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Original article

Hinged elbow fixator: An extracorporeal technique to position the hinge based on an original guidewire device[☆]

Fixateur externe articulé de coude : une technique extracorporelle pour positionner la charnière basée sur un viseur original

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Abstract

Introduction. – The application of a hinged elbow external fixator is technically demanding because the hinge axis must coincide exactly with the flexion–extension axis of the elbow. The standard technique involves inserting a 3-mm K-wire freehand into the distal humerus to materialize the flexion–extension axis. We designed a guidewire device for extracorporeal hinge positioning without K-wire insertion. In a cadaver study, we compared freehand K-wire insertion and our extracorporeal technique.
Methods. – In 12 cadaveric elbows, we induced acute elbow instability by sectioning the medial collateral ligament complex and the anterior and posterior capsule. A hinged external fixator was applied to each elbow using both techniques. The outcome measures were procedure duration, number of image-intensifier shots (as a measure of radiation exposure), and passive motion range after fixator implantation.
Results. – Compared with the freehand K-wire technique, the extracorporeal technique provided greater motion range and significantly lower values for procedure duration and number of image-intensifier shots. Data dispersion was less marked with the extracorporeal technique, indicating better reproducibility.
Conclusion. – The extracorporeal technique based on a guidewire device enabled non-invasive positioning of a hinged elbow external fixator. This technique was faster, less irradiating, and more reproducible than the freehand K-wire technique.

Keywords: External fixator; Elbow instability; Elbow dislocation

Résumé

Q4 *Introduction.* – La mise en place d'un fixateur externe de coude à charnière et techniquement exigeante, car il faut que l'axe de la charnière coïncide exactement avec l'axe de flexion–extension du coude. La technique standard nécessite l'insertion d'une broche de Kirchner de 3 mm à main levée dans l'extrémité distale de l'humérus pour matérialiser l'axe de flexion–extension. Nous avons mis au point un fil guide pour la mise en place d'une charnière extracorporelle sans recourir à l'insertion d'une broche de Kirchner. Dans une étude cadavérique, nous avons comparé l'insertion d'une broche de Kirchner à main levée et notre technique extracorporelle.
Méthodes. – Sur 12 coups de deux cadavres, nous avons créé une instabilité aiguë du coude par la section du complexe ligamentaire collatéral médial, et de la capsule antérieure et postérieure. Un fixateur externe à charnière a été mis en place sur chaque coude en utilisant les deux techniques. Les mesures réalisées ont été la durée de la procédure, le nombre de coups d'amplificateurs de brillance (figurant l'exposition aux radiations) et l'amplitude de mobilités passives après l'implantation du fixateur.

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Résultats. – En comparaison avec la technique utilisant l'insertion d'une broche de Kirchner à main levée, la technique extracorporelle permettait une plus grande mobilité du coude au prix de valeur significativement plus basse pour la durée de la procédure et le nombre de coups d'amplificateurs de brillance. La dispersion des données était moindre avec la technique extracorporelle, indiquant une meilleure reproductibilité.
Conclusion. – La technique extracorporelle, grâce a un outil guide-broche, a rendu possible le positionnement moins invasif d'un fixateur externe de coude à charnière. Cette technique était plus rapide, moins irradiante et plus reproductible que la technique d'insertion d'une broche de Kirchner à main levée.

Mots clés : Fixateur externe ; Instabilité du coude ; Luxation du coude

1. Introduction

The humeroulnar joint is a trochlear joint allowing flexion–extension around a single rotation axis, which has been well defined by previous biomechanical studies [1,2]. On a lateral view, this axis can be represented as a dot in the center of the radioscopic projection of the trochlea. Hinged elbow external fixators (HEEF) were developed many years ago [3,4] to maintain congruency in flexion and extension of both the humeroulnar and humeroradial joints. HEEF enable early postoperative elbow rehabilitation and result in better final range of motion [5–8].

Several HEEF are available on the market, and each has a number of distinctive features [5,7,9,10]. However, with all HEEF, the flexion–extension axis of the elbow must be accurately aligned with the axis of the hinge. The standard procedure to achieve alignment is freehand insertion of a K-wire into the distal humeral epiphysis to materialize the flexion–extension axis of the elbow. However, accurate K-wire positioning is challenging. Faulty K-wire positioning leads to malalignment of the HEEF and therefore carries a risk of abnormal elbow kinematics with motion range limitation. Moreover, difficulty in K-wire positioning may increase both the duration of the procedure and the amount of radiation exposure.

We have developed an extracorporeal technique for positioning the hinge without inserting a K-wire. Our technique is based on an original guidewire device developed in our department.

The purpose of this cadaveric study was to compare the standard freehand K-wire technique with our extracorporeal technique. We evaluated these two techniques based on three outcome measurements: passive motion range after HEEF implantation, procedure duration, and radiation exposure.

2. Material and methods

2.1. Specimens

We used the 12 upper limbs of six cadavers. Median age at death was 75 years (range, 71–85). The specimens were thawed 24 hours before the beginning of the experiment. Each specimen underwent a clinical and fluoroscopic examination to rule out the exclusion criteria: fracture, dislocation, previous surgery, malunion, and abnormal range of flexion–extension or pronation–supination of the elbow.

2.2. Study procedure

Pins were inserted into the humerus and ulna of each elbow and left in the same position throughout the experiment (Fig. 1). Elbow instability was induced by severing the medial collateral ligament and the anterior and posterior capsule (Fig. 2). The HEEF was the DJD II™ (Stryker, Kalamazoo, MI, USA). The hinge was positioned and connected using the freehand K-wire technique and the extracorporeal technique in succession, in random order, with six specimens in each group.

To assess the efficacy of the hinge positioning technique, we used three outcome measures, namely, number of image-intensifier shots (taken as a measure of radiation exposure, as the same shot duration was used for all shots), procedure duration, and range of passive flexion–extension with the hinge in place. Procedure duration was measured as the time required to position and connect the hinge, in seconds, using a chronometer. Passive range of flexion–extension was measured by two independent observers who used a universal standard goniometer placed in contact with the lateral aspect of the upper limb, as described by Armstrong et al. [11]. The goniometer was centered on the lateral epicondyle and used to measure maximal flexion and extension produced by gravity alone.

Each procedure was performed by the same three surgeons who had an experience of at least five implantations of HEEF.

2.3. Description of the freehand technique

Fluoroscopic guidance using two views, namely antero-posterior and strict lateral, was used to insert a 3-mm K-wire freehand into the distal humerus, to materialize the flexion–extension axis. When at least two of the three surgeons performing the experiment felt the K-wire was not correctly positioned, based on their subjective reference in both fluoroscopic views, a second attempt was made. Insertion attempts were stopped when K-wire position was deemed satisfactory by at least two of the surgeons. However, when it proved impossible to prevent the K-wire from following one of the tunnels created by previous attempts, suboptimal K-wire position was accepted. Correct K-wire position was defined based on two criteria:

- on the strict lateral view, visualization of the K-wire as a dot in the center of the fluoroscopic projection of the trochlea;

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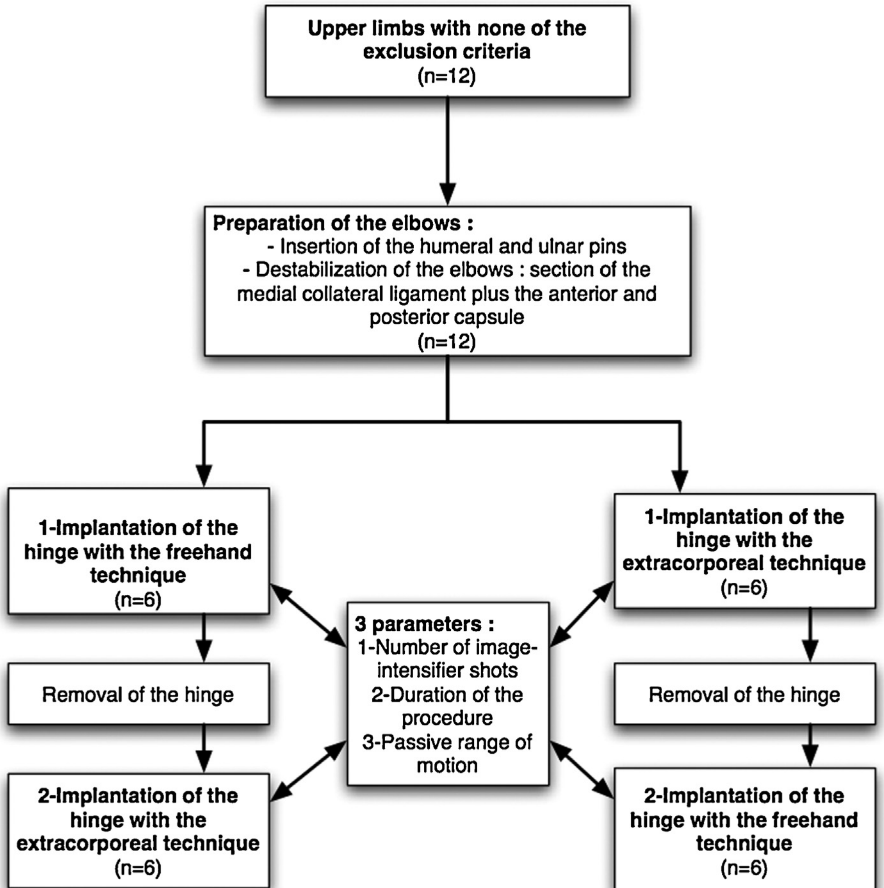

Fig. 1. Flowchart diagram detailing the protocol of the study.

- on the antero-posterior view, K-wire passing through the tip of the lateral epicondyle and tangent to the inferior edge of the medial epicondyle [1,2].

The perforated hinge was positioned on the K-wire and connected to the humeral and ulnar pins.

2.4. Description of our device and extracorporeal technique

The device is composed of two connected pieces (Fig. 3): a suction pad that securely attaches the device to the C-arm and a rigid open frame. The superior part of the frame is a cylinder and the inferior part is a flat surface bearing a small fluoroscopic cross-shaped marker. Three axes must be aligned: the intrinsic axis of the device, the axis of the C-arm, and the flexion–extension axis of the elbow. The intrinsic axis of the device runs through the cylinder and fluoroscopic cross-shaped marker. The C-arm axis is the axis of the central X-ray beam emitted by the image-intensifier. The flexion–extension axis of the elbow runs through the center of the circular fluoroscopic projection of the trochlea. Alignment of the axis of the device with the axis of the C-arm is achieved by placing the fluoroscopic projection of the cross-shaped marker at the center of the image (Fig. 4).

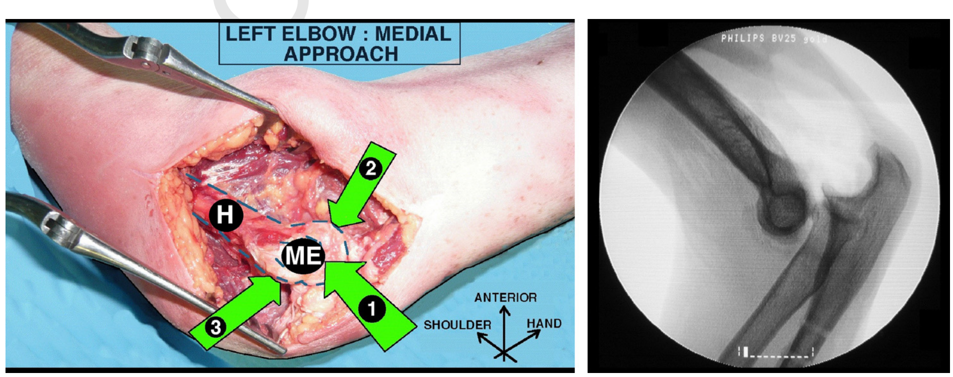

Fig. 2. A and B. A medial approach allowed sectioning the medial collateral ligament (1) as well as the anterior (2) and posterior (3) parts of the capsule (A). The so induced instability was confirmed thanks to a fluoroscopic view (B). ME: medial epicondyle; H: humerus.

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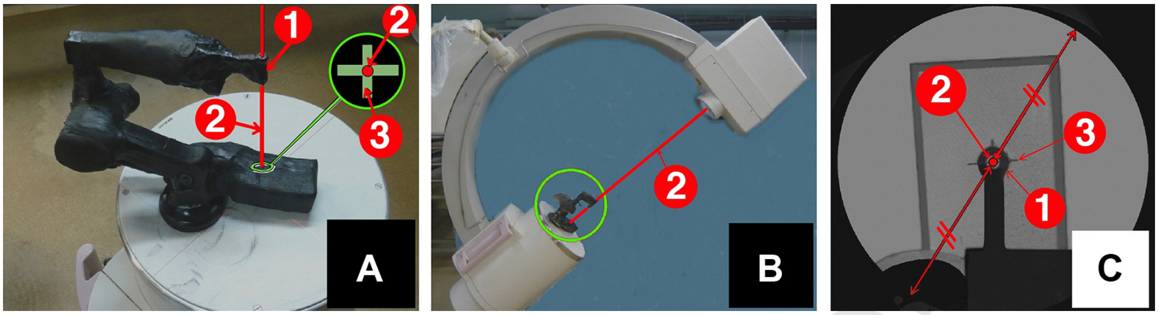

Fig. 3. A–C. Description of the device. The device is attached to the C-arm thanks to a suction pad. The superior part of the open frame is a cylinder (1) while the inferior part is a flat surface bearing a small fluoroscopic cross-shaped marker (3) (A). When properly positioned, the intrinsic axis of the device and the central X-ray beam (2) are aligned (B). Fluoroscopic view showing the alignment of the axis (i.e. the cross-shaped marker appears centered on the projection of the cylinder) (C).

Then, the axis of the device is aligned with the elbow's flexion–extension axis using the humeral pins of the fixator as a joystick to obtain a strict lateral fluoroscopic view of the distal humerus. A K-wire is slipped into the cylinder and into the perforated hinge of the fixator. The K-wire remains outside the elbow. Finally, the hinge is attached to the humeral and ulnar pins.

2.5. Statistical analysis

Statistical analyses were performed using R software [12] (http://CRAN.R-project. org/doc/FAQ/R-FAQ.html; ISBN 3-900051-08-9) (R). Values were described as medians with the interquartile range (IQR). Dispersion was assessed by

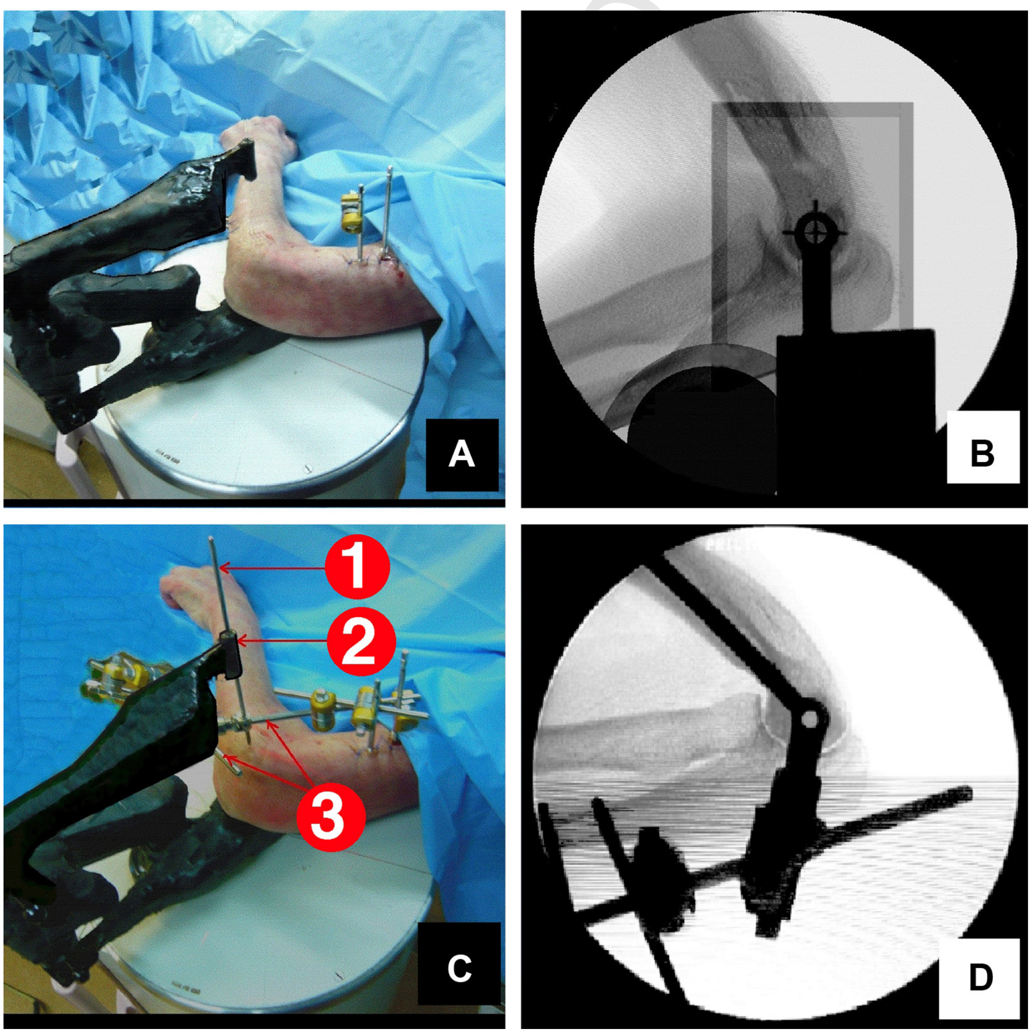

Fig. 4. A–D. Description of the technique. The elbow is positioned in the open frame (A). Strict lateral view of the elbow in the open frame with alignment of both the elbow and device axes (B). A K-wire (1) is introduced into the cylinder (2) to materialize the aligned axes. It remains extracorporeal. The hinge of the external fixator (3) can be positioned thanks to the K-wire (C). Final lateral view of the hinge and the reduced elbow (D).

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computing the standard deviations (SD). Because the data were not normally distributed, paired nonparametric Wilcoxon tests were used to compare the three outcome measurements with each technique. For the range of flexion–extension, the correlation between the two observers was tested using the Spearman correlation test.

3. Results

Position of the K-wire was deemed satisfactory in seven of the 12 freehand procedures. In five of the 12 procedures, it proved impossible to prevent the K-wire from following one of the tunnels created by previous attempts which the positions, although close to the correct position, were not considered optimal (e.g. suboptimal position). The number of attempts before stating that it was impossible to prevent the K-wire from following one of the tunnels previously created was five in three cases and six in two cases.

3.1. Procedure duration

The procedure was significantly ($P = 0.00049$) shorter with the extracorporeal technique (633 s, 629 s–639 s) than with the freehand technique (731 s, 697 s–782 s) (Table 1) (Fig. 5). Dispersion of the values was less marked with the extracorporeal technique than with the freehand technique (SD, 7.6 s and 69.5 s, respectively).

3.2. Number of image-intensifier shots

The number of shots required to perform the procedure was significantly ($P = 0.006$) smaller with the extracorporeal technique (13, 12–14) compared to the freehand technique (20, 17–26) (Table 2) (Fig. 6). Dispersion of the values was less marked with the extracorporeal technique than with the freehand technique (SD, 2 and 6.1 s, respectively).

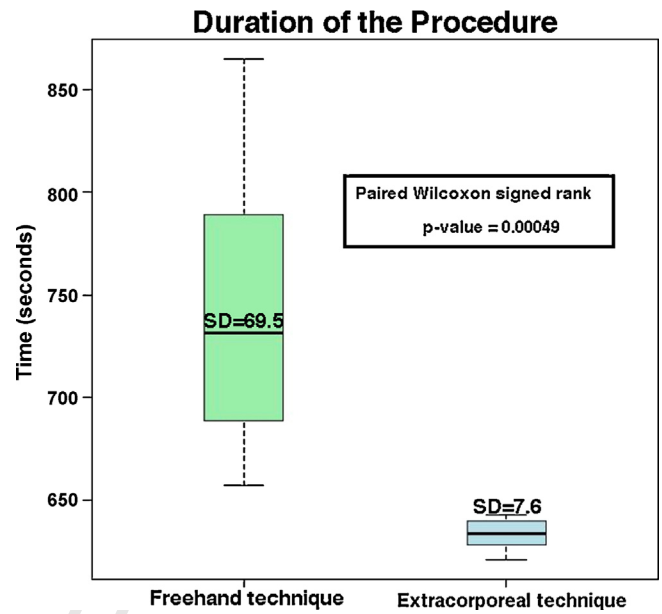

Fig. 5. Duration of the procedure. SD: standard deviation.

3.3. Passive range of flexion–extension

Maximal flexion was significantly ($P = 0.022$) greater with the extracorporeal technique (135°, 133°–136°) compared to the freehand technique (129°, 123°–134°) (Table 3) (Figs. 7 and 8). Maximal extension was also significantly ($P = 0.015$) better with the extracorporeal technique (4° of flexion, 3°–5°) compared to the freehand technique (6° of flexion, 4°–10°). The Spearman correlation coefficient between the two observers was 0.94 for flexion and 0.85 for extension. Dispersion of the values was less marked with the extracorporeal technique than with the freehand technique for both

Table 1
Duration of the procedure for each technique and each elbow.

Specimens	Duration of the procedure (sec)	
	Freehand technique	Extracorporeal technique
Elbow 01	662	639
Elbow 02	776	626
Elbow 03	732	643
Elbow 04	865	631
Elbow 05	771	643
Elbow 06	657	639
Elbow 07	731	623
Elbow 08	802	634
Elbow 09	853	641
Elbow 10	706	621
Elbow 11	728	630
Elbow 12	671	633
Median	731.5	633.5
IQR 25th percentile	697.25	629
IQR 75th percentile	782.5	639.5
Standard deviation (sec)	69.6	7.6

IQR: interquartile range.

Table 2
Number of image-intensifier shots for each technique and each elbow.

Specimens	Freehand technique	Extracorporeal technique
	Number of image-intensifier shots	Number of image-intensifier shots
Elbow 01	15	13
Elbow 02	22	12
Elbow 03	19	14
Elbow 04	31	13
Elbow 05	27	15
Elbow 06	16	16
Elbow 07	18	11
Elbow 08	25	12
Elbow 09	32	18
Elbow 10	17	11
Elbow 11	21	13
Elbow 12	14	14
Median	20	13
IQR 25th percentile	16.75	12
IQR 75th percentile	25.5	14.25
Standard deviation	6.1	2.06

IQR: interquartile range.

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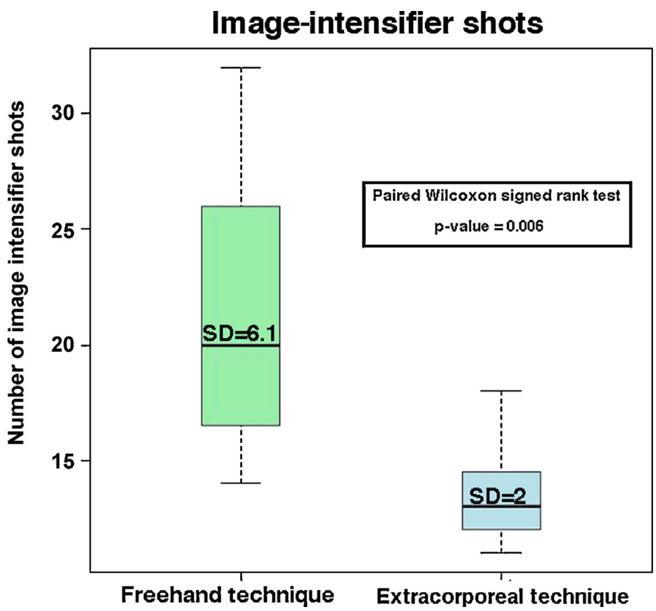

Fig. 6. Number of image-intensifier shots. SD: standard deviation.

maximal flexion (SD, 2.8° and 6.1°, respectively) and maximal extension (SD, 1.6° and 7.3°, respectively).

4. Discussion

We developed an original guidewire device for extracorporeal positioning of the hinge of an articulated elbow fixator. Compared to the standard freehand technique requiring an intra-osseous K-wire, the extracorporeal technique was faster and decreased radiation exposure. Moreover, reproducibility and range of motion were better with the extracorporeal technique compared to the freehand technique.

HEEF, when applied properly, allows early postoperative mobilization of the elbow while providing articular stability [13]. Hence, it is indicated when the elbow's stability is compromised, either in case of acute complex instability of the elbow [7–9,14,15] or in chronic settings [16,17] (i.e. elbow instability resulting from surgical release of severe joint contracture). All clinical studies show favorable outcomes using HEEF but experimental biomechanical studies emphasize the importance of correct hinge placement and the technical difficulty to accurately align the rotation axis of both the elbow and the hinge [18–21]. Malalignment of the hinge would generate abnormal joint kinematics, incongruous articulation and elbow instability. Increased stress induced by the abnormal kinematic of the elbow-HEEF-pin construct may be transferred to the pin-bone interface and could be accountable for pin breakage, pin loosening and persistent instability reported by several authors [22].

With the freehand technique, the K-wire must be removed if the initial insertion attempt fails to achieve proper positioning. Removal of the K-wire leaves a tunnel in the cancellous bone, which the K-wire tends to re-enter during subsequent attempts. Consequently, an important goal is to keep the number of attempts as low as possible. With the freehand technique, a suboptimal K-wire position was accepted in five cases. With our extracorporeal technique, no wire needs to be inserted into the distal humerus. Therefore, there is no restriction on the number of attempts that can be performed to achieve optimal HEEF position.

The dispersion of values for maximal flexion, maximal extension, procedure duration, and number of image-intensifier shots was greater with the freehand technique than with the extracorporeal technique. This suggests that our device improves the reproducibility of HEEF positioning. Further studies will be needed to look for a learning curve, which was not evaluated in this study.

Previous implantation of surgical material (screw or lateral plate) on the distal humerus can impede K-wire insertion. With the extracorporeal technique, in contrast, the only requirement

Table 3
Range of motion of the elbows with each technique, measured by the two observers.

	Freehand technique				Extracorporeal technique			
	Maximal Extension		Maximal Flexion		Maximal Extension		Maximal Flexion	
	Observer n° 1	Observer n° 2	Observer n° 1	Observer n° 2	Observer n° 1	Observer n° 2	Observer n° 1	Observer n° 2
Elbow 01	5	6	135	133	0	2	137	135
Elbow 02	18	16	125	123	4	5	135	134
Elbow 03	4	5	130	128	6	4	132	131
Elbow 04	20	21	121	123	3	4	138	136
Elbow 05	17	19	123	125	5	6	139	137
Elbow 06	4	5	136	134	5	4	134	134
Elbow 07	3	3	137	135	4	5	135	136
Elbow 08	3	4	130	130	3	4	131	132
Elbow 09	19	18	120	121	6	7	129	131
Elbow 10	6	7	138	137	2	4	135	136
Elbow 11	5	6	134	130	4	6	135	134
Elbow 12	18	20	122	123	5	7	140	138
Median	5.5	6.5	130	129	4	4.5	135	134.5
Standard deviation (SD)	7.3	7.1	6.7	5.5	1.7	1.5	3.2	2.3
Mean SD	7.2		6.1		1.6		2.8	

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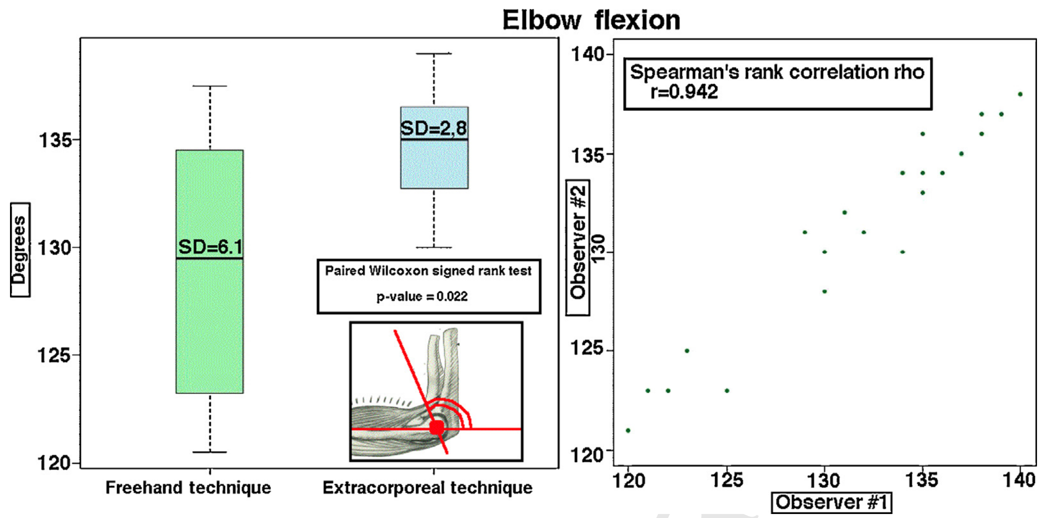

Fig. 7. Elbow flexion and correlation between measurements by the two observers. SD: standard deviation.

for HEEF implantation is preservation of trochlea morphology on the fluoroscopic views.

Both techniques assessed in our study require the best possible alignment of the flexion–extension axis and the guidewire device (extracorporeal technique) or K-wire (freehand technique). With the freehand technique, the hinge axis is guided by the K-wire inserted from the lateral to the medial side of the distal humerus. The projections of divergent K-wire directions on the lateral view appear very similar at the lateral elbow compartment (Fig. 9), which creates difficulties in determining the correct direction. Conversely, the correct direction appears clearly when the K-wire reaches the medial elbow compartment. However, the entry point in the lateral compartment is easy to pinpoint but the exact exit point in the medial compartment may be difficult to determine. Yet, the medial compartment supports the humeroulnar joint, which plays a crucial role in flexion–extension. With the extracorporeal technique, the hinge axis is automatically aligned with the device axis, which passes through the cylinder and cross-shaped marker. Because this marker is on the medial side of the elbow, the device enables greater accuracy of alignment of the device axis and flexion–extension axis. This point may contribute to explain the greater range of motion with the extracorporeal technique. Analysis of literature reveals that techniques used to align both the axis of the hinge and the elbow can be classified depending on whether a K-wire is used or not (i.e. intracorporeal or extracorporeal technique), whether the position of the axis at the level of the medial compartment is determined or not, and whether the axis is found with surgical anatomical landmarks, fluoroscopic landmarks or navigation. For instance, Ring et al. [16] used a K-wire and determined its entry and exit points thanks to a combined medial and lateral approach. Edigy et al. [18] have used navigation to determine the entry and exit points of a K-wire inserted from lateral to medial. Von Knoch et al. [15] have used an extracorporeal technique (i.e. no K-wire insertion) based on the use of a strictly

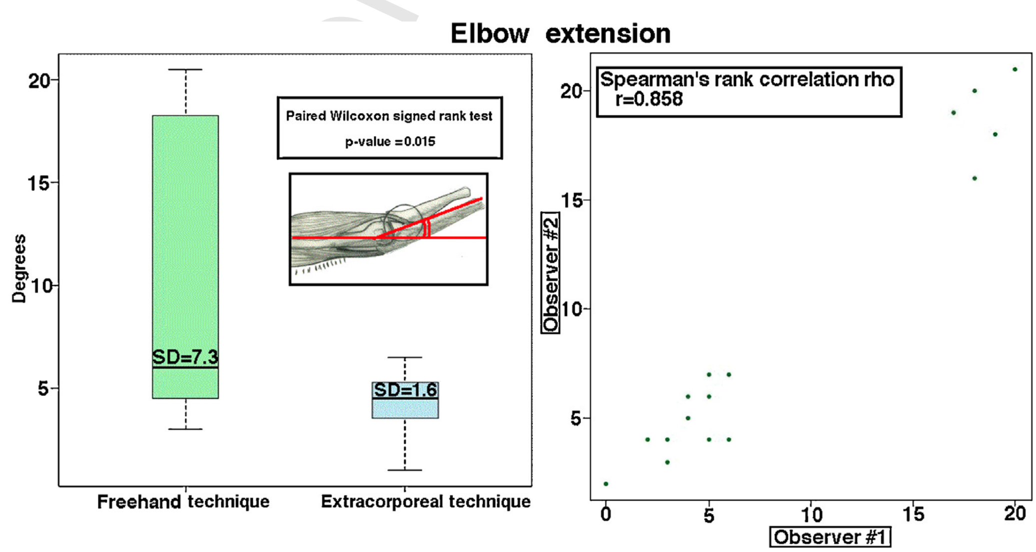

Fig. 8. Elbow extension and correlation between measurements by the two observers. SD: standard deviation.

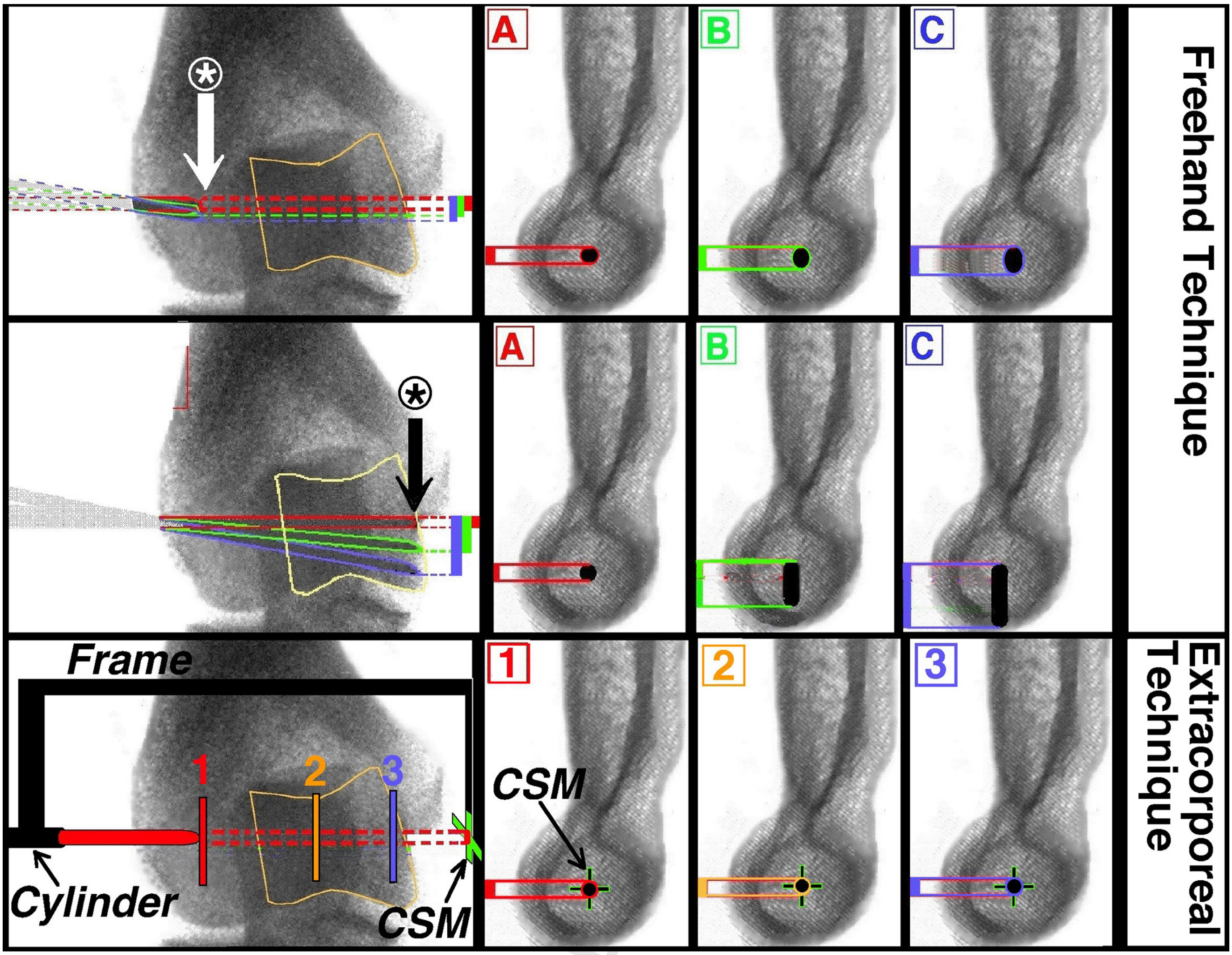

Fig. 9. Geometrical description of the issue raised by the K-wire insertion. Upper line. Schematic representation of three different directions (red, green, purple) of the K-wire close to the insertion point (i.e. lateral compartment). The fluoroscopic projections of each direction (A–C) are very similar and it is difficult to distinguish the optimal direction from eccentric directions. Middle line. The same three directions and their fluoroscopic projections when the K-wire reaches the medial compartment. The divergence of the eccentric directions in respect to the optimal one becomes obvious. However, changing the position of the probe becomes challenging at this point. Lower line. With the extracorporeal device, the cross-shaped marker (CSM) guarantees that the axis is correctly positioned in both the lateral and medial compartment.

lateral marker allowing precise determination of the entry point only. Our technique combines an extracorporeal technique with the control of both entry and exit points under fluoroscopic guidance (Fig. 9). It is difficult to compare the range of motion obtained in our study with those reported in clinical studies since our model did not include the active action of muscles and the subsequent stiffness induced by healing process. However, the present cadaveric model was sensitive enough to show a significant difference between the freehand and the extracorporeal techniques and the range of motion obtained is compatible with a very good function of the elbow. Considering the irradiation, we found a significant decrease when using the extracorporeal technique but unfortunately we did not find any other study assessing this parameter which makes comparison impossible.

Our technique and our study have a number of limitations. With the freehand technique, the flexion–extension axis and hinge axis are mechanically aligned with the K-wire. With the extracorporeal technique, these axes are aligned based on the fluoroscopic projections, which may be unstable. Moreover, insertion of the humeral and ulnar pins generates erratic movements that may upset the alignment. Therefore, the pins should be inserted before the extracorporeal technique is performed. In contrast, with the freehand technique, the K-wire and therefore the hinge are positioned first. While the main difficulty in the freehand technique consists in placing the K-wire properly, the most difficult part in the extracorporeal technique is connection of the pins with the hinge without changing the axis alignment. This implies that surgeons anticipate the proper placement of the pins when they use the extracorporeal technique. To compensate for this technical difficulty, the HEEF must be as modular as possible.

Both techniques require strict lateral fluoroscopic views of the elbow. In clinical practice, in patients with shoulder

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stiffness, a strict lateral view is difficult to obtain without rotating the C-arm around the patient's elbow. Our device is fastened to the C-arm by a suction pad. Thus, the C-arm and device can be rotated together to compensate for motion range limitation in the shoulder.

5. Conclusion

In this cadaveric study, we compared our extracorporeal technique with the classical freehand technique for HEEF positioning. The extracorporeal technique based on our original guidewire device allows faster HEEF positioning and connection, with less radiation exposure, compared to the standard freehand technique. Moreover, our results show that the extracorporeal technique provides greater range of motion and better reproducibility.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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