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Radiographic assessment of overlengthening of the MoPyC radial head prosthesis: a cadaveric study

Marc Schnetzke[1] · Frank Feuchtenhofer[1] · Holger Keil[1] · Benedict Swartman[1] · Sven Vetter[1] · Paul-Alfred Grützner[1] · Jochen Franke[1]

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Abstract

Introduction The aim of this study was to evaluate a radiographic measurement method for assessment of overlengthening of the MoPyC radial head prosthesis.

Materials and methods Seven cadaver specimens were studied in ten stages: native specimen (1), radial head resection (2), and implantation of the MoPyC radial head prostheses (Bioprofile, Tornier, Montbonnot-Saint-Martin, France) in four increasing length (correct length, overlengthening of 1.5 mm, 3 mm, and 5 mm) with an intact medial collateral ligament (MCL 3–6) and following transection of the MCL (7–10). The radiographic measurement method according to Athwal et al. was evaluated to detect overlengthening. Statistical analysis included calculation of the diagnostic accuracy of the radiographic method.

Results The radiographic measurement method correctly determined the size of the radial head prosthesis within ± 1 mm in 224 of 336 scenarios (67%) and within ± 2 mm in 320 of 336 scenarios (95%). With a threshold value of ≥ 1 mm, the overall diagnostic sensitivity for detecting overlengthening when it was present and was 90% and the specificity was 79%. The sensitivity was higher with increasing size of the prosthesis: in cases with overlengthening of 1.5 mm, the sensitivity was 76%, with an overlengthening of 3 mm, the sensitivity was 95%, and with an overlengthening of 5 mm, the sensitivity was 100%.

Conclusion The radiographic measurement method of Athwal et al. can be used to estimate and to diagnose the magnitude overlengthening of the MoPyC radial head prosthesis. However, the sensitivity is limited (76%) in cases with a small amount of overlengthening of 1.5 mm.

Keywords Elbow · Radial head prosthesis · Overstuffing · Fluoroscopy · Ulnohumeral · Joint gapping · Oversizing

Introduction

Reconstruction of the radial head in the context of complex instability of the elbow is an essential factor in restoring joint stability [11]. In principle, the aim is to achieve an anatomic reconstruction of the radial head by screw and/or plate osteosynthesis [13, 12]. If the fracture morphology precludes anatomic repositioning of the fracture, endoprosthetic replacement using a radial head prosthesis is another option [9, 21, 23]. One essential and technically demanding aspect of this option is the correct dimensioning of the radial head prosthesis [7, 22, 8]. Van Glabbeek et al. demonstrated that overlengthening of > 2.5 mm is associated with a nonphysiologic increase in pressure on the corresponding joint partner, the capitulum of the humerus [17]. Even if numerous papers on anatomical landmarks for correct dimensioning of the radial head prosthesis have been published, overlengthening remains to be significant problem in elbow surgery [5, 4, 18, 17]. Radial head prosthesis overlengthening can lead to pain, decreased elbow range of motion, and secondary osteoarthritis [19, 15]. Therefore, diagnosing the presence of overlengthening is of clinical importance. Athwal et al. published a radiographic method that allows to detect oversizing of ± 1 mm of the monopolar Evolve prosthesis (Wright medical, Tennessee, USA) with a high sensitivity of 97% by comparing the operated side with the contralateral elbow [1]. The aim of the present experimental study was to

✉ Jochen Franke
jochen.franke@bgu-ludwigshafen.de

[1] BG Trauma Center Ludwigshafen at the University of Heidelberg, Clinic for Trauma and Orthopaedic Surgery, Ludwig-Guttmann-Strasse 13, 67071 Ludwigshafen on the Rhine, Germany

validate the radiographic measurement method from Athwal et al. for the MoPyC radial head prosthesis.

Materials and methods

Specimen preparation and test protocol

Seven intact adult upper limbs from cadavera (mean age at the time of death, 74 years; range, 68–84 years) donated, for scientific research, to the Department of Anatomy of the Medical University of Graz under the approval of the Anatomical Donation Program of the University of Graz and embalmed with Thiel's method were investigated. This unique embalming procedure almost completely preserves tissue color and consistency [2, 3, 20]. The specimens were dissected from the scapula with the humerus, elbow, forearm, and hand left intact. Prior to their inclusion, the elbows were assessed radiographically and manually for pathological changes, range of motion, and stability. Each specimen was mounted on a custom-made radiolucent jig to control elbow flexion/extension and forearm rotation (Fig. 1) and was positioned to make it possible to obtain standardized anteroposterior radiographs during fluoroscopy. The humerus was then fixed with a threaded 4.0 mm Kirschner wire 20 cm above the elbow joint line. Elbow flexion/extension could be held in a fixed position to allow repeated measurements.

The measurements were taken in six different positions of the elbow: 80° pronation, neutral position, and 90° supination, each in 0° and 30° flexion of the elbow. The ulnohumeral joint space width was determined visually and radiographically in each stage and each position of the elbow.

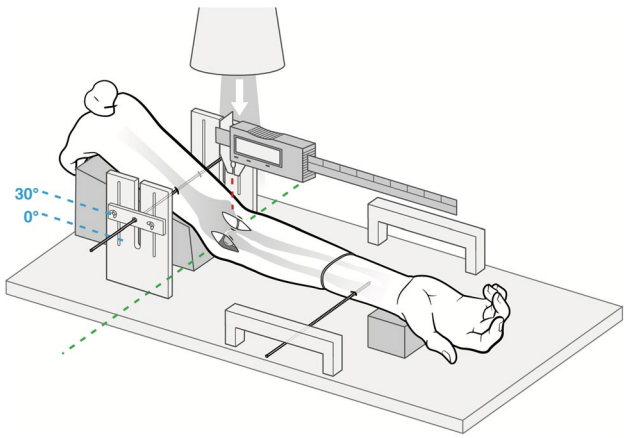

Fig. 1 Schematic illustration of the custom-made fixation device. In this example the elbow is held in 30° of flexion with 90° supination of the forearm. In each stage, the ulnohumeral joint space gapping was determined visually with an electronic gauge (red dotted line) and radiographically by fluoroscopy (white arrow)

The measurements were taken in ten different stages: on the native specimen (stage 1), after radial head resection of 15 mm (stage 2), and after implantation of monopolar, modular radial head prostheses of the MoPyC type (Biorofile, Tornier, Montbonnot-Saint-Martin, France) in four increasing sizes (correct length, overlengthening of 1.5 mm, 3 mm, and 5 mm) with an intact medial collateral ligamentous apparatus (MCL stages 3–6) and after transection of the MCL (stages 7–10). For access to the radial head, Kocher's approach involving preservation of the extensor tendons by longitudinal incision was performed and, if necessary, the radial ligament complex was sutured to achieve a stable elbow joint for the repeated measurements. For resection of the MCL, the Hotchkiss approach was used and the MCL completely dissected near the attachment at the humerus.

Visual measurement

Visual measurement of the ulnohumeral gapping was performed by two independent examiners [M.S. and F.F.] using an electronic gauge. An additional anterior access was created for visual measurement. A window to the ulnohumeral joint space was created between the brachial biceps muscle and the brachial muscle. To provide a good view of the ulnohumeral joint space, the anterior capsule was partially resected (Fig. 2).

Radiographic measurement

The radiographic measurement was performed by two independent examiners [M.S. and F.F.] using the method of Athwal et al. (Fig. 3). In the anteroposterior fluoroscopic image, the α angle is defined by two lines: the lowest point of the medial ulnar joint line (um) forms a line with the lateral ulnar border (ul) and a line with the humeral interface (h). The point h is obtained from the intersection of a perpendicular line to the yellow line through the point ul with the humeral joint surface.

Statistics

Means and standard deviations are given for continuous variables. The Bland and Altman technique that allows for graphical representation of the differences between the calculated and actual implant sizes across the spectrum of implants was conducted, and the mean error plus the two standard deviation limits around that error were portrayed. A standard contingency table was used to calculate the sensitivity, specificity, 95% Confidence intervals, standard error of the mean (SEM), and standard deviation (SD) for the accuracy of the measurement method for diagnosing radial overlengthening. The interrater and intrarater reliabilities of the radiographic and visual measurements were

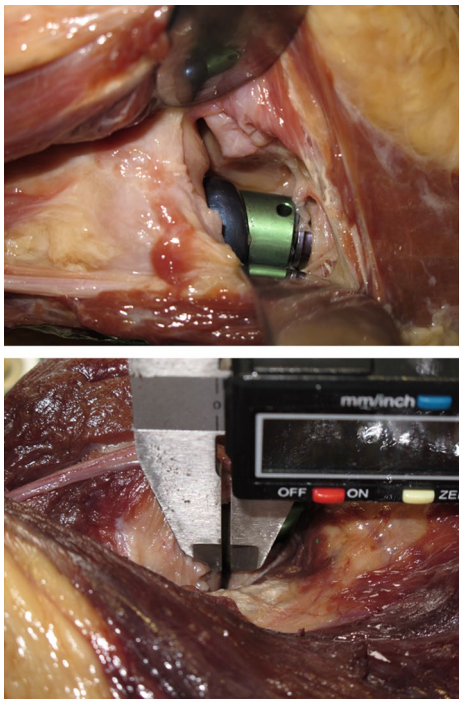

Fig. 2 Visual measurement of ulnohumeral gapping was performed using an electronic gauge through a ventrally created window on the lateral ulnar border (in the present example: 1.80 mm)

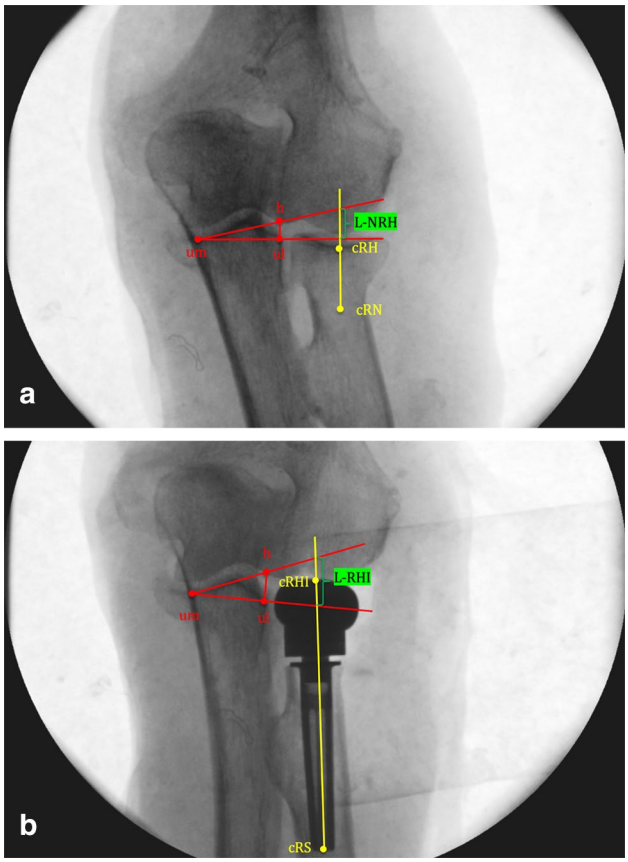

Fig. 3 **a** In the native elbow joint, the virtual length of the native radial head (L-NRH) was calculated. **b** After prosthetic replacement, the virtual length of the radial head implant (L-RHI) was measured. The magnitude of implant overlengthening is calculated with the formula: (L-RHI) − (L-NRH) = overlengthening in mm (cRH, center of the radial head; cRN, center of the radial neck; cRHI, center of the radial head implant)

analyzed using the intraclass correlation (ICC). The ICC was reported to indicate the agreement of the measurement results between two different people and the agreement of the measurements by one and the same person at two different timepoints. ICCs of <0.40 were regarded as poor agreement, between 0.40 and 0.59 as moderate agreement, between 0.60 and 0.74 as good agreement, between 0.75 and 0.89 as very good agreement, and >0.90 as excellent agreement.

Results

Interrater agreement of the visual measurement of the ulnohumeral gapping (0.996 [95% CI 0.994–0.998]) and of radiographic measurement (ICC 0.972 [95% CI 0.959–0.982]) between the two examiners was excellent. Intrarater agreement of the visual measurement of the ulnohumeral gapping (0.997 [95% CI 0.995–0.998]) and of the the radiographic measurement (ICC 0.984 [95% CI 0.975–0.990]) was also excellent.

When measured visually, the ulnohumeral gapping was negligible (0 ± 0 mm) in stages 1 and 2 and with correct length of the prosthesis (stages 3 and 7) (Fig. 4).

Through the stages 4–6 and 8–10, there was a significant increase of the ulnohumeral gapping. The mean gap in prosthesis with 1.5 mm of overlengthening and intact MCL was 0.7 ± 0.8 mm (stage 4), 3 mm overlengthening led to an ulnohumeral gapping of 1.6 ± 0.8 mm (stage 5), and 5 mm overlengthening resulted in an ulnohumeral gapping of 2.3 ± 0.8 mm. The transection of the MCL did not influence the amount of the ulnohumeral gapping in the respective stages (1.5 mm: 0.7 ± 0.8 mm; 3 mm: 1.6 ± 0.8 mm; 5 mm: 2.4 ± 0.8 mm). The visually measured ulnohumeral gapping did not differ among the elbow flexion of 0° and 30° and the forearm positions of pronation, supination, and neutral rotation at any stage ($p \geq 0.396$).

The radiographic measurement method correctly determined the size of the radial head prosthesis within ± 1 mm in 224 of 336 scenarios (67%) and within ± 2 mm in 320 of 336 scenarios (95%). The radiographic measurement method had a lower accuracy in predicting the actual size with increasing overlengthening: in prosthesis with correct length, the prosthesis length was precisely (± 1 mm) determined in 66 of 84 cases (79%), with an overlengthening of 1.5 mm in 58 of 84 cases (69%), with an overlengthening of 3 mm in 56

of 84 cases (67%), and with an overlengthening in 40 of 84 cases (48%). With the radiographic measurement method, there was a trend towards underestimating the actual prosthesis length (Fig. 5).

The estimated overlengthening and actual overlengthening were analyzed separately for each increment of actual overlengthening (Table 1). Mean values, standard error of mean, 95% confidence intervals, and standard deviation were calculated. With a threshold value of ≥ 1 mm, the overall diagnostic sensitivity for detecting overlengthening, when it was present, was 90% and the specificity was 79%. The sensitivity was higher with increasing size of the prosthesis:

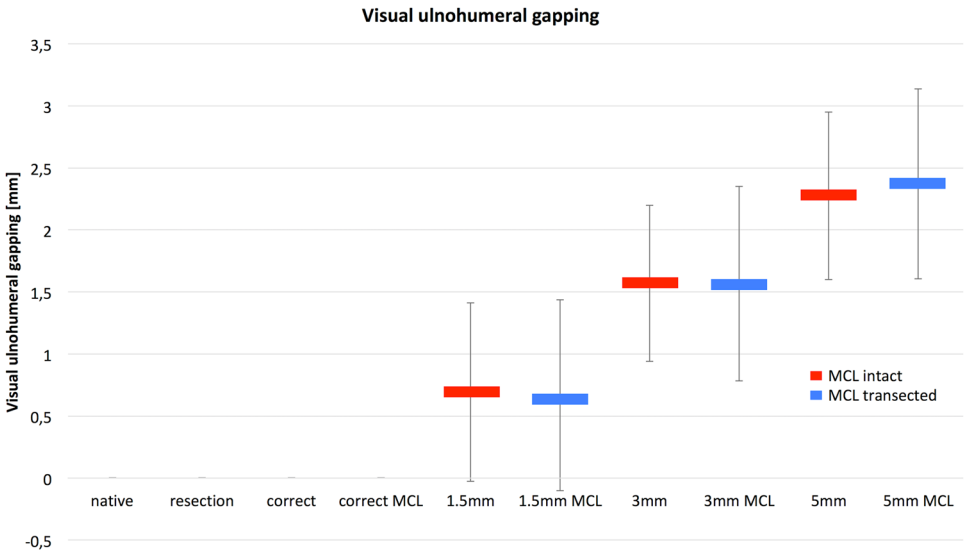

Fig. 4 Means and SD of visual ulnohumeral gapping

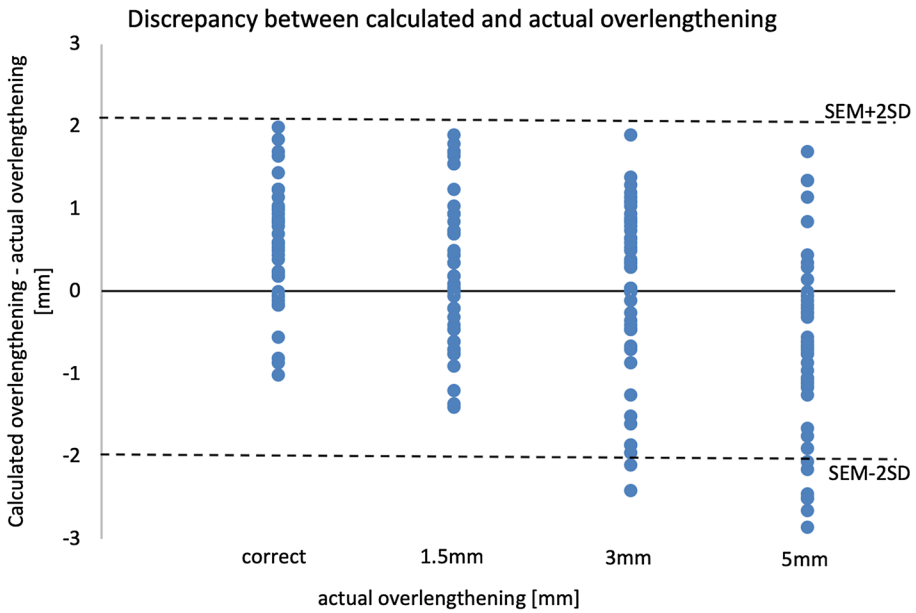

Fig. 5 Bland and Altman technique for visualization of the error between the estimated and actual implant sizes for each measurement performed

Table 1 Detailed results of the estimated overlengthening

Actual implant size	Estimated implant size	SEM	95% CI		SD
	Mean (mm)		Lower limit	Upper limit	
Correct	0.54	0.10	0.34	0.75	0.70
1.5 mm	1.80	0.13	1.54	2.06	0.90
3 mm	3.02	0.15	2.72	3.32	1.04
5 mm	4.29	0.16	3.98	4.60	1.08

in cases with overlengthening of 1.5 mm, the sensitivity was 76%, with an overlengthening of 3 mm, the sensitivity was 95%, and with an overlengthening of 5 mm, the sensitivity was 100%.

No significant difference for the estimated length of the prosthesis was found between stages with intact MCL and with transected MCL ($p \geq 0.657$). Furthermore, the values did not differ among the different elbow positions at any stage ($p \geq 0.388$).

Discussion

The determination of the correct prosthesis length for restoring the original anatomic relationships is an essential and technically demanding aspect of implanting the radial head prosthesis and continues to pose a relevant clinical problem [5, 4, 18, 17]. Determining the correct prosthesis size is an essential precondition for a good clinical outcome. In a retrospective analysis of our own patient population, overlengthening of the radial head prosthesis was shown to be associated with a significantly poorer clinical outcome as measured by the MEPS (63 ± 21 vs. 85 ± 9; $p = 0.001$) [15]. The complication rate (67% vs. 27%) and revision rate (47% vs. 13%) were also significantly increased in the presence of overlengthening of the radial head prosthesis ($p < 0.046$). The cadaver study of Van Glabbeek et al. reveals that the overlengthening of just 2.5 mm results in a measurable increase in pressure on the capitulum of the humerus, deemed responsible for the clinical symptoms such as pain and restricted movement, and predisposes to the development of early secondary osteoarthritis [17].

Various approaches to avoid overlengthening of the radial head prosthesis are described in the literature. In a cadaver study, Frank et al. assessed several parameters that may be used intraoperatively as a guide to the correct length of the radial head prosthesis [7]. In this context, intraoperative visualization of the lateral ulnohumeral joint space appears to be best suited as an anatomic landmark and reference for determining length. There is no ulnohumeral joint space gapping in the native radial head or after implantation of a radial head prosthesis of the correct length, which has been confirmed in the current study. However, with overlengthening of as little as ≥ 2 mm, ulnohumeral joint space gapping was already apparent. Frank et al., therefore, proposed visualizing the lateral ulnohumeral border intraoperatively with a dental mirror [7]. Due to the limited intraoperative visualizability of the lateral ulnohumeral border, alternative approaches to resolving this problem were already being sought in other studies.

Shors et al. investigated in a cadaver study whether conventional radiographs enable any existing overlengthening to be detected [16]. In the study, four different scenarios were tested: intact collateral ligaments, medial collateral ligament ruptured, lateral collateral ligament ruptured, and finally, lateral and medial collateral ligaments ruptured. In that study, no difference was found in the radiographic parameters recorded in prostheses overlengthened by as much as +4 mm.

In a further cadaver study of this issue, Rowland et al. investigated whether parallelism of the ulnohumeral joint represents a suitable radiographic parameter for detecting overlengthening of the radial head prosthesis [14]. In this study, the authors were able to show that asymmetry of the ulnohumeral joint space does not occur until overlengthening of 6 mm and this radiographic parameter is, therefore, unsuitable.

Moon et al. investigated whether a measuring template constitutes a suitable tool for determining the correct dimensioning of a radial head prosthesis on radiographs [10]. The authors were able to show that a measuring template represents a reliable tool for determining the size and length of the radial head prosthesis. It should, however, be noted that this procedure was only validated on intact specimens.

In 2011, Athwal et al. have described a radiographic measurement method for the assessment of overlengthening of the monopolar Evolve prosthesis (Evolve Proline; Wright Medical Technology, Arlington, Tennessee, USA) [1]. This method was validated in a cadaveric study, and this method was able to predict the implant size ±1 mm in 104 (87%) of the 120 scenarios tested. The sensitivity of the technique to correctly identify overlengthening (within ±1 mm) was 98%.

Burkhardt et al. used this method of Athwal et al. for a bipolar radial head prosthesis (CRF-II®-Prosthesis, Floating Radial Head Prosthesis; Tornier, Saint-Ismier, France) in a cadaveric study [22]. With a sensitivity of only 61%, the authors concluded that this method was not reliable for ruling out or quantifying overlengthening of the tested bipolar prosthesis.

In the current study, the overall sensitivity for diagnosis overlengthening was 90% and the specificity was 79%. Detailed analysis revealed that an overlengthening of 3 mm and 5 mm could be diagnosed with a high sensitivity of 95% and 100%, respectively. However, it should be noted that in cases with smaller amount of overlengthening of 1.5 mm, the sensitivity was lower (79%). Athwal et al. reported better overall accuracy for their measurement method, even if both prosthesis types are monopolar. In the study of Athwal et al., the sensitivity for detecting overlengthening was 97%. This might be related to the study setup, as Athwal et al. have used prosthesis with a higher magnitude of overlengthening starting with +2 mm, followed by +4 mm, +6 mm, and +8 mm. Beside this, the accuracy was not reported separately for each stage of overlengthening.

This current study is limited by the cadaver setup and the fact that even though the common extensor and flexor tendons were left intact, the model lacked the input from the dynamic stabilizers of the elbow. In addition, it should be noted that the Thiel-embalming method is not commonly utilized for specimens in orthopedic ligamentous sectioning studies. There has been controversy over whether there is a potential for mechanical degradation of ligaments due to the Thiel-embalming method [6]. In the current study, implantation of a radial head prosthesis with an overlengthening of 5 mm was possible without detaching the extensor tendons. This might be related to the Thiel-embalming method. However, Völllner et al. reported that stiffness of the medial and lateral ligament complexes in the knee was comparable between cadavers embalmed with the Thiel method and living patients undergoing total knee arthroplasty and, therefore, concluded that Thiel fixation seems to preserve the soft-tissue, so that they are similar to those in vivo [20]. The current study is also limited by the fact that the elbow was mounted on a custom-made fixation device. This was done for reasons of repeatability, but it does not completely resemble clinical conditions.

Conclusions

The radiographic method of Athwal et al. was found to be reliable to detect overlengthening of the MoPyC radial head prosthesis. Therefore, this radiographic method might be helpful to rule out the presence of overlengthening in postoperative controls. However, the sensitivity is limited (76%) in cases with a small amount of overlengthening of 1.5 mm.

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Compliance with ethical standards

Conflict of interest The radial head prostheses for this cadaver study were provided by Fa. Wright/Medical. No company had any input into the study design, protocol, testing, data analysis, or manuscript preparation. The authors, their immediate families, and any research foundations 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.

Ethical approval Ethical Committee Approval was obtained: no. 837.297.17(11131).

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