Osteoarthritis and Cartilage 27 (2019) 1057–1063

Osteoarthritis and Cartilage

Intraobserver and interobserver reliability of the computed tomography-based radiographic classification of primary elbow osteoarthritis: comparison with plain radiograph-based classification and clinical assessment

J.-M. Kwak †, E. Kholinne ‡, Y. Sun §, A.M. Alhazmi †, K.-H. Koh †, I.-H. Jeon † *

† *Department of Orthopedic Surgery, Asan Medical Center, College of Medicine, Ulsan University, Seoul, South Korea*
‡ *Department of Orthopedic Surgery, St. Carolus Hospital, Jakarta, Indonesia*
§ *Department of Hand Surgery, Affiliated Hospital of Nantong University, Nantong, Jiangsu, China*

ARTICLE INFO

Article history:
Received 13 October 2018
Accepted 16 March 2019

Keywords:
Elbow
Arthritis
Staging
Grading system
Classification
CT-based

SUMMARY

Objectives: To develop a staging system that could better reflect symptoms by the spurs quantification in the fossa and joint space narrowing using computed tomography (CT) for elbow arthritis and to evaluate its reproducibility with multiple readers.
Methods: This retrospective study evaluated 81 cases of primary elbow osteoarthritis using both plain radiography and CT. Qualitative and quantitative analyses were independently performed by four orthopedic surgeons using previous and newly proposed staging systems. The reproducibility of the new system was analyzed with intraclass correlation coefficients (ICC). Correlations between symptoms and radiologic classification were assessed using Pearson's correlation coefficient (PCC).
Results: The interobserver agreement (1) and intraobserver agreement (2) among the four evaluators was present by ICC. (1) The system of Hastings and Rettig [first observation, 0.544 (95% confidence interval (CI), 0.436–0.649); second observation, 0.582 (95% CI, 0.478–0.682)] and Broberg and Morrey's staging system [first observation, 0.620 (95% CI, 0.521–0.714); second observation, 0.656 (95% CI, 0.562–0.743)] showed substantial and moderate retrospective agreement, whereas the CT-based staging system showed almost perfect agreement [first observation, 0.867 (95% CI, 0.820–0.906); second observation, 0.909 (95% CI, 0.875–0.936)]. (2) The intraobserver agreement was almost perfect in the Brogerg and Morrey's and CT-based staging systems. CT-based staging showed high correlation with visual analogue scale (PCC 0.754, $P < 0.001$) and Mayo elbow performance score (PCC −0.614, $P < 0.001$) and moderate correlation with range of motion (PCC −0.458, $P < 0.001$).
Conclusions: CT-based staging system was highly reproducible and clinically feasible than previous plain radiograph-based staging systems.

Introduction

The incidence of primary osteoarthritis of the elbow had been reported to affect up to 2% of the general population and is more prevalent in men than in women[1,2]. Compared with osteoarthritis in other joints, elbow osteoarthritis is not common. Nevertheless, the incidence of osteoarthritis is relatively high in individuals with overused upper extremities (e.g., manual laborers, throwing athletes, and wheelchair-assisted individuals)[3,4].

Because the main symptoms of elbow arthritis are resting pain, mid-arc pain due to joint cartilage destruction, endpoint pain, and limited range of motion (ROM) due to spurs and loose bodies[2,5], a staging system or classification for elbow arthritis should include symptom-related factors as a guide to determine treatment options. Although many treatment options have been developed for elbow arthritis[1,6–8], decision-making remains challenging, especially in early-stage patients[1]. Proper treatment is based on multiple factors, including the severity of disease. To determine the

* Address correspondence and reprint requests to: I.-H. Jeon, 86 Asanbyeongwon-gil, Songpa-gu, Seoul, 05505, South Korea. Tel: 82-10-7295-5637; Fax: 82-02-3010-3536.
E-mail address: jeonchoi@gmail.com (I.-H. Jeon).

https://doi.org/10.1016/j.joca.2019.03.004
1063-4584/

severity of disease, the Broberg and Morrey, and the Hastings and Rettig classifications have been introduced and used for qualitative staging. The Broberg and Morrey system[9] is based on osteophyte formation and joint space narrowing. The Hastings and Rettig system[10] is based on the presence of subluxation and involvement of the radiocapitellar joint. However, because these systems are based on plain radiography, which is a two-dimensional imaging technique, they are highly observer-dependent and have poor reproducibility[11].

The objective of this study was to develop a new staging system that could better reflect symptoms, by quantification of spurs in the fossa and joint space narrowing on computed tomography (CT) in patients with elbow arthritis and to evaluate its reproducibility among multiple readers.

Method

Ethics board review approval was obtained. All patients who were diagnosed to have primary elbow osteoarthritis between January 2010 and December 2015 at a tertiary university hospital were reviewed. Primary osteoarthritis was diagnosed by history, clinical examination, radiologic investigation, and laboratory examination. History of previous injury and surgery of the elbow was excluded. Clinical examination included symptoms of (1) terminal or mid-arc pain, (2) decreased elbow ROM, and (3) painful locking or catching during elbow ROM. The radiologic investigation on standard anteroposterior and lateral plain radiographs included findings of (1) osteophyte, (2) loose body, and (3) joint space narrowing. Laboratory examination with blood tests was performed to exclude other causes, such as rheumatoid arthritis.

After review of the medical records from the database, 104 cases without bilateral observation were collected. Inclusion criteria were (1) documented primary elbow osteoarthritis; (2) available medical information, including ROM, visual analogue scale (VAS), and Mayo elbow performance score (MEPS); (3) radiologic assessment with both plain radiograph and CT. We excluded 23 patients due to (1) suspicion of previous elbow trauma that was not documented on medical records in eight patients, (2) suspicious previous elbow surgery in four patients, (3) improper radiography, which was not a true lateral plain radiograph and was not suitable for choosing a reference section (Figs. 1–3) with the CT images to evaluate staging, in 11 patients after review of plain radiographs and CT.

Radiograph selection

Two of the subspecialty-trained upper extremity orthopedic surgeons collected standard true anteroposterior and lateral radiographs and CT image of the elbow from 81 patients using a medical imaging database. All identifying materials were removed. The films were then electronically distributed to the four evaluators, who were orthopedic surgeons with fellowship training on upper extremity surgery (AMA, EK, SY, and JMK). The evaluators performed the grading, following the instruction of each classification (Broberg and Morrey, Hastings and Rettig, and CT-based classification), with blind control. Standard anteroposterior and lateral plain radiographs and full CT images were sent to the evaluator, so that they could choose the most reliable reference section (Figs. 1–3) for staging. The order of radiologic films was randomly changed and electronically redistributed to the evaluators after 1 month from the first evaluation. A second evaluation was conducted by the same evaluators in the same way, and the results of grading were sent to the statistician of our hospital.

Plain radiographic staging systems

Qualitative and quantitative analyses were independently performed by four orthopedic surgeons, using two previous staging systems (Broberg and Morrey, Hastings and Rettig; Figs. 1 and 2). In the Broberg and Morrey system[9], grade 0 was defined as a normal joint; grade one as a slight joint space narrowing with minimum osteophyte formation; grade two as moderate joint space narrowing with moderate osteophyte formation; and grade three as severe degenerative change with gross destruction of the joint. In the Hastings and Rettig system[10], class I was defined as degeneration at the margins of the ulnotrochlear joint, with the presence of coronoid and olecranon spurring, and absence of degenerative changes within the radiocapitellar joint; class II was defined as class I plus mild joint space narrowing within the radiocapitellar joint, without subluxation of the radial head; and class III was defined as class II plus radiocapitellar subluxation.

New, computed tomography-based staging system

In the new staging system (Fig. 4), quantification of spurs in the fossa was performed by measuring the involved depth on sagittal CT sections. More than 50% involvement of the fossa was defined as an “involved fossa” (Fig. 3). “Joint space narrowing” was defined as the presence of less than 1-mm gap in the ulnohumeral joint in more than 50% of the joint space on the reference section (Fig. 3). The new classification was based on the definitions for quantification of spurs and joint narrowing as below.

Stage 0: No involved fossa with intact joint space.

Stage 1: Unicompartemental involved fossa with intact joint space.

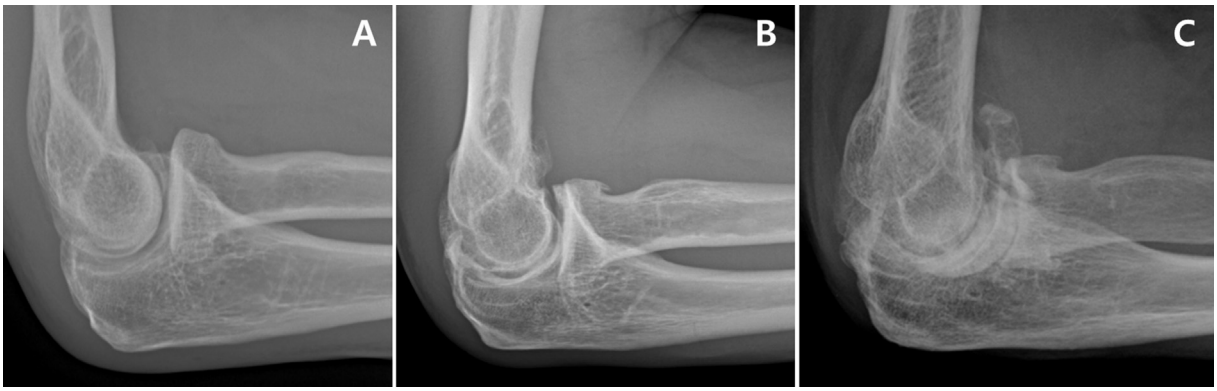

Fig. 1. Broberg and Morrey classification of elbow arthritis (A) Grade 1: slight joint space narrowing with minimal osteophyte formation (B) Grade 2: moderate joint space narrowing with moderate osteophyte formation (C) Grade 3: severe degenerative change with gross destruction of the joint.

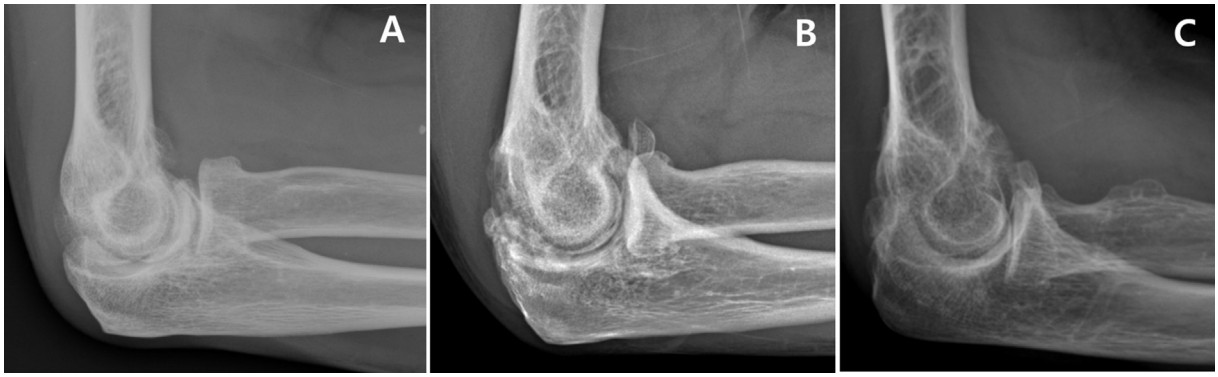

Fig. 2. Hasting and Rettig classification of elbow arthritis (A) Class I: degeneration in the margins of the ulnotrochlear joint with the presence of coronoid and olecranon spurring; absence of degenerative changes within the radiocapitellar joint (B) Class II: class I with mild joint space narrowing within the radiocapitellar joint, without subluxation of the radial head (C) Class III: class II with radiocapitellar subluxation.

Stage 2: Bicompartemental involved fossa with intact joint space.

Stage 3: Joint space narrowing regardless of the state of the fossa.

The reproducibility of the new staging system was analyzed using intraclass correlation coefficients (ICC).

Intra- and interobserver reliability and correlation with clinical scores

Each evaluator classified the radiographs according to both previous systems (Figs. 1 and 2) and the new CT-based system (Fig. 4) at an interval of at least 4 weeks, which was the duration used in other reliability studies on upper extremity surgery[12–14]. Intraobserver and interobserver reliability were calculated with ICC and 95% confidence intervals, and agreement was stratified. The correlations of each stage with the clinical scores and assessments (ROM, VAS, and MEPS) were evaluated. The clinical score was evaluated by an orthopedic surgeon preoperatively.

Statistical assessment

Statistical analyses were performed using the SPSS software (version 12, IBM; Armonk, NY, USA). The intraobserver and

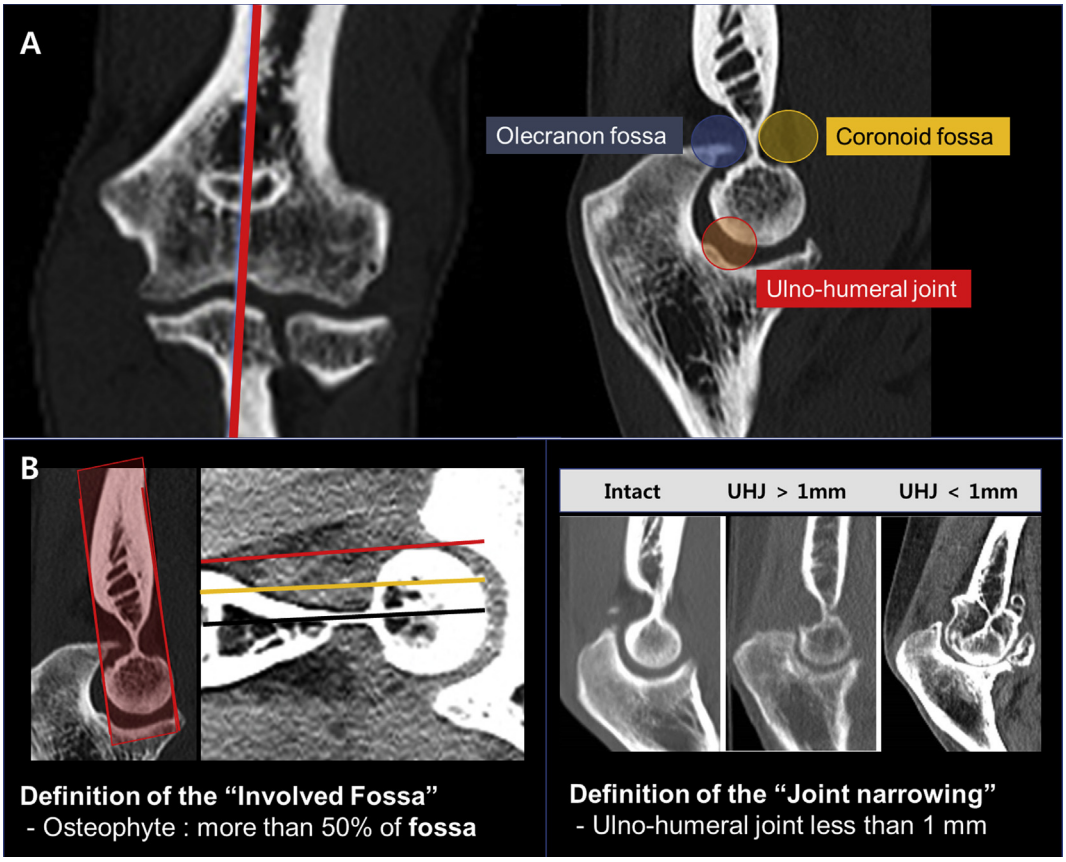

Fig. 3. (A) Reference section for computed tomography (CT) based Classification for elbow primary OA. The center of fossas as reference section (Left). Spur in the coronoid and olecranon fossa is related with limitation of flexion and extension. Joint narrowing is related with resting or mid arc pain clinically (Right). (B) Definition of the "Involved fossa" (Left) and "Joint narrowing" (Right).

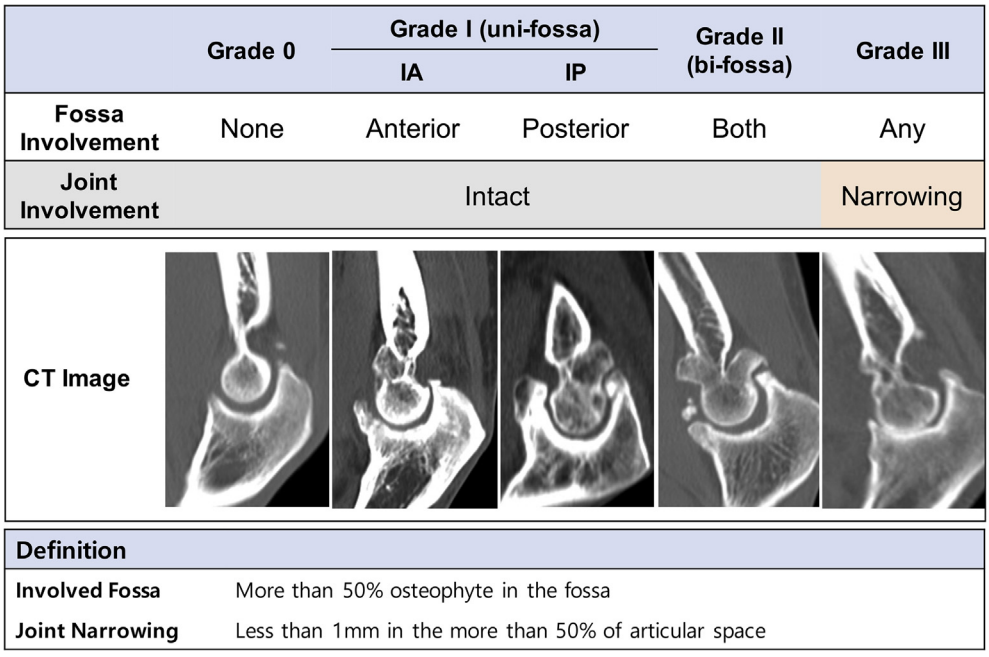

Fig. 4. Summery of CT based Classification for Elbow Primary OA.

interobserver reliability for each measure was assessed using the ICC, which served as a viable option for the testing agreement when more than two raters assess the ordinal content. Interpretation of the ICC was performed as described by Landis and Koch in 1977[15]. The ICC reported a value between 0.0 and 1.0, as follows: 0.01 to 0.20 for slight agreement; 0.21 to 0.40 for fair agreement; 0.41 to 0.60 for moderate agreement; 0.61 to 0.80 for substantial agreement; 0.81 to 0.99 for almost perfect agreement; and 1.00 for perfect agreement. Correlations between symptoms and radiologic classification were assessed using Pearson's correlation coefficient (PCC). A correlation coefficient of less than 0.3 was considered low, 0.3 to 0.6 was moderate, and >0.6 was high. The null hypothesis of no difference was rejected if the *P*-value was <0.05.

Results

The average age of the patients was 51.0 ± 6.0 (range, 40–75) years; 60 patients were men and 21 were women. The clinical assessment scores were normally distributed, based on the Kolmogorov Smirnov normality test. The mean score was 84.3 ± 22.8° for ROM, 6.6 ± 2.1 for VAS, and 49.9 ± 23 for MEP.he interobserver and intraobserver agreement among the four evaluators was presented as ICC.

(1) *The interobserver agreement*: The system of Hastings and Rettig [first observation, 0.544 (95% CI, 0.436–0.649); second observation, 0.582 (95% CI, 0.478–0.682)] and Broberg and Morrey's staging system [first observation, 0.620 (95% CI, 0.521–0.714); second observation, 0.656 (95% CI, 0.562–0.743)] showed substantial and moderate retrospective agreement, whereas the computed tomography (CT)-based staging system showed almost perfect agreement [first observation, 0.867 (95% CI, 0.820–0.906); second observation, 0.909 (95% CI, 0.875–0.936)] (Table I).

(2) *Intraobserver agreement:* It was almost perfect in Brogerg and Morrey's and CT-based staging systems. The staging system of Hastings and Rettig's showed substantial agreement among the three different evaluators and almost perfect agreement with the other evaluator (Table II).

(3) *Correlation with clinical outcomes*: Brogerg and Morrey's staging system showed high correlation with Mayo elbow performance score (MEPS) (PCC −0.627, $P < 0.001$) and moderate correlation with range of motion (ROM) (PCC −0.327, $P = 0.003$) and visual analogue scale (VAS) (PCC 0.564, $P < 0.001$). Hastings and Rettig's staging system showed moderate correlation with MEPS (PCC −0.489, $P < 0.001$), ROM (PCC −0.367, $P = 0.001$), and VAS (PCC 0.493, $P < 0.001$). The CT-based staging system showed high correlation with VAS (PCC 0.754, $P < 0.001$) and MEPS (PCC −0.614, $P < 0.001$) and moderate correlation with ROM (PCC −0.458, $P < 0.001$) (Table III).

Discussion

Quantifying the severity of elbow arthritis is essential for prognostication and clinical decision-making. Previous studies on osteoarthritis of the knee and hip suggested that a simpler, more

Table I
Interobserver reliability

	First observation		Second observation	
	ICC	Category	ICC	Category
B-M	0.620 (95% CI, 0.521–0.714)	substantial	0.656 (95% CI, 0.562–0.743)	substantial
H-R	0.544 (95% CI, 0.436–0.649)	moderate	0.582 (95% CI, 0.478–0.682)	moderate
CT-based	0.867 (95% CI, 0.820–0.906)	**almost perfect**	0.909 (95% CI, 0.875–0.936)	**almost perfect**

B-M: Broberg and Morrey, H-R: Hastings and Rettig classification, ICC: Intraobserver Correlation Coefficient, CT: Computed Tomography.

Table II
Intraobserver reliability

	B-M	H-R	CT-based
Observer 1	0.864 (95% CI, 0.797–0.911)	0.709 (95% CI, 0.582–0.803)	0.873 (95% CI, 0.809–0.916)
Observer 2	0.928 (95% CI, 0.890–0.953)	0.720 (95% CI, 0.595–0.810)	0.873 (95% CI, 0.810–0.917)
Observer 3	0.891 (95% CI, 0.836–0.929)	0.716 (95% CI, 0.591–0.743)	0.883 (95% CI, 0.818–0.925)
Observer 4	0.910 (95% CI, 0.864–0.942)	0.866 (95% CI, 0.797–0.911)	0.987 (95% CI, 0.981–0.992)

B-M: Broberg and Morrey, H-R: Hastings and Rettig classification, CT: Computed Tomography.

clearly-defined rating system might be more reliable[16]. In our study, CT-based staging system for primary elbow osteoarthritis showed almost perfect interobserver reliability and moderate to high correlation with clinical outcomes, including VAS, ROM, and MEPS. Although the previous radiograph-based staging system had been popular for screening and confirmation of the diagnosis, plain radiograph has a limitation when describing the amount of osteophytes and the severity of joint narrowing, which are the main characteristics of elbow osteoarthritis[17].

Two components determine the severity of primary elbow osteoarthritis: osteophyte and joint space narrowing

Sun *et al.* reviewed 10 studies that measured the reliability of hip and knee osteoarthritis ratings and found moderate to good agreement for the overall scores and for the separate grading of osteophytes and joint space narrowing; the other radiographic features were less reliable. Because the main symptoms of primary elbow osteoarthritis are (1) limited ROM and end-arc pain due to mechanical impingement by osteophytes and (2) resting pain due to cartilage destruction, evaluation of osteophytes and joint narrowing should be used to quantify the severity of elbow arthritis, which is essential for prognostication and clinical decision-making. Broberg and Morrey also developed their staging system for elbow arthritis using these two components, based on plain radiograph studies. However, because the severity of the two components does not always match clinically and radiologically, separate staging may be preferable.

Quantification of the osteophyte

The elbow is basically a hinged joint and requires a large functional ROM of >100°[18]. Therefore, in the early to moderate stages, limited ROM of the elbow is clinically more critical, compared with joint narrowing. Elbow stiffness can occur due to either extrinsic or intrinsic cause. Although extrinsic stiffness is mostly associated with posttraumatic contracture of extraarticular soft tissue structures, such as the joint capsule, triceps, and brachialis muscles, intrinsic stiffness is mostly caused by intraarticular pathology, such as osteophytes and loose bodies, which are correlated with the symptoms of osteoarthritis. Because the formation of osteophytes is one of the main causes of stiffness in primary elbow arthritis, proper description is important to understand the degree of severity[19]. Kashiwagi[20] previously described the relationship between size of the osteophytes in the coronoid and olecranon fossae and the limitation of flexion and extension; they proved that osteophytes strongly correlated with limited ROM in elbow arthritis. For this reason, osteophyte formation should be considered and highlighted in any classification. The location of osteophytes is also important. Nishiwaki *et al.*[21] evaluated the volume of bony overlap in the arthritic elbow on full extension and flexion using a simulation study with three-dimensional CT imaging. They showed that the most common location for spur formation was near the coronoid and olecranon fossae. Lim *et al.*[22] also evaluated osteophyte distribution around the elbow and found that in 95% of patients, the osteophyte was near the anterior coronoid fossa in the anterior compartment. Based on these previous reports, we selected one section as the reference in order to observe the center of both fossae on sagittal CT sections. This led to the concept of the involved fossa, using over 50% involvement of a spur in the fossa for staging. An anterior involved fossa correlated with flexion limitation and a posterior involved fossa correlated with extension limitation. We defined two different subgrades according to symptom dominance (anterior–flexion–dominant and posterior–extension-dominant) in stage I.

Quantification of joint space narrowing

Morrey *et al.* reported that primary osteoarthritis of the elbow is unique, in that there is relative preservation of articular cartilage and maintenance of the joint space[5]. This meant that the diagnostic weight was not equal. Ratzlaff *et al.* reported that joint space narrowing was a sign of advanced osteoarthritis and reflected the severity of cartilage destruction that can lead to mid-arc or resting pain[23]. Although joint narrowing is assessed in the early stages of knee arthritis, joint narrowing in the elbow is not as clear as that in the knee, because the elbow joint is non-weight-bearing. The elbow is composed of the radiocapitellar and ulnohumeral joints. Hastings emphasized the radiocapitellar joint, and Morrey considered only ulnohumeral joint narrowing. Because ulnohumeral joint narrowing, in contrast with radiocapitellar joint narrowing, is usually found in the advanced stages of arthritis, this component was included in our staging system as end-stage involvement. CT was more useful than plain radiograph in evaluating the status of joint narrowing.

Table III
Correlation with clinical assessments

		ROM		VAS		MEPS	
B-M	PCC	−0.327	moderate	0.564	moderate	−0.627	**high**
	P-value	0.003		<0.001		<0.001	
H-R	PCC	−0.367	moderate	0.493	moderate	−0.489	moderate
	P-value	0.001		<0.001		<0.001	
CT-based	PCC	−0.458	moderate	0.754	**high**	−0.614	**high**
	P-value	<0.001		<0.001		<0.001	

B-M: Broberg and Morrey, H-R: Hastings and Rettig classification, PCC: Pearson's correlation coefficient, ROM: Range of Motion, VAS: Visual Analogue Scale, MEPS: Mayo Elbow Performance Score, CT: Computed Tomography.

Strengths and limitations

The strengths of our study include the development of a new classification for elbow arthritis based on CT and the participation of multiple evaluators in the determination of interobserver reliability. The scoring was only performed by fellowship-trained orthopedic surgeons who had high proficiency ratings. Moreover, we evaluated the correlation between the staging systems and clinical scores, in order to understand better which among the staging system is superior in reflecting clinical symptoms.

One of the limitations of the current study was the small number of cases especially for early staged osteoarthritis (OA) that were all from a single institution. Second, we acknowledge the inherent difference of the classification values between plain radiograph and CT; CT can be inherently more accurate for subcentimeter measurements. Future study with a large sample size and on different ethnicities is recommended to confirm the usefulness and suitability of this grading system.

Conclusion

CT-based staging system was highly reproducible and clinically feasible, compared with previous plain radiograph-based staging systems, for elbow osteoarthritis.

Author contributions

JM Kwak contributed to the study concept and design, data collection, data analysis, and drafting of the manuscript. E Kholinne, Y Sun, and A Alhazmi contributed to data analysis as raters. KH Koh contributed to editing the manuscript. IH Jeon contributed to the study concept, design and critical revision of the manuscript. 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.

Competing interest statement

The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Funding

None.

Disclaimer

The authors or their immediate families have not received any financial payment or benefits from any commercial company related to this study. The keynote of this paper was presented at.

1)Sixty second Annual Congress of the Korean Orthopedic Association in South Korea, 2018
2)The Thirty first Annual Meeting of the Japan Elbow Society in Japan, 2019

IRB/ethical committee approval

AMC IRB 2017–1221.

Data statement

Our data without patient's information can be accessed on your special request to the corresponding author.

Acknowledgements

None.

References

1. Gramstad GD, Galatz LM. Management of elbow osteoarthritis. J Bone Joint Surg Am 2006;88(2):421–30.
2. Papatheodorou LK, Baratz ME, Sotereanos DG. Elbow arthritis: current concepts. J Hand Surg 2013;38(3):605–13.
3. Kroonen LT, Piper SL, Ghatan AC. Arthroscopic management of elbow osteoarthritis. J Hand Surg 2017;42(8):640–50.
4. Morrey BF. Primary degenerative arthritis of the elbow. Treatment by ulnohumeral arthroplasty. J Bone Joint Surg Br 1992;74(3):409–13.
5. Cheung EV, Adams R, Morrey BF. Primary osteoarthritis of the elbow: current treatment options. J Am Acad Orthop Surg 2008;16(2):77–87.
6. Galle SE, Beck JD, Burchette RJ, Harness NG. Outcomes of elbow arthroscopic osteocapsular arthroplasty. J Hand Surg 2016;41(2):184–91.
7. Katolik LI. Osteocapsular debridement for elbow arthritis. Hand Clin 2011;27(2):165–70.
8. Ramirez MA, Cheung EV, Murthi AM. Revision total elbow arthroplasty. J Am Acad Orthop Surg 2017;25(8):e166–74.
9. Broberg MA, Morrey BF. Results of delayed excision of the radial head after fracture. J Bone Joint Surg Am 1986;68(5):669–74.
10. Rettig LA, Hastings 2nd H, Feinberg JR. Primary osteoarthritis of the elbow: lack of radiographic evidence for morphologic predisposition, results of operative debridement at intermediate follow-up, and basis for a new radiographic classification system. J Shoulder Elb Surg 2008;17(1):97–105.
11. Guitton TG, Ring D. Interobserver reliability of radial head fracture classification: two-dimensional compared with three-dimensional CT. J Bone Joint Surg Am 2011;93(21):2015–21.
12. Blonna D, Zarkadas PC, Fitzsimmons JS, O'Driscoll SW. Validation of a photography-based goniometry method for measuring joint range of motion. J Shoulder Elb Surg 2012;21(1):29–35.
13. Iannotti JP, McCarron J, Raymond CJ, Ricchetti ET, Abboud JA, Brems JJ, *et al*. Agreement study of radiographic classification of rotator cuff tear arthropathy. J Shoulder Elb Surg 2010;19(8):1243–9.
14. Howells NR, Hughes AW, Jackson M, Atkins RM, Livingstone JA. Interobserver and intraobserver reliability assessment of calcaneal fracture classification systems. J Foot Ankle Surg Off Publ Am Coll Foot Ankle Surg 2014;53(1):47–51.
15. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(1):159–74.
16. Culvenor AG, Engen CN, Oiestad BE, Engebretsen L, Risberg MA. Defining the presence of radiographic knee osteoarthritis: a comparison between the Kellgren and Lawrence system and OARSI atlas criteria. Knee Surg. Sports Traumatol Arthrosc Off J ESSKA 2015;23(12):3532–9.
17. Amini MH, Sykes JB, Olson ST, Smith RA, Mauck BM, Azar FM, *et al*. Reliability testing of two classification systems for osteoarthritis and post-traumatic arthritis of the elbow. J Shoulder Elb Surg 2015;24(3):353–7.
18. Morrey BF, Askew LJ, Chao EY. A biomechanical study of normal functional elbow motion. J Bone Joint Surg Am 1981;63(6):872–7.
19. Junker S, Krumbholz G, Frommer KW, Rehart S, Steinmeyer J, Rickert M, *et al*. Differentiation of osteophyte types in

osteoarthritis - proposal of a histological classification. Joint Bone Spine Rev Rhum 2016;83(1):63–7.
20. Kashiwagi D. Elbow Joint. Excerpta Medica; 1985.
21. Nishiwaki M, Willing R, Johnson JA, King GJ, Athwal GS. Identifying the location and volume of bony impingement in elbow osteoarthritis by 3-dimensional computational modeling. J Hand Surg 2013;38(7):1370–6.
22. Lim YW, van Riet RP, Mittal R, Bain GI. Pattern of osteophyte distribution in primary osteoarthritis of the elbow. J Shoulder Elb Surg 2008;17(6):963–6.
23. Ratzlaff C, Ashbeck EL, Guermazi A, Roemer FW, Duryea J, Kwoh CK. A quantitative metric for knee osteoarthritis: reference values of joint space loss. Osteoarthritis Cartilage 2018;26(9):1215–24.