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Correlation of Clinical Disease Severity to Radiographic Thumb Osteoarthritis Index

Amy L Ladd, MD⁽¹⁾, Joseph Messana, MD⁽¹⁾, Aaron J. Berger, MD PhD⁽¹⁾, and Arnold-Peter C. Weiss, MD⁽²⁾

⁽¹⁾Robert A. Chase Hand & Upper Limb Center, Department of Orthopaedic Surgery, Stanford University Medical Center, Palo Alto, CA

⁽²⁾Department of Orthopaedics, Warren Alpert Medical School at Brown University

Abstract

Purpose—To determine if a slight modification of the 1987 Eaton-Glickel staging and interpreting 4 standardized radiographs for trapeziometacarpal arthritis improved analysis, to determine if a quantifiable index measurement from a single Robert (pronated anteroposterior) view enhanced reproducibility, and to examine whether improved radiographic staging correlated to clinically relevant disease and thus support validity.

Methods—We analyzed 4 thumb radiographs (posteroanterior, lateral, a Robert, and stress views) in 60 consecutive subjects representing an adult population spectrum of asymptomatic to advanced disease. Two experienced hand surgeons, 1 chief resident, and 1 medical student performed the analysis on each subject's radiographs. We analyzed all 4 radiographs for Eaton and modified Eaton staging and then later analyzed only the Robert view for the thumb osteoarthritis (ThOA) index measurement. The radiographs were randomized and re-read a week later for each classification at separate times. Surgically excised trapeziums from 20/60 subjects were inspected for first metacarpal surface disease and correlated to the 3 classifications.

Results—All 3 staging classifications demonstrated high reproducibility, with the intraclass correlation coefficient averaging 0.73 for the Eaton, 0.83 for the modified Eaton, and 0.95 for the ThOA index. Articular wear and metacarpal surface eburnation correlated highest to the ThOA index, with advanced disease 1.55 correlating to Eaton III/IV and modified Eaton stage 3/4 in a linear relationship.

Discussion—The ThOA index based on a Robert view provided a measurable alternative to Eaton staging and correlated to severity of surgically relevant thumb TMC OA.

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Corresponding Author: Amy L. Ladd, M.D., Professor & Chief, Robert A. Chase Hand & Upper Limb Center, Department of Orthopaedic Surgery, 770 Welch Road, Suite 400, Stanford, CA 94304, W: (650) 721-7626 F: (650) 721-3474, alad@stanford.edu.

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Clinical Relevance—A simple reproducible radiographic measurement may enhance TMC OA classification and provide a reliable means to predict clinical disease.

Level of Evidence—Level of Evidence II/Diagnostic

Keywords

(Hand/wrist) - Eaton classification; inter-rater reliability; radiographic index; thumb carpometacarpal arthritis; trapeziometacarpal arthritis

INTRODUCTION

The prevalence of trapeziometacarpal osteoarthritis (TMC OA) and its myriad surgical operations underscore its importance as a major musculoskeletal disease (1,2,3). Symptoms may not correspond to radiographic findings, and a patient's perceived disability typically drives surgical intervention. The orthopedic and hand literature commonly cites Eaton radiographic classification in clinical series (4,5,6,7). This severity staging is derived from the Kellgren-Lawrence classification (8,9), a widely used arthritis staging system in the rheumatology and orthopedic literature. The Eaton-Littler radiographic staging reported in 1973 correlated surgical results of one procedure to TMC joint radiographic and surgical joint degeneration and subluxation (4). Eaton and Glickel's revised 1987 surgical indications classification included stage IV scaphotrapezial arthritis and complete TMC joint deterioration, while eliminating subluxation as defining criteria (5) (Table 1).

Although often a surgeon's guidepost for decision-making, the Eaton staging possesses fair to moderate intra-observer reliability ($\kappa = .54$ to $.66$ range) and poor to fair inter-observer reliability ($\kappa = .37$ to $.53$ range) (6,10,11,12). The descriptive Eaton-Littler (4) and Eaton-Glickel (5) classifications, the criteria differences between stages, and confusion regarding which classification is specified potentially contribute to this phenomenon. Criteria include joint space narrowing, peripheral bone formation, and subluxation. The 1987 adaptation changes 1973 joint narrowing and joint destruction staging: "slight" joint narrowing changes from stage III to stage II disease and joint space destruction changes from stage IV to stage III (Table 1). The 2 classifications do not delineate between "slight" or "markedly" narrowed joints or define joint destruction degree. Bony "fragments" (4) or "joint debris" (5) are not distinguished as osteophytes or loose bodies/ossicles. In the Kellgren-Lawrence classification, osteophytes (grade I) and ossicles (grade 2) indicate progression of disease, although size is not specifically measured (9). Subluxation, both in its presence and degree, is variably reported in the Eaton classifications (Table 1). Subluxation is a defining criterion in stages I–III in the 1973 scheme (4) but identified only in stage III with the 1987 scheme (5). Literature analyzing Eaton classification utility is inconsistent regarding which classification to use. A 2011 article referenced the 1973 classification including subluxation (11). A 2002 article cited both schemes (10), and a 2004 article used the 1987 classification (6). Recent evidence indicates subluxation is a normal phenomenon in both men and women (13,14). Although one lateral x-ray view forms the basis for the 1987 Eaton-Glickel classification (5), in practice, many surgeons today use additional views to stage disease. As a result, lack of agreement in defining radiographic

disease possibly contributes to the poor correlation of symptoms to severity and the definition of severity itself.

We hypothesized that a reproducible, quantifiable radiographic scheme would correlate to clinically relevant disease. To test this hypothesis, we proposed a slight modification to the 1987 Eaton-Glickel grading system encompassing multiple views with a goal to improve accuracy, and, secondarily, create a new measurable index based on a single, reproducible radiographic view of the TMC joint. We then posed 3 questions. Does a standardized set of radiographs representing multiple views of the thumb provide better accuracy when using our modified Eaton classification? Is an index measuring the height and width of the trapezium on the Robert (pronated anteroposterior) view (15–19) (Figure 1,2) reproducible among various examiners? Does this index correlate to surgical disease severity?

MATERIALS AND METHODS

The study design investigated the accepted diagnostic criteria of Eaton radiographic staging for thumb TMC OA (4,5,6,10,11) by retrospectively examining a consecutive series of x-rays. We analyzed 4 thumb x-rays (posteroanterior, lateral, Robert (17–19), and stress views (13)) in 60 subjects (asymptomatic to advanced disease population spectrum). We then performed analysis with an interpretation of combined Eaton classifications (4,5), modified Eaton-Glickel classification (5) (Table 2), and analysis of the Robert view alone with a new index measurement. Intraclass correlation coefficients with 95% confidence intervals were chosen to measure test/retest reproducibility of each examiner and agreement between examiners. For clarity, we used intraclass correlation (ICC) for the test/retest of each examiner and interrater reliability (IRR) to examine the agreement between examiners using the same test. The ICC measures concordance ranging from 0 to 1; 1.0 represents perfect agreement, and 0 suggests that measurements are entirely random. The confidence interval width to detect discernible differences was selected to be less than .20.

We obtained the x-rays and clinical specimens of the 60 subjects (27 left and 33 right hands) in consecutive order from a single institution (Stanford University). We selected the first 20 x-rays of asymptomatic subjects with absent radiographic disease enrolled at one institution from a combined prospective cohort of 44 control subjects in a co-institutional NIH research investigation initiated January 2012, which examined functional tasks and longitudinal thumb TMC OA development. Asymptomatic subjects included 12 women (average age 44, range 23–70), and 8 men (average age 38, range 18–75). From the clinical practice of one of the senior surgeons (ALL), we selected consecutive x-rays from 20 additional subjects with mild to advanced radiographic disease and 20 subjects who had previously undergone trapeziectomy for clinically advanced arthritis. The 20 non-surgical x-rays included 14 women (average age 61, range 51–84) and 6 men (average age 61, range 49–71). The 20 surgical x-rays were from 18 women (average age 64, range 51–84) and 2 men (average age 72, range 71–73). Inclusion criteria required 4 complete, satisfactory x-rays, the standard series in our practice since January 2012. The 20 surgical subjects represented trapeziectomies (11 right and 9 left) with a complete x-ray series performed between August 2011 and April 2013. Eighteen excluded subjects (16 women and 2 men of 38 total) with trapeziectomy in this time frame had incomplete x-rays, the majority of whom had care that

preceded the x-ray protocol implementation. One additional subject was excluded because of an inflammatory condition.

Two senior hand surgeons (ALL and APCW) 1 chief resident (AJB), and 1 medical student (JM) performed the analysis on each subject's radiographs, reflecting a range of clinical experience. After reviewing the 1973 Eaton-Littler (4) and 1987 Eaton-Glickel staging (5), and its reported use (6,10,11), each investigator categorized the x-rays according to one's own interpretation of the Eaton classification. We discussed the literature reference of each stage, and then evaluated the x-rays independently. We also analyzed x-rays with our slightly modified version of the 1987 Eaton-Glickel classification (5) where we redefined early disease (Eaton stage I) for stage 0 and stage 1, eliminated subluxation as a measure of progressive radiographic deterioration, and included posteroanterior (PA), lateral, Robert, and stress radiographic views for determining the stage (Table 2). Our modified Eaton classification addresses mild disease by designating normal contour and joint space as stage 0, and designating stage 1 as minimal joint findings. In concordance with the 1987 criteria we used "joint debris" to indicate extra bone formation, < 2mm for stage 2, and > 2mm for stage 3. Our stage 4 differs from 1987 Eaton-Glickel stage IV to include severe TMC disease and any other joint, not just the scaphotrapezial joint (Table 2). With these modifications, we anticipated a more reproducible classification scheme.

We also created a thumb osteoarthritis (ThOA) index enabling trapezial height and width radiographic measurements (Figure 3) based on a single Robert view alone (Figure 1,2). This projection reveals an unimpeded view of articular contours in its ulnar to radial position (Figure 2,4) (15–19). We measured trapezial height to width ratio (Figure 2) using ImageJ software (NIH open source, <http://rsb.info.nih.gov/ij/>).

The radiographs were randomized using randomization software and re-read a week later for each classification. We did not perform simultaneous classification of the different schemes. The medical student performed the randomization, assigning numbers blinded to all examiners. We inspected surgically excised trapeziums from the 20 operative subjects for first metacarpal base articular surface cartilage wear and eburnation and stratified the degree of arthritis according to the 3 different radiographic staging schemes.

We inspected and recorded the surgical specimens at several time points. The primary surgeon (ALL) photographed the excised trapeziums and the intact articulating joint surfaces intra-operatively and dictated detailed operative findings. The trapeziums were preserved in formalin and later photographed in a staging environment. We re-inspected the specimens (range of 2–18 months after surgery), measured height and width with calipers, and digitally photographed and measured these using a calibrated stage with identical lighting and camera settings. The percentage of complete cartilage wear ("eburnation" as described by Pellegrini (20)) of the first metacarpal surface of the trapezium was recorded and determined using all available information: operative photographs, operative report, and visual and manual inspection. The 4 observers determined the percentage of wear by consensus; the intraoperative photographs compared to operative descriptions were deemed the most consistent, whereas discriminating joint surface detail with the staging photographs proved

difficult. We compared the percentage of articular surface wear of the excised trapeziums to the average Eaton stage, our modified Eaton stage, and the ThOA index.

Although operative findings reported irregular or thinned cartilage according to the Outerbridge classification (21), we only used complete loss/polished bone for determining the percentage of eburnation, consistent with Pellegrini's measure of severity (20). Marked dysplastic and surface morphology changes were described (22,23).

In addition, we harvested 11 cadaveric trapezial specimens (5 male/6 female, age > 65) with minimal arthritis and intact saddle joint morphology of the first metacarpal surface, consistent with absent radiographic disease and Outerbridge stage 1 (21), which we similarly measured and photographed to simulate the Robert x-ray view of a normal trapezium.

Our institutional review board approved this project. Informed consent and HIPAA consent were obtained from each patient. The handling of human remains adhered strictly to ethical and practice protocols.

RESULTS

The examiner retest of the rater interpreted Eaton and our modified Eaton classifications yielded the following results. The average Eaton stage ICC for the 4 observers, each performing 2 evaluations, was .73; 95% CI = 0.65 – 0.98. The medical student demonstrated the lowest reproducibility, and one of the senior surgeons the highest. For the modified Eaton, the average ICC was .83; 95% CI = 0.74 – 0.99 with the chief resident demonstrating the lowest reliability, and the other senior surgeon the highest. For comparison between examiners, the Eaton stage IRR averaged 0.80; 95% CI = 0.74 – 0.88, and the modified Eaton stage IRR averaged 0.83; 95% CI = 0.76– 0.80. The difference between the 2 staging schemes was not statistically significant ($P = 0.12$).

The ThOA index measurements yielded an average ICC = 0.95; 95% CI, 0.94 – 0.98) and average IRR = 0.85; 95% CI, 0.81 – 0.89.

The Eaton and modified Eaton stages and the ThOA index of the 20 surgical subjects demonstrated a continuum of severity. The percentage of eburnation moderately correlated to the Eaton and modified Eaton stages with Pearson correlation coefficient of 0.71 and 0.66 respectively. The percentage of eburnation highly correlated to ThOA index, with a Pearson correlation 0.86. The improved correlation of the ThOA index to eburnation, compared to either the Eaton or modified Eaton stage, was statistically significant in 3 of the 4 rater's measurements using the Steiger Z-test for dependent correlations ($P < 0.05$).

The ThOA index in all asymptomatic subjects was <1.55 (Figures 5,6). All subjects with advanced, dysmorphic disease possessed a ThOA index >3.0 (Figures 5,7). Specimen with >60% articular wear possessed a ThOA index >1.5, with 1 exception (Figure 5). The normal cadaveric specimens possessed ratios <1.5. The intraoperative inspection and digital photographs revealed the most cartilage wear detail and contrast; the formalin specimens removed distinguishing tissue color characteristics, making articular loss difficult to

determine by visual inspection alone. ThOA index correlated almost linearly to eburnation between indices of 1.35 – 2.35, with ThOA index values >2.35 demonstrating 100% eburnation (Figure 5).

The dysplastic trapeziums with articular shape changes including loss of volar-dorsal convexity, preferential wear with a volar concave neo-facet, and large rimming osteophytes demonstrated complete or near complete eburnation of the entire original articular surface. Minimal remaining irregular cartilage was encountered peripherally. The specimens corresponded to previously described morphology changes with OA (20,23).

DISCUSSION

Our investigation demonstrated that obtaining 4 standardized x-rays improves Eaton intra- and interrater reproducibility compared to previous reports of the 1973 Eaton-Littler and 1987 Eaton-Glickel classifications (10,11,12). A spectrum ranging from asymptomatic subjects with normal x-rays to clinically symptomatic surgical subjects with radiographic advanced disease expands staging levels from 0–4 (Table 2). Our modified 1987 Eaton-Glickel classification that addresses early arthritis (modified stage 1), removes subluxation as a criterion (all modified stages), and includes arthritic joints besides the scaphotrapezial joint is in concept more clinically relevant and potentially more useful to clinicians. Our modified classification, however, fared no better statistically in our own analysis of referenced Eaton classifications (10,11,12). This likely reflects the descriptive, qualitative nature of these and the original Kellgren-Lawrence (8,9) grading systems, which challenges efforts to make standardized clinical comparisons.

The quantitative ThOA index obtained from a single Robert view measuring trapezial width to height increased numerically with radiographic and clinical disease progression. The index was statistically more reproducible and reliable than both reported 1973 and 1987 Eaton (4,5) and our modified 1987 Eaton-Glickel scores obtained from all 4 x-rays. The ThOA index proposes an attractive alternative, obtaining clear view through the TMC joint. The index captures qualitative dysplastic surface morphology and peripheral joint debris/osteophytes/ossicles consistent with OA severity, indicators of progressive severity in Kellgren-Lawrence staging (8,9) and both Eaton classifications (4,5). Progressive first metacarpal surface eburnation of surgical specimens correlated to increased ThOA index, suggesting a reproducibly relevant TMC OA radiographic measurement.

Several investigation limitations exist. Common to imaging studies, x-rays alone are insufficient to predict functional status and treatment response. While the reliable ThOA index matches articular wear degree, its ability to predict pain, dysfunction, or surgical need is unknown. In addition, trapezial specimens came from symptomatic patients desiring surgery. We do not report trapezial findings from asymptomatic subjects and thus our surgical cohort represents but one segment of a population. Most (18/20) of the excised trapeziums represented women, a sample size too small to suggest wear differences between sexes. The spectrum of shape and wear patterns, however, correspond to a larger trapezial series more inclusive of sex (9 male/27 female trapeziums) (23). Furthermore, x-ray randomization mitigated potential sex-bias x-ray interpretation (16 male/44 female).

Studies comparing radiographic classification schemes typically include musculoskeletal radiology raters. Ours did not. We intentionally chose rater clinical experience reflecting the varied experience treating this common disease. This, in our opinion, suggests a more realistic clinical decision-maker scenario.

Removing an intact trapezium is technically challenging. Large or semi-attached osteophytes may easily dislodge, and articular cartilage is vulnerable to surgical trauma. Ossicles/loose bodies, as opposed to osteophytes, are poorly differentiated on x-ray and their contribution considered equally regarding ThOA index width. We did not find disease severity progressed from osteophyte to loose body formation (8,9). At surgery, loose bodies are typically encountered radially underneath the abductor pollicis longus (Figure 7) and ulnarly at the attachment of the flexor carpi radialis. Loose bodies free of the trapezium alter the actual trapezial width measurement, compared to preoperative x-ray width including loose bodies. We found, however, that large radial and ulnar osteophytes or large loose bodies identified in the Robert view accompanied grossly dysplastic trapeziums. For these, radiographic and photographic ThOA index typically measured > 2.0 , and therefore inclusion or elimination of loose bodies made no relevant difference.

Our study addressed the TMC joint. Advanced disease often includes the adjacent joints, not just the scaphotrapezial (ST) joint in Eaton-Glickel 1987 stage IV (5). Our modified stage 4 included trapezio-trapezoid, trapezial-second metacarpal, and scaphotrapezial arthritis, although these joints are not captured in the ThOA index. We believe that ST arthritis in conjunction with TMC OA, or other joint involvement, represents a different entity than TMC OA alone. Surgery findings often reveal that a dysplastic trapezium with an elongated ulnar surface (Figure 7) typically has surgical and radiographic changes at or around the second metacarpal and trapezoid facets. We postulate that different wear patterns suggest different etiology, rather than representing disease progression (23). Its clinical and radiographic meaning requires further investigation. To date, current accepted surgical management with trapeziectomy addresses peri-trapezial arthritis, whether or not other facet involvement accompanies TMC OA. Future studies evaluating the morphologic and kinematic relationship of the trapezium to its carpal neighbors, including predictive modeling, will provide an opportunity to refine treatment for joint specific disease.

We did not quantify detailed cartilage description, including patterns of wear, thickness, and irregularity. Such characterization would require immunohistochemical techniques beyond the scope of the study. Quantifying shape and volume characteristics, subchondral bone, and trabecular morphology would more accurately reflect disease progression. These measures would require analysis with computed tomography and micro-computed tomography, also beyond the scope of this study.

ThOA index predictably correlates to joint degeneration, and is more reliable than the descriptive Eaton classification system. A broad range of ThOA index measurements in surgical subjects further supports patterns of degeneration exist beyond our paradigm of radiographic disease progression. Eaton found that radiographic staging correlated to results of surgery (4,5) and provided a guide to surgical treatment (5). With current lack of surgical treatment consensus, we propose instead that the ThOA index relates radiographic severity

to surgical disease severity. Thus, a specific, reproducible measurement provides the basis for better characterization of disease, which provides the opportunity to guide prevention and tailor treatment.

A single Robert view lacks familiar qualitative terminology reported in the orthopedic literature and limits description afforded with multiple x-ray views, and we propose it at least as an adjunct to standard x-rays in the clinical setting. The increased reliability of the ThOA index and its correlation to surgical arthritis provides the opportunity for improving diagnostic and treatment methods across the disease continuum. The relative low radiation of one view suitably obtained in a range of clinical settings suggests a simple, reproducible, and clinically relevant means of quantifying the severity of thumb TMC osteoarthritis.

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Figure 1. The Lewis technique of the Robert projection

The x-ray beam is aimed 15 degrees proximal compared to a vertically oriented beam.

Figure 2. Robert normal x-ray

The Robert view of an asymptomatic thumb demonstrates the horizontal profile of both the trapeziometacarpal and scaphotrapezial joints. The flexor carpi radialis groove (*) lies parallel to the long axis of the wrist and finger metacarpals, reflecting the oblique trapezial and thumb position relative to the remaining hand.

$$\text{ThOA Index} = X/Y$$

Figure 3. The Thumb Osteoarthritis (ThOA) Index

The thumb osteoarthritis (ThOA) index measures the ratio of the trapezial width (X) and height (Y) as obtained from the Robert view (17,18). The width (X) represents the distal most prominences of trapezium facing the first metacarpal, including non-articular osteophytes. The height (Y) is obtained from the central, most narrow sulcus in the central region of the trapezium. The ratio increases with disease progression. The left figure represents absence of radiographic disease, whereas the right represents significant arthritic changes with osteophytes present.

Figure 4. Normal trapezium

A normal right trapezium photographed from the volar side reveals the same horizontal profile as the x-ray in Figure 2, and the second metacarpal and trapezoid facets are seen on the ulnar (U) side. This image demonstrates the concave contour in the ulnar to radial (R) direction, and a convex contour in the volar to dorsal direction. The oblique flexor carpi radialis groove (*) corresponds to the oblique line seen in Figure 2.

Figure 5. Metacarpal Eburnation vs. ThOA in Excised Samples

For excised trapeziums, a linear relationship existed between ThOA from 1.35 – 2.35. ThOA values > 2.35 demonstrated 100% eburnation.

Figure 6. Preserved saddle shape with less advanced radiographic findings

A surgically explanted trapezium demonstrating <60% eburnation of metacarpal surface (A) and relative retention of saddle configuration with minimal osteophytes (B). The average Eaton rating was 1.5; the modified Eaton 2, and the ThOA index measured 1.36.

Figure 7. Advanced trapezial degeneration with advanced radiographic findings

Figure 4A, 4B: A surgically explanted trapezium demonstrating 100% eburnation of metacarpal surface, extensive dysplasia and osteophyte formation, and elongation in both the radial (pin side) and ulnar positions. The radial loose body was encountered beneath the abductor pollicis longus. The dotted line (A) indicates volar concave wear, reversing the normal convex shape in the dorsal-volar plane (22). The Robert view confirms the dysplasia (C). The average Eaton and modified rating measured 3.5, and the ThOA index measured 2.59.

TABLE 1

Eaton-Littler (4) and Eaton-Glickel (5) Classification schemes

Stage	1973 Eaton-Littler (4)	1987 Eaton-Glickel (5)
X-ray images	Multiple, variable	Lateral
0	--	--
I	Slight joint widening, < 1/3 subluxation, normal articular contours	Slight joint widening
II	Small bone/calcific fragments < 2 mm volar or dorsal, 1/3 subluxation	Slight joint narrowing, minimal subchondral sclerosis, joint debris (osteophytes or loose bodies) < 2 mm
III	> 1/3 subluxation, fragments > 2mm volar and/or dorsal, slight joint narrowing	Marked narrowing/obliteration joint space, cystic changes, sclerotic bone, varying degrees of dorsal subluxation, joint debris > 2 mm
IV	Advanced changes applicable to rheumatoid arthritis, major subluxation, very narrow joint space, cystic sclerotic subchondral bone, lipping and osteophyte trapezial formation, erosion dorsoradial facet	Stage III deterioration + scaphotrapezial joint narrowed with sclerosis and cystic changes

TABLE 2**Modified Eaton Classification**

Stage	Modified Eaton
X-ray images	PA, lateral, Robert (15–18), stress view (13)
0	No evidence of any arthritis
1	Minimal joint narrowing (compared to adjacent joints), minimal contour changes, no debris, minimal or no subluxation
2	Joint narrowing, debris < 2 mm, subchondral sclerosis, contour changes, +/- joint subluxation
3	Marked narrowing or no joint space remaining, contour changes, +/- subluxation of joint, debris/osteophytes > 2 mm
4	Stage 3 + additional joints, including scaphotrapezial and pantrapezial arthritis