Long-Term Outcomes of Radial Osteotomy for the Treatment of Kienböck Disease

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Abstract

Background Kienböck disease is an aseptic necrosis of the lunate of unknown etiology, prevalent in young adults. Treatment aims to lower forces on the lunate, decrease pain and improve function. We conducted a retrospective evaluation of the 10-year clinical and radiological outcomes of radial osteotomy as a treatment for Kienböck disease.

Materials and Methods We analyzed pain, grip strength, wrist range of motion (ROM), radiological carpal geometry, and staging of osteoarthritic changes over a 10-year period, postosteotomy, for 18 patients. The Mayo wrist score was used as an overall measure of outcome.

Technique Outcomes for two types of osteotomies were included, a step-cut osteotomy with fixed screws and an updated technique of two linear transverse osteotomies with volar locking plates. For cases with negative ulnar variance, resection of the radius was included to obtain a final ulnar variance of –1 to 0 mm. For positive ulnar variance, the goal was to obtain a correction of radial inclination of 10 to 15 degrees.

Results Improvements in pain, ROM, and grip strength were maintained over the 10-year follow-up, without radiological improvement in geometry (carpal height ratio and Stahl index). Mild osteoarthritic changes were identified in 33% of patients, with no effect on clinical results. Degree of cartilage damage determined postoperative grip strength improvement. The Mayo wrist score at the final follow-up was excellent in one patient, good in nine, and fair in eight.

Conclusions Radial osteotomy provides reasonable and long-term clinical benefits. Preoperative arthroscopic evaluation of cartilage damage can inform treatment decisions.

Keywords

- Kienböck disease
- radial osteotomy
- long-term outcome
- lunate
- arthroscopy

Kienböck disease is an aseptic necrosis of the lunate bone, resulting from impairment in the vascularization of the lunate of unknown etiology. The condition is more prevalent in young adults, often in the absence of significant injury.¹ Overloading across the radiolunate joint is believed to be a predisposing factor to the development of necrosis, with high forces impairing revascularization. Ulnar variance may also be a contributing factor to the lunatomalacia. As Kienböck disease affects young adults, long-term outcomes of treatment are important.²

Various treatment options have been proposed, with no clear evidence or consensus to inform practice. Therapeutic interventions can roughly be classified into two technical approaches, the first aiming to reduce dynamic loading across the radiolunate joint and the second aiming to regenerate vascular flow.³ Although overloading of the lunate is insufficient to completely explain the etiology of Kienböck disease,⁴ there is evidence of the effects of mechanical factors on the development of osteonecrosis.⁵ Therefore, several lunate

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Fig. 1 Representative case of radial shortening osteotomy, showing radiographic image (A and B) preoperatively and (C and D) at the final follow-up.

unloading techniques have been described to prevent progression of the condition.⁵ Among the different lunate unloading techniques which have been proposed, radial osteotomy has been commonly used as an extra-articular, lunate-preserving technique since the 1950s, with numerous studies having shown good-to-excellent long-term clinical outcomes achieved in 69 to 100% of patients.^{6–14} Therefore, radial osteotomy can be considered as the benchmark against which to evaluate the effectiveness of other techniques.⁶ Two radial osteotomy techniques are used, depending on ulnar variance. For patients with negative ulnar variance, osteotomy is combined with radial shortening, while a closing wedge osteotomy is the treatment of choice for patients with a null or positive ulnar variance (→Figs. 1 and 2).^{10,11}

Although radial osteotomy is the treatment of choice of Kienböck disease, the long-term outcomes have not been comprehensively evaluated by Lichtman classification, which is based on plain radiographs.¹⁵ However, as Kienböck disease is an intra-articular lesion, arthroscopic evaluation may be useful to directly visualize and evaluate the integrity and health of the articular cartilage at the radiolunate joint. Therefore, the purpose of our retrospective study was to

evaluate the preoperative arthroscopic evaluation and long-term clinical and radiological outcomes of radial osteotomy in patients with Kienböck disease. We hypothesized that radial osteotomy would provide reasonable results over a > 10-year follow-up, and that there would be a correlation between preoperative arthroscopic evaluation of cartilage and clinical outcomes.

Methods

Study Design and Patients

We conducted a retrospective review of our hospital database to identify patients with a diagnosis of Kienböck disease who had been treated by radial osteotomy, including arthroscopic evaluation, with a follow-up of 10 or more years. The methods of our study were approved by our institutional review board.

Between 1993 and 2005, we identified 67 cases of unilateral Kienböck disease treated by radial osteotomy, with arthroscopic evaluation. Of these cases, 18 included a follow-up period ≥ 10 years and formed our study group. The group comprised 12 men and 6 women, with right side involvement in 11 cases and left side involvement in 7. The mean age at the time of surgery was

Fig. 2 Representative case of closing wedge radial osteotomy, showing radiographic image (A and B) preoperatively and (C and D) at the final follow-up.

37 years (range, 18–64 years) and the follow-up period ranged from 10 years 1 month to 17 years 5 months (mean, 11 years 6 months). The average length of the symptomatic period was 9.5 months. The final follow-up evaluation included assessment of pain (graded as none, mild, moderate, or severe), wrist range of motion (ROM) in flexion and extension (expressed as a percentage of the contralateral wrist) and grip strength (expressed as a percentage of the contralateral). ROM and grip strength were evaluated using standard methods.⁶ The grades for pain assessment were defined as follows: mild, occasional pain or pain after strenuous activity; moderate, pain on weight-bearing or strenuous activity; and severe, pain with daily activities. The modified Mayo wrist score was calculated to provide a final evaluation of wrist function.¹⁶

Radiological Assessment

Both pre- and postoperative wrist radiographs were obtained in a standardized position with the forearm in neutral rotation and the wrist in neutral position. The carpal height ratio (CHR), the radioscapoid angle (RSA), and Stahl lunette index (SI) were calculated.¹⁷ Radiological staging of the disease was performed using the modified classification system of Lichtman et al,¹⁵ with fragmentation of the lunate and the progression of osteoarthritic (OA) changes also investigated from plain radiography images.

Indication, Arthroscopic Assessment, and Surgical Technique

As a standard procedure, radial osteotomy with shortening was performed for cases with negative ulnar variance and closing wedge osteotomy for cases with positive ulnar variance. Among our study group of 18 patients, an osteotomy with shortening was performed in 8 cases and a closing wedge osteotomy in 10.

Arthroscopic assessment was performed on the same day as the radial osteotomy, under axial block, or general anesthesia, and tourniquet control. For the assessment, the hand was suspended using 3 to 5 kg of traction. Lesions of the articular cartilage were defined as softening, fibrillation, erosion, or defects of the joint cartilage, with an absence of lesions defined by a smooth appearance of the cartilage surface. All arthroscopic findings were classified in terms of the location of cartilage lesions: (a) lunette fossa of the radius, (b) proximal surface of the lunette bone, (c) distal surface of the lunette bone, and (d) head of the capitate head (→ Fig. 3).¹⁸

Regarding the radial osteotomy technique, we originally used a dorsolateral approach for a step cut osteotomy, but now prefer a palmar approach for a volar locking plate, also known as Henry approach, between the flexor carpi radialis and brachioradialis. The flexor carpi radialis tendon is retracted radially with the other flexor tendons retracted ulnarly to expose the pronator quadratus muscle. The pronator quadratus is incised at its radial insertion and the distal third of the radius is exposed subperiosteally. In our initial cases, we used the technique described by Nakamura et al¹¹ of step cut osteotomy 5 cm proximal to the tip of the radial styloid process with screw fixation. By comparison, using a volar locking plate, a simple osteotomy was performed, 3 cm proximal to the tip of the radial styloid process so as not to

Fig. 3 Arthroscopic evaluation: (A) lunette fossa of the radius, (B) proximal surface of the lunette bone, (C) distal surface of the lunette bone, and (D) head of the capitate head.

obstruct the distal radioulnar joint. For all osteotomies, we used saline to prevent heat damage to the bone during cutting. For cases with a negative ulnar variance, we performed two parallel transverse osteotomies, using an oscillating saw with a thin blade, removing approximately 2 to 5 mm of bone to obtain a final ulnar variance of 0 or –1 mm, with final variance confirmed by posterior-anterior radiography. For cases with a positive ulnar variance, the target was to achieve an optimal correction angle of radial deviation of 15 degrees^{19,20} and the work of Nakamura et al, who provided evidence that 10 to 15 degrees of radial deviation provided better clinical outcomes than 5 to 9 degrees.¹¹ Preoperatively, we identified the appropriate osteotomy line to decrease the radial inclination from 5 to 10 degrees, to achieve a final radial inclination of 10 to 15 degrees postoperatively. A cast or splint fixation was applied for several weeks postoperatively.

Statistical Analysis

Pre- and postoperative clinical and radiological outcomes were evaluated, as appropriate for the data type and distribution: wrist ROM and grip strength using Wilcoxon rank-sum test, and lunette fragmentation, Mayo wrist score and radiographic osteoarthritic changes by chi-squared analysis. The association between clinical measures (ROM, grip strength, and Mayo wrist score) and radiographic/arthroscopic variables (RSA, CHR, radial inclination [RI], lunette fragmentation, OA changes, and cartilage damage) was evaluated by using a Mann-Whitney U bivariate test and

Spearman rank correlation coefficient to calculate the extent of the association.

Results

Postoperatively, grip strength increased by 59 to 89% and ROM, in flexion–extension, by 63 to 99 degrees. Before surgery, the distribution of pain was as follows: mild pain reported by 1 patient; moderate pain by 11; and severe pain by 6. Although mild wrist pain postsurgery was commonly reported postoperatively, pain decreased from preoperative levels for the majority of patients, with recovery of powerful grip strength. At the final follow-up assessment, nine patients reported being free of wrist pain, eight patients reported experiencing mild pain on occasion, and one patient reported a moderate level of pain. The modified Mayo wrist function score at the final follow-up visit was excellent for one patient, good for nine, and fair for eight (average score: 77.8). Postoperatively, measures of carpal geometry did not improve significantly, nor did they progress, with only a slight decrease in SI identified. The pre- and postoperative measures of carpal geometry were as follows: ulnar variance, -0.4 and 1.3 ; RI, 28.1 and 20.4 ; CHR, 0.50 and 0.50 ; RSA, 67 and 67 ; SI, 0.35 and 0.30 . Cartilage lesions were identified by arthroscopy in all cases: in seven patients, cartilage lesions were localized in proximal surface of the lunate (b); two patients presented with lesions both in the lunate fossa and proximal surface of the lunate (a + b); five

patients with lesions on both the proximal and distal surfaces of the lunate (b + c); and four with lesions at the lunate fossa and both proximal and distal surfaces of the lunate (a + b + c). Lesion of the cartilage on the head of the capitate bone was not identified. Bivariate analysis identified cartilage damage, localized to the proximal surface of the lunate, to be associated with a significantly higher percentile increase in grip strength at the final follow-up (► **Tables 1 and 2**). Preoperatively, lunate fragmentation was identified in 11 cases, with 5 of these 11 cases achieving bony union postoperatively. The Lichtman classification had no significant correlation with clinical outcomes. Postoperative radiological osteoarthritic changes were identified in six cases, but these patients did not have worse postoperative clinical outcomes. Among the 18 patients forming our study group, 16 returned to their original work or sport activity, with two patients quit work for reasons other than their wrist condition. No correlation was identified between arthroscopic evaluation and postoperative osteoarthritic changes and Lichtman classification.

Discussion

Our retrospective study provides level IV evidence of reasonable clinical outcomes achieved by radial osteotomy for the treatment of Kienböck disease, albeit with mild radiological progression of the osteoarthritic degeneration of the lunate. Surgical intervention is performed in the early stages of

Table 1 Preoperative summary of relevant demographic variables and clinical, radiographic, and arthroscopic measures for our study group

Location of cartilage lesion	N	Mean age (y)	Duration (mo)	Lichtman class	Fragmentation	Preoperative				
						CHR	SI	RSA	ROM	Grip strength
(b)	7	35.1	14.6	II:2, IIIa:2, IIIb:3	2/7	0.51	0.35	66.7	72.0	66.5
(a) + (b)	2	40.0	3.5	IIIa:1, IIIb:1	1/2	0.49	0.39	59.9	60.2	47.7
(b) + (c)	5	33.0	6.0	IIIa:4, IIIb:1	4/5	0.48	0.35	68.8	66.1	43.2
(a) + (b) + (c)	4	45.0	9.3	IIIb:4	4/4	0.50	0.33	69.7	48.5	71.8
Total	18	37.1	9.5	II:2, IIIa:11, IIIb:5	6/18	0.50	0.35	66.9	64.2	58.2

Abbreviations: CHR, carpal height ratio; RSA, radioscapoid angle; ROM, range of motion; SI, Stahl lunate index.

Table 2 Postoperative summary of relevant demographic variables and clinical, radiographic, and arthroscopic measures for our study group

Cartilage lesions	Follow-up periods	Union of fragmentation	OA	Postoperative						Score
				CHR	SI	RSA	ROM	Grip strength	Pain	
(b)	11 y 4 mo	0/2	2/7	0.51	0.33	62.7	76.6	101.2	non:2, mild:5	E1G3F3
(a) + (b)	11 y 10 mo	0/1	0/2	0.48	0.32	72.8	80.4	85.5	non:2	G1F1
(b) + (c)	10 y 7 mo	2/4	1/5	0.48	0.26	71.6	83.3	78.7	non:2, mild:3	G4F1
(a) + (b) + (c)	13 y 3 mo	3/4	3/4	0.49	0.27	68.5	69.9	84.2	non:3, moderate:1	G1F3
Total	11 y 6 mo	5/11	6/18	0.50	0.30	67.3	77.8	89.3	non:9, mild:8, moderate:1	E1G9F8

Abbreviations: CHR, carpal height ratio; OA, osteoarthritic; RSA, radioscapoid angle; ROM, range of motion; SI, Stahl lunate index.

Kienböck disease to improve vascularization to the lunate through an unloading of the forces across the radiolunate joint.²¹ This unloading of the lunate can be effectively achieved by radial osteotomy, and our data confirm the long-term effectiveness of this treatment, with the majority of patients reporting either complete resolution of pain or mild pain with their usual activities of work and sport. Therefore, radial osteotomy achieved the clinical aims of treatment, namely, decreasing pain, maintaining or improving wrist ROM, and increasing grip strength.^{4,6}

Our finding of continued radiological progression of the disease after radial osteotomy, albeit at a slower rate, confirms previously published studies. Koh et al reported continued degenerative changes around the scaphoid after a radial osteotomy.¹⁰ Interestingly, Innes et al in their systematic review of interventions for Kienböck disease, reported that radial osteotomy did not correct SI or CHR, concluding that no active treatment was superior to any other intervention in the treatment of Kienböck disease.²² In agreement with our findings, Schuind et al stated that radial osteotomy can slow down continued progression of the disease, offering durable pain relief and possible improvement in grip strength, without offering a definitive cure.²³ It is important to note that some studies have indicated that the clinical symptoms of Kienböck disease do not necessarily progress in all patients.² Therefore, at this point, indications for surgical intervention should only be based on patients' symptoms and functional impairment, and not on radiographic evidence.²

In our study, we identified cartilage health to be a determinant factor of clinical outcomes, with patients having mild or no cartilage damage achieving a better recovery of grip strength, postoperatively. Once the articular cartilage has deteriorated, full recovery will not occur, which explains why the severity of cartilage lesions affects clinical outcomes. Worse clinical outcome with damage on the proximal surface of the lunate was also described by Bain et al.²⁴ Although plain radiographs provide an assessment of carpal geometry, they do not provide information on cartilage health. Therefore, we propose preoperative arthroscopy, although invasive, would provide important for assessment of the severity of articular cartilage damage to inform decisions regarding performing an osteotomy, which cannot improve cartilage damage.^{18,24}

The clinical benefits of radial osteotomy result from an unloading across the radiolunate joint, which has been shown to promote the process of creeping revascularization,⁷⁻¹⁴ which is important to improved functional outcomes postoperatively.²⁵ Given that vascularity of the wrist is a network of vascular anastomoses encircling the radius and extending across the carpus, osteotomy of the radius may stimulate sufficient hyperemia to accelerate revascularization of the lunate.^{26,27} Theoretically, any surgical procedure near the lunate may induce changes in arterial inflow or venous drainage, resulting in pain relief and, occasionally, in changes in the architecture of the lunate.⁴ Nakamura et al reported better postoperative radiological outcomes for younger patients, indicative of a higher capacity for revascularization than in older patients.²⁸ In our study, we reported a postoperative union of the lunate in approximately 50% of our cases.

There is prior evidence that even displaced fractures of the lunate have the potential to achieve union after radial osteotomy.²⁹ Therefore, there is no one ideal treatment for displaced fractures of the lunate, and a simple radial osteotomy can achieve outcomes comparable to other treatments which have been proposed of patients at this stage of the disease progression.

Reports on the long-term clinical and radiological outcomes of radial osteotomy as a treatment for Kienböck disease are relatively rare. Kristensen et al reported a 20-year follow-up evaluation of patients with Kienböck disease who were treated with conservative methods, reporting an overall positive outcome in terms of pain resolution, but with radiological evidence of progressive osteoarthritic changes identified in 67% of the cases.³⁰ Unfortunately, measures of wrist function were not included in this long-term study of outcomes. Trail et al reported that progression of osteoarthritic is almost inevitable after joint leveling procedures, such as radial osteotomy.⁹ We confirm the progression of osteoarthritic changes in our study group, but the extent of these radiological changes was deemed to be mild. The question of whether osteoarthritic changes affect clinical outcomes has been controversial and, yet, we found no evidence of a correlation between postoperative osteoarthritic progression and clinical outcomes. In fact, our study showed reasonable clinical results compared with previous reports.⁷⁻¹⁴

The limitations of our study need to be acknowledged in the interpretation and application of our results. Foremost, this is a retrospective study and of the 67 cases of Kienböck disease treated with radial osteotomy, only 18 patients (27%) completed the 10-year follow-up. Additionally, as the study spanned from 1993 to 2005, surgeries were performed by several surgeons and using different radial osteotomy techniques. Certainly, a randomized prospective study evaluating the outcomes for different surgical techniques at different stages of disease progression would be informative.³¹ However, Kienböck disease is classified as a rare disease by the Office of Rare Diseases of the National Institutes of Health, affecting less than 200,000 people in the United States.^{32,33} Our study provides foundational information on the long-term outcomes of radial osteotomy for the treatment of Kienböck disease to justify a multicenter prospective study.

Conflict of Interest

None.

References

- Green D, Hotchkiss R, Peterson W, et al. *Green's Operative Hand Surgery*. 5th ed. New York, NY: Churchill Livingstone; 2008
- Martin GR, Squire D. Long-term outcomes for Kienböck's disease. *Hand (NY)* 2013;8(1):23-26
- Fujiwara H, Oda R, Morisaki S, Ikoma K, Kubo T. Long-term results of vascularized bone graft for stage III Kienböck disease. *J Hand Surg Am* 2013;38(5):904-908
- Blanco RH, Blanco FR. Osteotomy of the radius without shortening for Kienböck disease: a 10-year follow-up. *J Hand Surg Am* 2012;37(11):2221-2225

- 5 Luo J, Diao E. Kienböck's disease: an approach to treatment. *Hand Clin* 2006;22(4):465–473, abstract vi
- 6 Crisco JJ, Halilaj E, Moore DC, Patel T, Weiss AP, Ladd AL. In Vivo kinematics of the trapeziometacarpal joint during thumb extension-flexion and abduction-adduction. *J Hand Surg Am* 2015;40(2):289–296
- 7 Zenzai K, Shibata M, Endo N. Long-term outcome of radial shortening with or without ulnar shortening for treatment of Kienböck's disease: a 13–25 year follow-up. *J Hand Surg [Br]* 2005;30(2):226–228
- 8 Raven EEJ, Haverkamp D, Marti RK. Outcome of Kienböck's disease 22 years after distal radius shortening osteotomy. *Clin Orthop Relat Res* 2007;460(460):137–141
- 9 Trail IA, Linscheid RL, Quenzer DE, Scherer PA. Ulnar lengthening and radial recession procedures for Kienböck's disease. Long-term clinical and radiographic follow-up. *J Hand Surg [Br]* 1996;21(2):169–176
- 10 Koh S, Nakamura R, Horii E, Nakao E, Inagaki H, Yajima H. Surgical outcome of radial osteotomy for Kienböck's disease—minimum 10 years of follow-up. *J Hand Surg Am* 2003;28(6):910–916
- 11 Nakamura R, Tsuge S, Watanabe K, Tsunoda K. Radial wedge osteotomy for Kienböck disease. *J Bone Joint Surg Am* 1991;73(9):1391–1396
- 12 Watanabe T, Takahara M, Tsuchida H, Yamahara S, Kikuchi N, Ogino T. Long-term follow-up of radial shortening osteotomy for Kienböck disease. *J Bone Joint Surg Am* 2008;90(8):1705–1711
- 13 Wada A, Miura H, Kubota H, Iwamoto Y, Uchida Y, Kojima T. Radial closing wedge osteotomy for Kienböck's disease: an over 10 year clinical and radiographic follow-up. *J Hand Surg [Br]* 2002;27(2):175–179
- 14 Soejima O, Iida H, Komine S, Kikuta T, Naito M. Lateral closing wedge osteotomy of the distal radius for advanced stages of Kienböck's disease. *J Hand Surg Am* 2002;27(1):31–36
- 15 Lichtman DM, Alexander AH, Mack GR, Gunther SF. Kienböck's disease—update on silicone replacement arthroplasty. *J Hand Surg Am* 1982;7(4):343–347
- 16 Tsuge S, Nakamura R. Anatomical risk factors for Kienböck's disease. *J Hand Surg [Br]* 1993;18:70–75
- 17 Amadio PC, Berquist TH, Smith DK, Ilstrup DM, Cooney WP III, Linscheid RL. Scaphoid malunion. *J Hand Surg Am* 1989;14(4):679–687
- 18 Tatebe M, Hirata H, Shinohara T, et al. Arthroscopic findings of Kienböck's disease. *J Orthop Sci* 2011;16(6):745–748
- 19 Tsumura H, Himeno S, Morita H, et al. The optimum correcting angle of wedge osteotomy at the distal end of the radius for Kienböck's disease. *J Jpn Soc Surg Hand* 1984;1:435–439
- 20 Miura H, Sugioka Y. Radial closing wedge osteotomy for Kienböck's disease. *J Hand Surg Am* 1996;21(6):1029–1034
- 21 Gay AM, Parratte S, Glard Y, Mutaftschiev N, Legre R. Isolated capitate shortening osteotomy for the early stage of Kienböck disease with neutral ulnar variance. *Plast Reconstr Surg* 2009;124(2):560–566
- 22 Innes L, Strauch RJ. Systematic review of the treatment of Kienböck's disease in its early and late stages. *J Hand Surg Am* 2010;35(5):713–717
- 23 Schuind F, Eslami S, Ledoux P. Kienböck's disease. *J Bone Joint Surg Br* 2008;90(2):133–139
- 24 Bain GI, Begg M. Arthroscopic assessment and classification of Kienböck's disease. *Tech Hand Up Extrem Surg* 2006;10(1):8–13
- 25 Arora R, Lutz M, Deml C, Krappinger D, Zimmermann R, Gabl M. Long-term subjective and radiological outcome after reconstruction of Kienböck's disease stage 3 treated by a free vascularized iliac bone graft. *J Hand Surg Am* 2008;33(2):175–181
- 26 Illarramendi AA, Schulz C, De Carli P. The surgical treatment of Kienböck's disease by radius and ulna metaphyseal core decompression. *J Hand Surg Am* 2001;26(2):252–260
- 27 Nakamura R, Watanabe K, Tsunoda K, Miura T. Radial osteotomy for Kienböck's disease evaluated by magnetic resonance imaging. 24 cases followed for 1–3 years. *Acta Orthop Scand* 1993;64(2):207–211
- 28 Nakamura R, Imaeda T, Miura T. Radial shortening for Kienböck's disease: factors affecting the operative result. *J Hand Surg [Br]* 1990;15(1):40–45
- 29 Tatebe M, Horii E, Majima M, Koh S, Nakamura R, Hirata H. Radial osteotomy for Kienböck's disease with displaced fracture of the lunate. *J Hand Surg Am* 2007;32(9):1343–1347
- 30 Kristensen SS, Thomassen E, Christensen F. Kienböck's disease—late results by non-surgical treatment. A follow-up study. *J Hand Surg [Br]* 1986;11(3):422–425
- 31 Kirkeby L, von Varfalva Palffy L, Hansen TB. Long-term results after vascularised bone graft as treatment of Kienböck disease. *J Plast Surg Hand Surg* 2014;48(1):21–23
- 32 Squitieri L, Petruska E, Chung KC. Publication bias in Kienböck's disease: systematic review. *J Hand Surg Am* 2010;35(3):359–367.e5
- 33 National Institutes of Health Office of Genetic and Rare Diseases (GARD) Information Center. Rare disease terms. Available at: <http://rarediseases.info.nih.gov/Default.aspx>. Accessed December 20, 2015