The elbow axis before and after total elbow replacement
M. Stokdijk, J. Nagels, E.H. Garling, P.M. Rozing
Department of Orthopaedics, Leiden University Medical Center, Leiden, The Netherlands

Introduction
The kinematic axes of ten embalmed elbows were determined before and after placement of the iBP elbow endoprosthesis using the iBPTM Elbow System (Biomet, Inc, Warsaw, Indiana, USA). Reconstruction of the normal kinematic axis during surgery is considered to be of importance, because a deviating axis may result in a changed movement pattern of the forearm with respect to the upper arm and changed moment arms of muscles crossing the elbow, which can have far-reaching consequences for the functional outcome (Schuind et al., 1995). Furthermore, changing the kinematic pattern towards the structural limits of an implant can lead to high stresses at the bone-cement-implant interface, which can lead to aseptic loosening (Schuind et al., 1994).

Methods
Ten embalmed upper extremities with intact soft tissues were measured with the calibrated Flock of Birds® (FoB) (Meskers et al. 1999) 3D electromagnetic measurement system. First, five scapular bony landmarks (acromial clavicular joint, coracoid process, acromial angle, trigonum spinae, and the inferior angle) and two humeral bony landmarks (the lateral and medial epicondyle (EM and EL)) were measured with a sensor serving as a spatial digitizer. The bony landmarks were related to the scapular sensor (S1, figure 1) and humeral sensor (S2) respectively. Subsequently, the movement of the forearm with respect to the upper arm was registered during controlled passive flexion and extension, using the ulnar sensor (S3) and the humeral (S2) sensor. Results were expressed in a humeral coordinate system (X, Y, Z), defined with EM, EL, and the glenohumeral joint rotation centre (GH). The origin of the coordinate system was between EM and EL:

\[
Y = \frac{GH - (EM + EL)}{2} \\
Z = Y \times \frac{EL - EM}{|EL - EM|} \\
X = Y \times Z
\]

GH was calculated with a regression method (Meskers et al. 1998), using the five scapular bony landmarks. For each elbow an optimal helical axis was calculated with the piercing in x=0 (Woltring 1990, Stokdijk et al. 1999, 2000). After an arm was measured with the FoB, an experienced orthopaedic surgeon (senior author) inserted the iBPTM elbow endoprosthesis according to the guidelines of the manufacturer using standard instrumentation for humeral component alignment. Subsequently, the measurements and data analysis procedures were repeated.
Results & Discussion

*Embalmed arms*

The axes after surgery could be compared to the kinematic axes of the intact elbows. The drawback was, that there was no active movement pattern. As a consequence, the calculated axes in underlying study can deviate from the kinematic axes in the active moving elbow in vivo. This is however of no concern for this study, because the point of interest was whether or not the measured axis before and after placement of an endoprosthesis remained the same. The study could not be performed in vivo because the pre-operative elbow in patients offers, due to destruction of the joint, no normal pre-operative kinematic axis.

![Figure 2a and 2b](image)

**Figure 2a and 2b**

*Position of the kinematic axes on the y-axis*

The post-operative position of the axis on the y-axis with respect to the pre-operative position are shown in the figure 2a. The pre-operative position is set to zero, this way the differences could be studied. Nine out of ten axes were located more distal after surgery (mean difference 7.0 mm, p = 0.004). When an elbow joint is replaced in vivo, severe destruction in the elbow is common especially in the elbows of patients with rheumatoid arthritis. This implicates that the endoprosthesis will be situated more proximal in affected elbows, due to deficient bone stock of the distal humerus. So, the distal displacement is expected to be smaller in patients compared to the embalmed arms used in this study. The kinematic and functional consequences are expected to be minimal (based on findings of Schuind et al., 1995).

*Position of the kinematic axes on the z-axis*

The positions of the post-operative kinematic axes on the z-axis, relative to the pre-operative axes are presented in figure 2b. The z-coordinate of the kinematic axis was not significantly different (mean difference 0.6 mm, p = 0.748) before and after surgery. There was however, a high standard deviation (6.1 mm) and a wide range in the differences between pre- and post-operative axes (from 10.4 mm displacement in dorsal to 10.5 mm in ventral direction). This reflects the difficulty to control ventral-dorsal displacement. Small adjustments of a setscrew on the alignment tool led to a changed kinematic axis in ventral-dorsal displacement. Another reason of the positional variation is that it is by definition not possible to reproduce the exact location of the kinematic axis using an alignment tool that is not individually adjustable. An alignment tool that can be adjusted to the anatomy of each individual elbow is required to accurately reproduce the position of the pre-operative kinematic axis.
Figure 3a and 3b

Direction of the kinematic axes
There were no significant differences in the direction of the elbow axes before and after placement of the endoprosthesis (p = 0.533, p = 0.333 and p = 0.616 for rotation about the x-, y- and z-axis). The small standard deviations in the differences (3.2°, 3.4° and 3.9° for the rotation about the x-, y- and z-axis) show that there was also little individual variation (figure 3a and b).

In conclusion it can be stated that the iBP™ Elbow System enables an experienced surgeon to reconstruct the direction of the pre-operative kinematic elbow axis very well. The position of the pre-operative axis is not reproduced exactly, and an individually adjustable alignment tool might be necessary to resolve this problem.

References

Acknowledgements
The authors like to thank Mrs Grittenberger-de Groot, M.D., Ph.D. (Head of the department of Anatomy, LUMC) for providing the cadaver material, Fred van Immerseel for his help and for storing the cadaver material, Jeroen Verwey for his help in dissecting the arms, Hans Fraterman for constructing the experimental set-up, Wil Meyer for her help during the measurements, and finally we would like to thank Biomet, Inc. and Othomed bv for providing us with the iBP™ Elbow System.