

The figure-of-four axis as a reference to determine stem rotation in hip arthroplasty. What does it really measure?

A cadaver study

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Background and purpose Implantation of the femoral component at 10–15° of anteversion is recommended in THA. Surgical guidelines suggest that the lower leg be positioned horizontally or vertically with the knee flexed to 90° (figure of four). By constructing a perpendicular axis (a “figure-of-four” axis) to the lower leg, anteversion of the stem is approximated. We assessed whether the figure-of-four axis is a reliable intraoperative tool to approximate the retrocondylar line as a reference for stem version.

Methods Cadavers (21 in total) were placed supine on an operating table and the lower legs were aligned to the horizontal plane. Cannulated titanium screws were inserted perpendicular to the lower leg into the medial epicondyle, representing the figure-of-four axis. The femoral neck axes, retrocondylar lines, and the figure-of-four axes were determined using CT images of the specimen.

Results The anteversion of the femoral neck was median 9.8 (4.5–15.1) degrees (interquartile range). The figure-of-four axis deviated by 0.5 (-2.1–2) degrees, whereas the median difference in the axis in relation to the femoral neck axis was 9.5 (-13.6 to -2) degrees.

Interpretation The figure-of-four axis, being nearly parallel to the retrocondylar line, is a valid indirect method for determination of stem version intraoperatively in patients without varus/valgus deviations of the knee.

Correct placement of components is one of the most critical factors influencing the outcome of THA (McCullum and Gray 1990, Nogler et al. 2004). The normal center of rotation of the femoral head is determined by the vertical length, medial offset, and anteversion of the stem (Karnezis 2001). In adults, median femoral neck axes (FNA) range from 10° to 18° (Drenckhahn 2003, Cibulka 2004). Version of the neck is defined as an angle relative to the retrocondylar line (RL) (Drenckhahn 2003). However, the RL is not directly accessible during surgery. In order to achieve a reproducible orientation method, the figure-of four axis (FFA) has been employed as an indirect reference system to approximate the RL. With the patient lying supine, the operated leg is held in the figure-of-four position with the knee flexed to 90° and the lower leg placed parallel to the horizontal plane (Bauer et al. 1994). When patients are positioned in lateral decubitus, the knee is flexed to 90° and the lower leg is aligned to the vertical plane (Harkess 2003). When the lower leg is held exactly vertical or horizontal, a perpendicular axis (FFA) to the lower leg is constructed and used as an orientation mark. Thus, femoral anteversion is approximated in relation to a tibial reference system while the intermediate knee joint is not taken into account. We have not found any published studies analyzing the actual direction of the FFA. We performed a cadaver study to evaluate the FFA as an intraopera-

tive tool to approximate the RL as a reference for stem version.

Material and methods

We studied 21 cadavers (13 female) that had had no knee or hip surgery. All knees had a minimum ROM of 90° flexion, and had stable collateral ligaments. 39 cases were studied. The mean height of the specimens was 169 (159–175) cm, mean weight was 67 (63–75) kg, and mean BMI was 22 (22–26). The legs had a median alignment of 180 (179–181) degrees.

Specimens were first CT-scanned (Lightspeed 16; GE Healthcare, WI) in supine position with the longitudinal axis parallel to the longitudinal axis of the scanner and the legs fixed in neutral position. The CT settings were: 100 kV, 100 mA, rotation 0.8 sec, DFOV 15, noise index 20, and a slice thickness of 0.625 mm.

After the CT investigation, the cadavers were positioned supine on an operating table. Osteotomy of the neck was performed, and the leg was held in the figure-of-four position. The lower leg was aligned to the horizontal plane by pressing a spirit level onto the medial epicondyle and the medial malleolus. In every case, the table was adjusted to the horizontal plane with the use of a spirit level. A box column drill (Quantum B25; Quantum Maschinen GmbH, Bamberg, Germany) was positioned above the flexed knee joint. A Steinmann pin (3.2 mm) was drilled into the medial epicondyle, exactly perpendicular to the horizontal plane (Figure 1). The Steinmann pins were replaced with cannulated titanium screws (Asnis III 6.5 mm Hip Fracture System; Stryker, Allendale, NJ). The femora were explanted and mounted onto Perspex plates. The mechanical axis of the femur was aligned to the longitudinal axis of the CT scanner and the scanning protocol given above was used.

Angle measurements

From the first scanning series, 2 slices containing the femoral head, neck, and the greater trochanter were obtained. FNA was determined by connecting the center of the head with the midpoint of the transverse diameter of the neck, creating a line which transects the most lateral aspect of the



Figure 1. The experimental set-up with a Steinmann pin inserted perpendicular to the lower leg, into the medial epicondyle.

greater trochanter. The head-neck axis was determined by superimposing the proximal slices and a summation image was created. Another distal slice was obtained at a location near the distal aspects of the epicondyles. The posterior-most surfaces of the distal condyles were determined and the RL was defined. After superimposing the proximal and the distal slices, the angles were measured with a plastic protractor. The angle between the head-neck axis and the retrocondylar line expresses the degree of version of FNA and is labeled “+” or “-” for anteversion or retroversion, respectively.

The FFA, which is represented by the axis of the cannulated titanium screw, was determined on 2 CT slices from the second scanning series. The first slice contained a representative cross section of the screw, indicating the FFA. A second slice was obtained and the RL was determined according to the aforementioned method. The FNA determined in the previous measurements and the FFA were related to the RL by superimposing the slices, and the resulting angles were measured with a plastic protractor.

For assessment of the reproducibility of the technique, each specimen was measured several times by 3 investigators (EM, MT, and AP). After 3 instruction sessions, each observer measured the specimen independently. All measurements were performed 3 times.

Statistics

Descriptive statistics were performed and calculations done using the SPSS 12.0 software. Pro-

Table 1. Comparison of the angles (in degrees) of the FNA, the FFA in relation to the RL, and the FFA in relation to the FNA—in total and with regard to the 3 observers

Axis	Observer	n	Median	Min	Max	10% percentile	25% percentile	75% percentile	90% percentile
FNA	1	39	9.8	-17.7	21.0	-9.6	4.4	15.2	17.0
FNA	2	39	11.2	-16.5	23.1	-7.7	4.5	16.7	17.8
FNA	3	39	9.5	-17.1	20.0	-9.3	4.0	13.2	16.3
FNA	total	117	9.8	-17.7	23.1	-8.0	4.5	15.1	17.1
FFA to RL	1	39	-0.3	-8.4	10.0	-5.0	-2.0	2.0	5.5
FFA to RL	2	39	-1.0	-7.7	11.0	-4.3	-2.1	2.0	6.7
FFA to RL	3	39	-0.5	-7.0	12.5	-6.0	-2.5	2.5	5.5
FFA to RL	total	117	-0.5	-8.4	12.5	-4.6	-2.1	2.0	5.5
FFA to FNA	1	39	-9.8	-18.9	15.8	-17.3	-13.7	-3.5	5.6
FFA to FNA	2	39	-8.8	-19.5	13.3	-17.0	-15.1	-0.8	10.1
FFA to FNA	3	39	-9.5	-17.4	14.8	-15.8	-13.0	-3.0	6.8
FFA to FNA	total	117	-9.5	-19.5	15.8	-16.8	-13.6	-2.1	6.7

FNA: femoral neck axis; FFA: figure-of-four axis; RL: retrocondylar line.

Table 2. Intrarater and interrater reliability for the FNA, FFA in relation to the RL, and FFA in relation to the FNA. Values denote differences

	Mean	SE	95% CI
<i>Intrarater reliability</i>			
FNA observer 1	-0.2	0.1	-0.5–0.0
FFA to RL observer 1	-0.2	0.2	-0.5–0.1
FFA to FNA observer 1	0	0.1	-0.2–0.2
<i>Interrater reliability</i>			
FNA observer 1 to 2	-0.4	0.3	-1.1–0.3
FNA observer 2 to 3	1.2	0.3	0.5–1.8
FNA observer 1 to 3	0.8	0.4	0.0–1.5
FFA to RL observer 1 to 2	0.2	0.2	-0.2–0.7
FFA to RL observer 2 to 3	-0.2	0.3	-0.8–0.4
FFA to RL observer 1 to 3	0	0.2	-0.4–0.5
FFA to FNA observer 1 to 2	-1.5	0.8	-3.2–0.2
FFA to FNA observer 2 to 3	0.6	0.9	-1.3–2.5
FFA to FNA observer 1 to 3	-0.9	0.3	-1.6– -0.2

FNA: femoral neck axis; FFA: figure-of-four axis; RL: retrocondylar line.

vided that our method of measurement has only random errors, we assessed its repeatability using repeated measurements by the same observer and we also assessed the reproducibility of measurement using 2 additional observers. Repeatability and reproducibility were determined from the 95% confidence interval of the mean difference of the measurements.

Results (Table 1)

The interrater reliability in the determination of the FNA, FFA to RL, and FFA to FNA ranged between 0.9° and 3.4° (Table 1). The median version of the femoral neck axis was anteversion of 9.8° (Figure 2), and ranged between 18° retroversion and 23° anteversion. The FFA was 0.5 (-2.1 to 2) degrees (Figure 3).

Discussion

Usually the anteversion angle is determined on the femur by relating the FNA to the RL (Drenckhahn 2003). During surgery, it is not possible to identify the RL. Thus, it has been suggested that anteversion should be determined indirectly by using an orientation system not based on the femur, but based on the lower leg. Yet, surgical guidelines are ambiguous in this regard (Bauer et al. 1994, Harkess 2003). The FFA is a commonly used method of orientation. Thus, we evaluated the orientation of FFA and its reliability as a tool for determination of stem anteversion.

The median anteversion angle of the femoral neck that we found was similar to that reported in anatomy textbooks (Kahle et al. 1991). Our findings are also corroborated by recent studies reporting the measurement of human femoral ante-

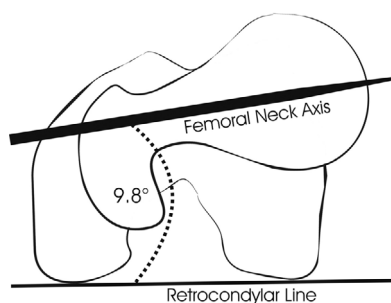


Figure 2. The median FNA or the anteversion angle in relation to the RL in degrees.

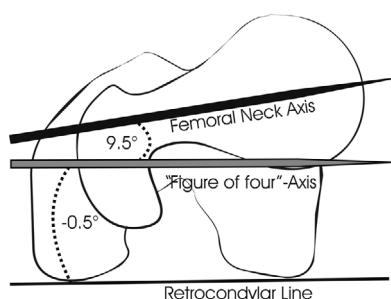


Figure 3. The median relation of the FFA to the FNA and the RL in degrees.

version by CT imaging. These methods appear to be accurate and valid procedures with good inter-rater reliability (Hernandez et al. 1981, Kuo et al. 2003). The fact that 2 specimens had retroverted femoral necks resulted in a wide range (41°) of version, which has not been described previously. The reliability of intraoperative methods in determining stem version has not been addressed either. Our measurements show that the median FFA runs nearly parallel to the RL, which is the starting point for the determination of anteversion. A stem aligned to the FFA is very likely to be placed in 0° of anteversion. To obtain the desired anteversion angle, a stem with no built-in anteversion has to be anteverted to this degree in relation to the FFA.

One limitation of our investigation is the fact that the measurements were done with the specimens in supine position. It is probably easier to precisely position the lower leg horizontally (supine position) rather than vertically (lateral decubitus position). Using the figure-of-four technique in THA, this might lead to different results. In addition, the results refer to measurements performed on CT

slices. As such sophisticated measurements are impossible in the intraoperative setting, the possibility of placing a stem at the correct degree of anteversion is uncertain.

The specimens we used had no or little varus/valgus deviation of the legs. Thus, the influence of mechanical leg axis deviation on the FFA is unknown. It may be speculated that a valgus deviation may lead to greater anteversion of the stem, while a varus deviation might result in less anteversion—if not retroversion.

In summary, femoral neck version varies a great deal, but with the FFA being nearly parallel to the RL, the figure-of-four technique is a valid indirect method to determine stem version intraoperatively in patients without varus/valgus deviations of the knee.

Contributions of authors

EM: designed the experimental set-up, and performed the pin insertions, the CT scans, the measurements, the analysis and interpretation of the results, and wrote the manuscript. MT and AW: helped perform the pin insertions, the CT-scans, and in measuring the angles. JM, MK, and MN: helped in generating the original idea, in transforming it into an experimental setup, and in revising the manuscript.

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