The biomechanical effect of radial shortening on the radiocapitellar articulation

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Repeated trauma to the radial head may be one of the causative factors in the genesis of osteochondritis dissecans of the capitellum. We measured the force, contact area and pressure across the radiocapitellar articulation of the elbow before and after radial shortening osteotomy in five fresh-frozen cadaver upper limbs with loads of 45, 90 and 135 N, respectively. Measurements were made on pressure-sensitive film placed in the radiocapitellar articulation with the forearm in the supinated, neutral and pronated positions before and after radial shortening. Radial shortening significantly reduced the mean force and contact area across the radiocapitellar articulation in all positions of the forearm.

Osteochondritis dissecans of the capitellum is a rare but well-recognised condition. Aetiological factors for this include primary disturbance of growth,¹ genetic predisposition and repetitive trauma, as evidenced by its frequent occurrence in gymnasts² and baseball players.³ It is often associated with pain in the elbow, stiffness, loose bodies, disturbance of growth and premature osteoarthritis.³⁻⁷

Non-surgical treatment consists of modification of activity and the use of non-steroidal anti-inflammatory agents, with or without short-term immobilisation.⁸ Arthroscopic drilling, debridement of the lesion and removal of loose bodies^{3,9-12} are the mainstays of surgical treatment. The long-term outcome has ranged from satisfactory¹³ to fair, with half of patients experiencing chronic pain.¹⁴ Residual symptoms have been associated with extensive lesions, osteoarthritis of the elbow and large osteochondral defects especially when triangular avulsion fragments were present.¹⁵ Other surgical treatments have included closing-wedge osteotomy of the capitellum,⁶ bone-peg grafting,¹⁶ osteochondral allografting¹⁷ and excision of the radial head.⁴

Treatment of osteochondritis dissecans of the capitellum remains controversial because all forms of treatment have been associated with a poor outcome.^{1,8} Radial shortening is a procedure which may reduce the force across the radiocapitellar joint, alleviate the symptoms and improve the functional outcome of the osteochondritis. As a first step in studying this procedure we investigated the biomechan-

ical effect of radial shortening on the loading characteristics across the radiocapitellar joint as a potential treatment for osteochondritis dissecans of the capitellum.

Patients and Methods

Preparation of specimens. Six fresh-frozen cadaver upper limbs were harvested at the level of the mid-shaft of the humerus. Primary abnormalities of the bones and joints, including osteoarthritis, previous operation or deformity were ruled out radiologically and by examination. The soft tissues were dissected only from the proximal 5 cm of the humerus, which was potted in plastic tubing of 2.5 cm in diameter using dental cement.

The radiocapitellar articulation was exposed through a lateral approach to the elbow 5 cm wide. A capsulotomy was performed anterior to the collateral ligaments so that pressure-sensitive film (Fuji Pressorsensor; C. Itoh and Co, New York) could be inserted between the radial head and the capitellum. Three holes were drilled transversely into the proximal end of the radius, about 5 mm distal to its articular surface, to accommodate a Steinmann pin which was inserted into one hole so that it did not interfere with the function of the radius. The protruding end of the pin was bent at a right angle. When the pressure film was inserted, its protruding tail was pressed against the end of the pin to create a reference mark on the film. This allowed prints to be superimposed on each other and showed the position of the areas of contact recorded on

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©2005 British Editorial Society of Bone and Joint Surgery
doi:10.1302/0301-620X.87B6.15543 \$2.00

J Bone Joint Surg [Br]
2005;87-B:879-83.
Received 7 April 2004;
Accepted after revision
4 October 2004

Fig. 1

Photograph of the apparatus showing the specimen with the elbow in extension, the pneumatic cylinder through which the load was applied across the elbow and the turntable which allowed the forearm to be positioned in pronation, neutral and supination.

the film in relation to the surface of the joint. After loading, the pin was removed and the arm repositioned. The pin was replaced into the second hole allowing the radius to move.

Loading apparatus. The loading apparatus is shown in Figure 1. The humerus was secured to the arm of a pneumatic piston and the hand was secured in a clamp attached to a turntable which allowed the forearm to rotate while an axial force was applied across the elbow and wrist. The elbow was positioned in full extension with the carrying angle specific to that specimen and then clamped in place. The turntable was not locked, but no rotation was noted once the position of the arm had been set. Pronation and supination were defined as 15° less than the maximum that each specimen would allow by manipulation; neutral rotation was defined as the midpoint between these two positions. The elbow was loaded with increasing force which

was calibrated using a load-cell. The joints of the elbow and wrist were free to move vertically under the compressive load.

Experimental procedure. A template of the radiocapitellar articulation surface was made using radiographic film. Two separate pieces of pressure-sensitive film were cut to match the template. These were sealed with clear plastic tape to form a transducer 0.3 mm thick which was inserted between the radial head and the capitellum. The joint was loaded for 30 seconds at 45 N. The test was repeated at axial loads of 90 and 135 N. These axial forces were considered to be within the physiological range. Each specimen was tested with the elbow in extension and with the forearm in the supination, neutral and pronation positions. The testing was repeated three times. The effects of loading time, ageing of the film and shear loading have been described in previous studies.¹⁸⁻²¹

After the intact specimen had been tested the radius was shortened by 2 to 3 mm. A 3-mm segment of the mid-shaft of the radius was removed. The amount of radial shortening was calculated by adding the length of the excised bone to twice the thickness of the saw blade. The radius was shortened and fixed using a six-hole, limited contact, dynamic compression plate applied to the surface with three bicortical screws on each side of the osteotomy. Radiographs were obtained after shortening to assess the relationship of the radial head and the capitellum, as well as the radio-ulnar variance. The shortened specimen was retested.

Measurement of force, contact area and pressure. After the loading period, the pressure transducer was removed from the radiocapitellar articulation. Calibration transducers were placed into a calibrator which loaded the film with a known pressure for the same time period as the transducers used in the experiment. These allowed conversion of the colour print on the pressure film to contact pressure based upon its relative darkness. The film images and calibrations were digitised using a scanner and converted to gray-level images. A computer software programme (NIH Image v 6.1; National Institutes of Health, Bethesda, Maryland) was used to convert the pressure prints into pressure maps, which were used to determine the total contact area and the mean pressure. Since the relationship between the gray level and pressure was non-linear, the image was arbitrarily divided into five zones based upon the calibration pressures selected, assuming a linear relationship within each zone. From this, the area of a zone with a mean pressure could be determined. The overall mean pressure was calculated from the following equation:

$$P_m = \sum (A_i \cdot P_i) / A_t$$

where P_m = the overall mean pressure (KPa), A_i = the area of zone i (mm^2) (area between any two calibration values), P_i = the mean pressure in zone i (KPa) and A_t = the total contact area (mm^2).

Table I. Summary of the median radiocapitellar force (N) and contact area (mm²), including range, for three positions of the forearm and at three axial compressive loads before and after a radial shortening osteotomy of 2 to 3 mm. All statistical tests were based on five observations

		Before osteotomy			After osteotomy			
Axial load (N)	Position	Median	Lower	Upper	Median	Lower	Upper	p value
45								
Force	Supination	70.5	3.5	77.0	10.4	0.0	25.1	0.05
	Neutral	96.3	57.6	136.5	16.5	7.4	83.7	0.05
	Pronation	66.6	22.4	150.2	67.1	2.5	134.3	0.72
Area	Supination	22.6	1.6	28.7	4.5	0.0	9.0	0.05
	Neutral	37.6	24.5	41.4	7.4	3.1	24.6	0.05
	Pronation	24.9	9.2	43.5	21.2	1.3	42.8	0.47
90								
Force	Supination	109.5	25.3	113.8	15.3	0.0	60.4	0.05
	Neutral	195.6	141.2	206.0	59.0	11.5	135.4	0.05
	Pronation	163.9	97.1	232.7	77.5	14.4	199.9	0.14
Area	Supination	32.0	10.7	56.6	6.1	0.0	17.9	0.05
	Neutral	62.3	51.0	66.8	22.4	5.0	37.1	0.05
	Pronation	51.5	36.9	66.4	26.9	6.7	54.1	0.14
135								
Force	Supination	155.4	59.1	258.8	67.4	0.0	206.0	0.05
	Neutral	255.8	233.4	370.4	89.3	17.2	166.3	0.05
	Pronation	250.6	152.3	300.8	143.3	59.0	257.6	0.05
Area	Supination	45.3	19.4	56.8	19.0	0.0	63.0	0.05
	Neutral	75.2	63.7	123.2	29.5	7.8	44.6	0.05
	Pronation	75.3	45.8	86.9	49.0	25.4	66.6	0.05

This method approximates the non-linear behaviour of the film by dividing the data into discrete linear zones. Previous studies have shown that it produces an estimate of total force (mean pressure multiplied by contact area) which agrees with a known force applied over a test area.²⁰ The mean radiocapitellar force was determined by dividing the overall mean pressure (P_m) by the total contact area (A_t).

Analysis of data. One specimen was used to set up the loading apparatus and to determine the experimental protocols. Data from five upper limbs were, therefore, used for analysis. A mean value was calculated from the three measurements for each specimen at each load and each position of the hand. This was used as an independent data sample. Median contact areas and forces were determined in supinated, neutral, and pronated positions of the forearm and at 45 N, 90 N and 135 N of axial load through the joint, as described above. A Wilcoxon signed rank test, using non-parametric statistics for small samples, was employed to compare measurements between the intact and osteotomised specimens. The null hypothesis was that radial shortening of 2 to 3 mm would have no effect on the radiocapitellar contact area and force. A statistically significant difference between the intact and osteotomised areas and forces was set at $p < 0.05$.

Results

Table I gives a summary of the mean radiocapitellar force and contact area in the three positions of the forearm (supination, neutral and pronation) and at three axial loads (45 N, 90 N and 135 N) before and after radial shortening

osteotomy of 2 to 3 mm. Figure 2 shows representative prints from one specimen in supination.

The mean radiocapitellar force decreased significantly after radial shortening in all cases except pronation at 45 N and 90 N of axial load. The mean decrease in force over all positions and axial loads with significant changes was approximately 70%. The mean radiocapitellar contact area decreased similarly for all positions except pronation at 45 N and 90 N, again with an overall mean decrease of approximately 66%.

Discussion

Traditional surgical treatments of osteochondritis dissecans of the capitellum have been unreliable. Recently, radiocapitellar unloading by shortening of the lateral column of the distal humerus has shown promise.⁶ In seven patients who underwent closing-wedge osteotomy of the capitellum for osteochondritis dissecans, the radiological distance between the radius and the capitellum was increased and clinical symptoms were relieved. The biomechanical effect of capitellar shortening has not been studied experimentally. The procedure is less familiar and carries a higher risk than radial shortening. Our results indicate that radial shortening significantly reduces the mean force and contact area across the radiocapitellar articulation and therefore it may be a viable alternative to capitellar shortening.

When the radius is shortened at its mid-shaft by 3 mm and fixed in this position, three situations are possible. First, the distal fragment may be drawn proximally by 3 mm, resulting in radial shortening at the wrist. Secondly, the proximal fragment may be drawn distally from the

Fig. 2

Sets of prints from a specimen tested in supination. The reference calibration pressures of film are shown in the left column. Results are shown for the intact radius and after osteotomy.

capitellum creating radial shortening at the elbow and thirdly, the effect may be a combination of the above. Radial shortening has been shown to reduce the force transmitted to the lunate bone in Kienböck's disease.²² This implies that the distal radius moves away from the wrist. By demonstrating a lower radiocapitellar force with radial shortening our results imply that, when the radius is shortened, the radial head moves distally. Radiological analysis of our specimens indicated that the radial head moved away from the capitellum and the distal radius moved away from the wrist.

Shepard, Markolf and Dunbar²³ addressed the biomechanical effects of distal radial shortening on the load transmission between the radius and ulna. They estimated

that the load on the distal ulna increased by approximately 10% for each millimetre of radial shortening. We found a mean reduction in force of approximately 55% in the radiocapitellar joint for 3 mm of radial shortening. Both Shepard et al²³ and Ofuchi et al²⁴ have pointed out the important contribution of the interosseous membrane in load-sharing between the radius and ulna, especially when the forearm was supinated more than 35°. It is interesting to note that our study showed that the greatest reduction in force occurred in supination and the smallest in pronation.

Our study has some limitations. First, we tested cadaver specimens which were fresh-frozen upper limbs with preservation of bone and soft tissues. Secondly, a lateral capsulotomy of the elbow was performed for the insertion of the pressure film between the radius and capitellum. The collateral ligaments and osseous architecture responsible for the stability of the elbow were not disturbed. Thirdly, only five specimens were analysed, excluding the first limb which was used to determine the details of the protocol. Each specimen served as its own control, reducing variation in the data. Even with this small number, statistically significant differences in the contact characteristics of the joint between the intact and osteotomised limbs were apparent. Fourthly, mid-shaft radial osteotomy results in proximal movement of the distal end of the bone away from the wrist in addition to distal movement of the radial head away from the capitellum. This implies that the procedure would be contraindicated in the setting of positive ulnar variance and lastly, the model represents only a single loading situation, direct axial loading. No muscle forces were modelled. However, the major load causing pressure across the joint is axial compression, from external sources such as body weight, and internal sources such as muscle tension.

Our study has shown the effectiveness of radial shortening in reducing the compressive forces across the radiocapitellar articulation through a combination of the decreased contact area of the radial head and the transfer of load to the humero-ulnar joint. The effects on the stability of the elbow are unknown. Unloading of the radiocapitellar articulation may alleviate symptoms and alter the natural history of osteochondritis dissecans of the capitellum. Clinical investigation is necessary to determine the efficacy of the procedure in the treatment of this disorder.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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