SCIENTIFIC ARTICLE

Comparison of Plain X-Rays and Computed Tomography for Assessing Distal Radioulnar Joint Inclination

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Purpose To compare the inclination of the distal radioulnar joint (DRUJ) on computed tomography (CT) and plain radiography (XR) in order to assess the effect of narrowing the range of inclination used in the original Tolat classification system to identify potentially problematic reverse oblique DRUJs.

Methods Two independent investigators compared the angle of inclination and Tolat type on matched wrist XRs in the coronal plane and CTs of the same patients with normal DRUJs. The degree of agreement between XR and CT was determined. Inter- and intra-observer reliabilities were calculated. The prevalence of the 3 inclination types of the DRUJs using Tolat's definition was recorded. Their original quantitative definition of the parallel Tolat type 1 DRUJ included all DRUJs with a measured inclination of ±10°. We noted and compared the resultant changes in prevalence of the different DRUJ types after narrowing the inclination range to ±5° and ±3°.

Results Highly significant correlation between CT and XR measurements were found for both observers. Despite this, the limits of agreement between CT and XR in determining the sigmoid notch inclination was −9° to 11° (±2° standard deviations from the mean difference). When measured from the CTs and using Tolat's original algorithm, the prevalence of Tolat type 1 DRUJ was 47% (N = 34), type 2 was 51% (N = 37), and type 3 was 1% (N = 1). These percentages changed to 7% (N = 5) for type 1, 78% (N = 56) for type 2, and 15% (N = 11) for type 3 when applying narrower ranges of inclination.

Conclusions Narrowing the range of sigmoid notch inclination that defines type 1 (parallel) DRUJs when using CT provided a more accurate representation of the morphological types. It revealed an increased number of potentially problematic type 3 DRUJs. However, the statistical limits of agreement between CT and XR suggested that high-resolution 3-dimensional imaging is required to apply the new algorithm. *(J Hand Surg Am. 2014;■(■):■−■. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Diagnostic II.

Key words Computed tomograph, distal radio-ulna joint, plain radiograph, ulna shortening osteotomy.

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Common causes of ulnar sided wrist pain include ulnar impaction syndrome, distal radioulnar joint (DRUJ) degenerative joint disease, and triangular fibrocartilage pathology. Ulnar shortening osteotomy is a well-established procedure used to treat these conditions.[1–8] This procedure is designed to decompress the distal ulnocarpal articulation, alter the force transmission across the DRUJ, and tighten the ulnocarpal ligaments.[9] Shortening the ulna relative to the radius will, depending on the inclination of the sigmoid notch, separate the ulna head from the sigmoid notch or pull the ulna head into the sigmoid notch. This has caused some concern as this may have an adverse effect on the intra-articular contact forces in the DRUJ.[8,10–12] Additionally, up to 25% of patients may exhibit radiological evidence of remodeling or osteoarthritis 2 years after ulnar shortening osteotomy, although this may be asymptomatic.[8,11]

Tolat et al studied 80 normal wrist plain x-rays (XRs)[10] and devised a classification system describing 3 main types of DRUJ according to the inclination of the sigmoid notch in relation to the long axis of the ulna. In a Tolat type 1 DRUJ, the sigmoid notch is parallel to the long axis of the ulna, if the actual measured angle is within ±10° of zero. A Tolat type 2 DRUJ is oblique facing proximally with an angle > 10°, and a Tolat type 3 DRUJ has obliquity facing distally, less than −10° (Fig. 1). Tolat et al postulated that shortening the ulna by 2−3 mm in type 3 DRUJs would lead to degenerative changes in the joint due to increasing joint contact pressure.[10] Sagerman et al[12] agreed with this but added that incongruity commonly exists between the ulnar head and the sigmoid notch, and that this could lead to symptomatic changes in contact forces following shortening of the ulna. Tolat et al recognized in a later cadaveric study that XRs provide an estimate of a 3-dimensional configuration of the sigmoid notch only. They maintained, however, “the radiological types previously described probably represent the practical distribution of the DRUJ types.”[13]

We endeavored to evaluate the use of XR in determining the DRUJ inclination compared with a corresponding mid-coronal computed tomography (CT) scan. The XR delivers a composite image of overlapping cortical and subchondral structures, which may introduce errors in determining the true inclination of the sigmoid notch. By comparing an XR image with a corresponding CT image, the composite image with a corresponding 2-dimensional representation of the sigmoid notch could be evaluated. Accurate representation of DRUJ inclination is important when considering clinical evaluation of the effect of ulnar shortening and DRUJ reconstruction and arthroplasty with respect to different DRUJ morphology types. Tolat’s XR classification included all DRUJ in the parallel type 1 group as long as their measured inclination was within ±10°. Parallel alignment should ideally mean zero degrees of inclination. By applying Tolat’s definition, surgeons risk underestimating the occurrence of the potentially problematic type 3 joint. In an attempt to achieve a more accurate estimation of the true prevalence of the type 3 DRUJ, we applied 2 modified algorithms, narrowing the inclination range to ±5° and ±3° to define a type 1 DRUJ. This implies that type 2 DRUJs have inclinations of greater than +5° or greater than +3° and type 3 DRUJs have inclinations of less than −5° or less than −3°, respectively.

The purpose of this study was to compare inclination of the DRUJ on CT and XR on the same wrists and to assess the effect of narrowing the range of inclination used in the original Tolat classification system to identify potentially problematic reverse oblique DRUJs. We hypothesized that CT would provide a more accurate representation of the true DRUJ inclination and would allow narrowing the DRUJ inclination to 3°.

METHODS

This study was performed with appropriate institutional review board approval for review of a database of XRs and CTs of the same wrist from the radiology department of a large tertiary hospital in Brisbane Australia.

The computer database was searched for all patients who underwent CT scanning of their wrists from 2002 to 2007. Of the initial 793 scans identified, we excluded 721 patients who had bony disruptions of the DRUJ (eg, those with a distal radius fracture). Additionally, only patients with corresponding XR and CT of the same wrist were included. Seventy-two patients with radiographs and no evidence of fracture or injury affecting the DRUJ were identified. Of these, 75% were male (N = 54) and 25% were female (N = 18). Although all included patients had unaltered DRUJs, a variety of pathologies were recorded on either their XR, CT, or medical file including scaphoid or perilunate injury (N = 49), metacarpal fracture or dislocation (N = 14), other carpal injuries (N = 5), and lipoma (N = 1). Three cases were investigated for DRUJ instability but had negative findings. Fifty-seven patients were of European descent, 11 of Chinese descent, 1 of Middle Eastern descent, and 3 of African descent.

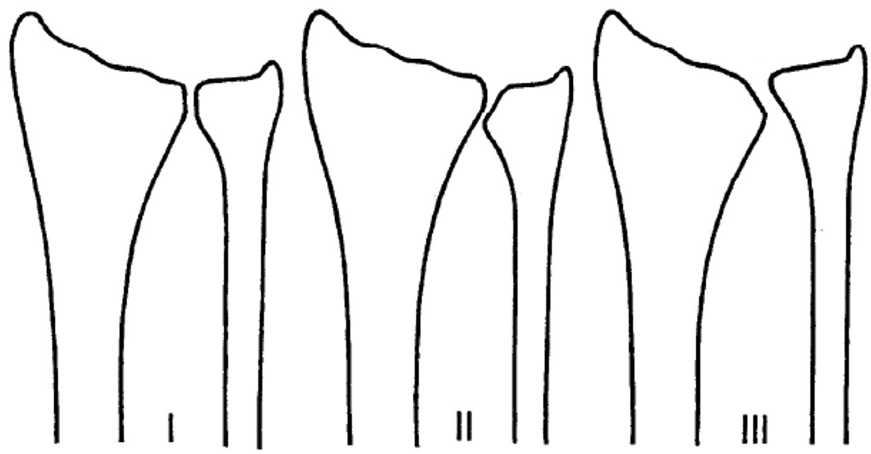

FIGURE 1: DRUJ Tolat types: I parallel, II oblique, III reverse oblique (from Tolat et al[10]). (Used with permission from Tolat AR, Sanderson PL, De Smet L, Stanley JK. The gymnast's wrist: acquired positive ulnar variance following chronic epiphyseal injury. *J Hand Surg Br*. 1992;17(6):678−681.)

A mid-coronal section of each wrist CT scan (Phillips Brilliance 64 slice, Amsterdam, The Netherlands) was evaluated to determine the true coronal plane angles of both the sigmoid notch inclination (SI) and ulna articular surface inclination (UI) relative to the ulna shaft axis according to the method reported by Sagerman et al (Fig. 2).[12] Angles were measured electronically using PACS software (Impax 6.4; Agfa Healthcare, Mortsel, Belgium). These angles were given positive values for DRUJs with inclinations of the sigmoid notch facing proximally and negative values for DRUJs with inclinations of the sigmoid notch facing distally. We accepted the CT scan as the reference standard for comparison with the matching posteroanterior XR. Two independent observers performed these tasks. One was a qualified orthopedic surgeon specializing in surgery of the upper extremity, and the other was an orthopedic surgery resident. X-rays and corresponding CT images were measured by both investigators individually and at a minimum time interval of 1 week. The intra-observer repeat measurements were performed after a further month time to allow minimization of recall.

The degree of agreement between XR and CT measurements was determined, establishing mean differences, standard deviations, and limits of agreement. The intra- and inter-observer reliability was assessed using the intra-class correlation coefficient (ICC) using a 2-way random effects model for consistency.

Furthermore, the prevalence of the 3 Tolat DRUJ types was calculated for our sample population. The Tolat type was initially determined using the original angular definition suggested by Tolat et al (Fig. 3).[10] Tolat et al defined type 1 (parallel) DRUJs as having sigmoid notch inclination of up to 10° in either direction from the long axis of the ulna, resulting in a 20° range of inclinations.

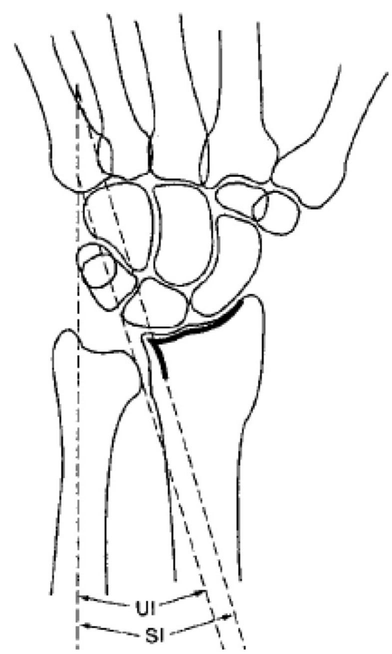

FIGURE 2: Measurement of ulnar articular surface inclination (UI) and sigmoid notch inclination (SI). (Reprinted from Sagerman SD, Zogby RG, Palmer AK, Werner MME, Fortino MD. Relative inclination of the distal radioulnar joint: a radiographic study. *J Hand Surg Am*. 1995;20(4):597−601.)

We also proposed a modified definition for measuring DRUJ types from Tolat et al's original algorithm. This modified definition used smaller ranges of sigmoid notch inclinations, namely, ±5° and ±3° to define the type 1 DRUJ. The changes in the resultant prevalence of the DRUJ types depending on the applied algorithm were noted. Our findings

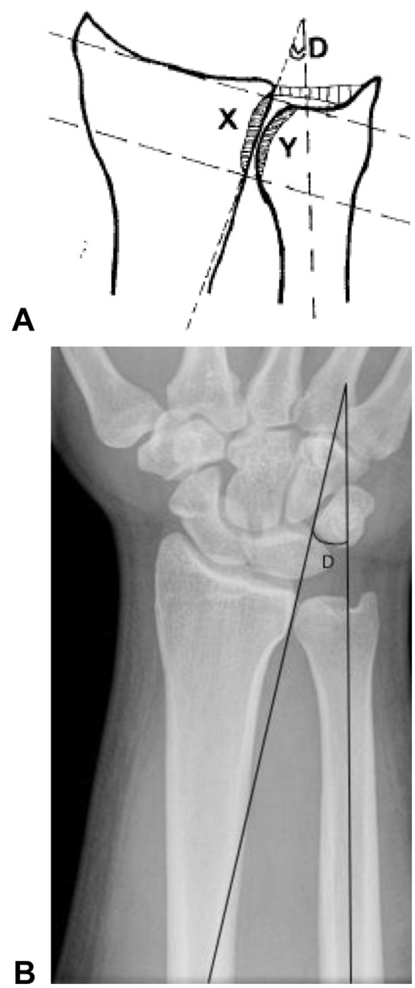

FIGURE 3: A Geometric construct for assessing DRUJ Tolat type. DRUJ angle D subtended by long axis of ulna and line parallel to sigmoid articular surface, D negative for a type 3 joint. Shaded areas X and Y: X sigmoid articular surface, Y ulnar articular surface. (Reprinted from Tolat AR, Stanley JK, Trail IA. A cadaveric study of the anatomy and stability of the distal radioulnar joint in the coronal and transverse planes. *J Hand Surg Br*. 1996; 21(5):587−594.) **B** Plain radiograph with DRUJ angle (D), example of type 2 DRUJ.

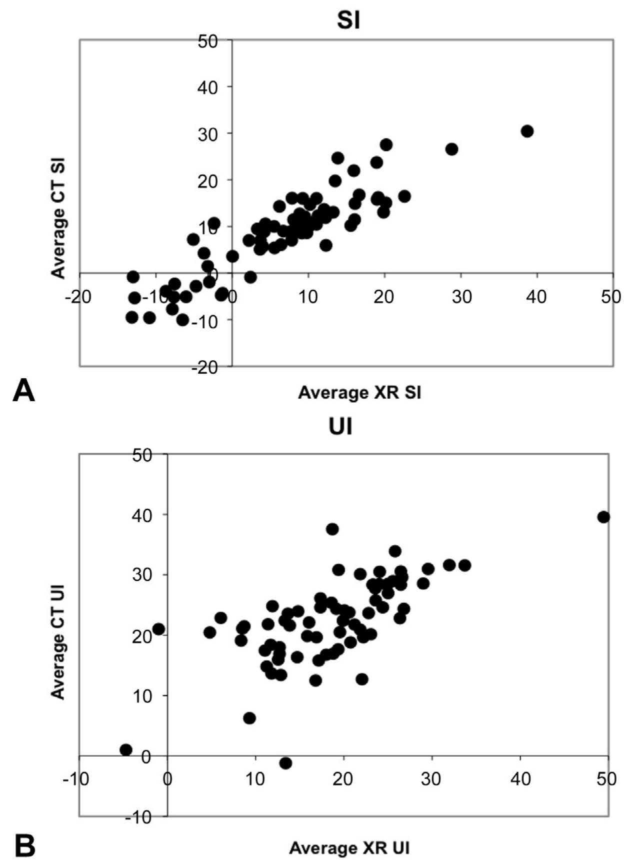

FIGURE 4: Averaged XR over CT measurements of **A** SI and **B** UI.

were finally compared with published prevalence data.

RESULTS

In our sample population the average SI relative to ulnar shaft was +9° with a continuous range from −10° to +37°. The average UI was +21° with a range from −11° to +42°.

Agreement Between X-ray and CT Measurements

For measurements of SI and for both observers, there was a highly significant correlation between the CT and XR measurements ($P < .001$). The ICCs and 95% confidence intervals (CIs) for SI were .94 (.91−.96) for observer 1 and .89 (.83−.93) for observer 2.

For measurements of UI and for both observers, there was again a significant correlation between CT and XR measurements ($P < .001$). The ICC and 95% CIs were .81 (.70−.88) for observer 1 and .65 (.44−1.78) for observer 2.

Using Bland and Altman's method to determine limits of agreement,[14] plotting averaged XR over CT measurements demonstrated greater clustering for SI compared with UI (Fig. 4). The mean difference between XR and CT measurements in determining the SI was 1° with limits of agreement between −9° and 11° (±2 standard deviations from the mean difference). For the UI measurements the mean difference between XR and CT was 4° with Bland−Altman limits of agreement between −9° and 16° (Fig. 5). This means that the precision level for determining the inclination of the sigmoid notch was superior to the ulnar articular surface angle measurements. Furthermore, Tolat et al's initially proposed range of ±10° of inclination to define type 1 DRUJs appears

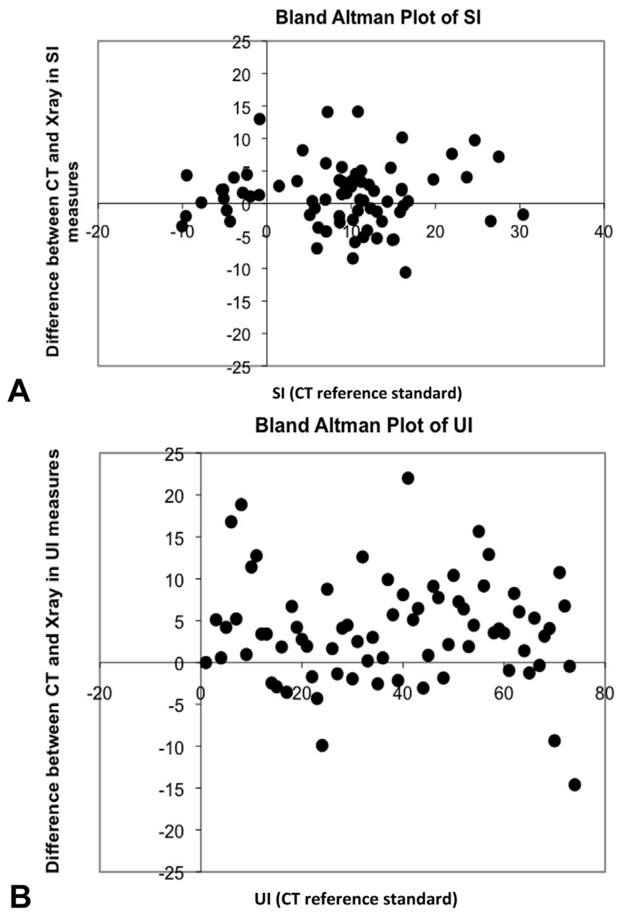

FIGURE 5: Bland−Altman plots for **A** SI and **B** UI.

sensible in light of the given standard deviations and limits of agreement (−9° to 11°) when using plain XRs.

Inter- and Intra-observer Reliabilities

For inter-observer error (between rater reliability for the XR measurements of SI and UI), both SI and UI measurements had highly significant ICCs ($P < .001$) (SI: ICC = .95, 95% CI .93−.97; UI: ICC = .92, 95% CI .88−.95).

For intra-observer error (repeatability for the x-ray measurements of SI and UI), both had highly significant correlations ($P < .001$) (SI: ICC = .90, 95% CI .84−.94; UI: ICC = .90, 95% CI .85−.94).

Prevalence of DRUJ Types

Table 1 presents the prevalence data in our study population derived from average CT measurements of the SI. Reference is also made to previous series recorded in the literature for comparison. The prevalence changed for each type according to the definition of inclination that was applied using either 10°, 5°, or 3° (Table 1). The large reduction of DRUJs that were categorized as parallel (type 1 using the modified definition) led to an increase of type 3 DRUJs. These changes of prevalence were statistically significant as was proven by a chi-square test comparing frequencies of distribution in groups B and C versus A (Table 1).

TABLE 1. Prevalence of Tolat Types

Type	Parallel	Oblique	Reverse Oblique
Current study, N = 72 Averaged CT measures			
(A) Type 1 range = +10° to −10°	34 (47%)	37 (51%)	1 (1%)
(B) Type 1 range = +5° to −5°	11 (15%)	54 (75%)	7 (10%)
(C) Type 1 range = +3° to −3°	5 (7%)	56 (78%)	11 (15%)
B vs **A**: $P < .0001$*			
C vs **A**: $P < .0001$*			
Tolat et al (1992), N = 80			
Type 1 range = +10° to −10°	38%	50%	12%
Deshmukh et al (2000), N = 13			
Type 1 range = +10° to −10°	46%	54%	0%
Hollevoet et al (2006), N = 248			
Qualitative assessment of type	43%	38%	19%

*Chi-square test of B or C vs frequency distribution of A.

Applying kappa statistics tested the strength of correlation. This is a measure of agreement in categorical outcomes. A kappa of 1 indicates full agreement and a kappa of 0 indicates complete discordance. The kappa statistic was .41 (95% CI .26−.56) for the comparison of algorithms A and B. This value dropped further to .28 (95% CI .17−.41), indicating a higher level of discordance. Agreement and changes between the outcomes when applying algorithm A and C are listed in Table 2. This highlighted the fact that the reason for the discordance between the 2 measurements was entirely due to changes affecting cases that were originally categorized as parallel with Tolat's original algorithm A. Of 33 cases (47%), only 5 cases (7%) remained in the parallel group. Nineteen cases (26%, CI 26% to 47%) were classified as oblique, and 10 cases (14%, 95% CI 8% to 24%) as reverse oblique.

DISCUSSION

A limitation of our study is that no reference standard exists for determining the actual inclination angle.

TABLE 2. Agreement Between Outcomes When Applying Algorithm C vs Algorithm A

C (±2.5°) / A (±10°)	Type 1 Parallel	Type 2 Oblique	Type 3 Reverse Oblique	
Type 1 Parallel	5 (7%)	19 (26%)	10 (14%)	34 (47%)
Type 2 Oblique	0 (0%)	37 (51%)	0 (0%)	37 (51%)
Type 3 Reverse oblique	0 (0%)	0 (0%)	1 (1%)	1 (1%)
	5 (7%)	56 (78%)	11 (15%)	72 (100%)

The kappa value is .28 (95% CI .17−.41).

For this reason, statistical analysis of our data was limited to determining the reliability with which XR images reflect the mid-coronal CT angle. In the absence of imaging studies on cadaver limbs, which would allow true anatomical measurements, it is our opinion that CT mid-coronal images are suitable first estimations. Our study found that CT and XR measurements for DRUJ inclination in the coronal plane correlated strongly when using Tolat's original algorithm.

Calculating the ICC tested the inter- and intra-observer reliability. The ICC provided a measure of agreement between 2 measurements. Fleiss suggested that ICC values of less than .40 may be taken to represent poor reliability, values of.75 and higher may be taken to represent excellent reliability, and values between .40 and .75 may be taken to represent fair to good reliability.[15] We found that, for measurements of SI, there was strong agreement between XR and CT measures for both observers, and both inter- and intra-observer reliability was strong. The ICC for all correlations was at least .89. The ICC for the correlation between XR and CT measurements of the ulna head inclination was less than that for the SI measurements. The average of .73 indicates good rather than excellent correlation. When calculating the Bland−Altman limits of agreement that are derived on the basis of the mean differences between CT and XR measurements, it is apparent that the sigmoid notch inclination can be determined with greater precision compared with the inclination of the ulnar head. For this reason SI measurements should be used when determining the DRUJ type. Applying the limits of agreement (ie, −9° to 11° for measurements of SI on XR compared with CT), suggests that using Tolat's original algorithm of ±10 degrees is sensible when using XR. The modified definition may be more useful in higher resolution scanning such as CT.

The reason to persist with the modified definition is that we showed that the inherent inaccuracy of Tolat et al's definition of type 1 DRUJ leads to a significant underreporting of the potentially problematic type 3 DRUJs. In previously published studies (Table 1), both Tolat et al[10] and Deshmukh[16] used the ±10° range. The prevalence of type 3 DRUJ was reported to be 12% and 0%, respectively. Hollevoet et al[17] did not measure absolute values for sigmoid notch inclination. They felt that it was more practical for clinical use to categorize the wrist qualitatively into morphological types. With their method applied to a large series, their prevalence of the reverse oblique type reached 19%. In our series, reducing the range of inclination that is included in the type 1 joints reduced the prevalence of type 1 and disproportionately increased the prevalence of type 3 from 1% (when applying the ±10°) to 15% (when applying the ±3°). For this reason this study supports narrowing the range of inclination (to ±3°) when using CT.

To exemplify the clinical relevance, a −9° DRUJ inclination would be considered parallel using Tolat et al's definition. The reverse oblique DRUJs are considered potentially problematic when performing ulnar shortening osteotomies, and for this reason it is important to identify type 3 DRUJs accurately. Our findings suggest that using our modified definition with the narrower range for CT would identify this potentially problematic type 3 DRUJ. However, caution should be taken using the modified definitions (±5° or ±2°) for XR, due to the detected limits of agreement between XR and CT.

We suggest that for ongoing studies regarding DRUJ morphology, high-resolution imaging that allows for true representation of a mid-coronal section of the DRUJ, such as CT or magnetic resonance scan, should be used. In cases of higher resolution imaging, our modified definition for DRUJ inclination is proposed.

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