally, the Kaplan approach afforded more medial access on the capitellum. Regardless of lesion location, it is possible to perform radial head OATS harvest through a Kocher or Kaplan approach and either address the capitellum through the same interval or if the lesion is more posterior, split the anconeus through the same skin incision. Due to specimen limitations, we were not able to flex the elbows far enough to perform anconeus split approaches and this should be an area of future investigation.

Conclusion

This cadaveric feasibility study demonstrates that the nonarticulating peripheral cartilaginous rim of the radial head may be a viable local harvest site for OATS for capitellar lesions up to 8 mm in diameter. Further investigation is needed to determine how to mitigate the risk of iatrogenic fracture with this operation. The cartilage thickness of the radial head closely approximates that of the capitellum. Biomechanical analysis did not demonstrate a significant difference in load to fracture when backfilling the radial head harvest site with corticocancellous bone graft vs. calcium phosphate cement. After harvest, the radial head was able to withstand forces much greater than those seen across the elbow when nonweight-bearing.

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