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Important tips and numbers on using the cortical step and diameter difference sign in assessing femoral rotation – Should we abandon the technique?

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ABSTRACT

Rotational malalignment during femoral nailing is common despite having various intraoperative assessment methods. The cortical step sign and diameter difference sign (CSSDDS) is commonly used because of convenience, yet it lack proper scientific scrutiny and is thought to be error prone.

Using a software algorithm, cross-sectional dimensions were obtained from CT scans of 22 intact adult femurs at the proximal, mid and distal diaphysis. With multiple simulated scenarios the sensitivity of CSSDDS was comprehensively determined at all possible C-arm positions.

At rotation, cortical width changed most significantly around the thick linea aspera and femoral diameter changed most significantly at the sagittal plane. At 15 degrees of rotation and with the linea aspera in view, CSSDDS thresholds of 0.3 mm, 0.6 mm and 1 mm had sensitivities of 98.8%, 93.1% and 73.8%. With the linea aspera masked behind the femur and out of view, the sensitivities significantly deteriorated to 96.4%, 77.1% and 44.1% respectively.

CSSDDS is sufficiently sensitive only when strict rules are followed. It is imperative that the operator position the image intensifier in lateral view under proper magnification so that steps of less than 0.6 mm around the linea aspera may be appreciated.

Introduction

Malrotation can easily be overlooked during intramedullary (IM) nailing of femur shaft fractures. Studies have recognized an alarming incidence of 22–43% for malrotations of more than 10° [1–5]. Malrotations of more than 15° are often clinically significant. Patients may experience symptoms with high demand activities [6–9], sometimes leading to surgical revisions and litigations.

The cortical step sign and diameter difference sign (CSSDDS) are commonly used to control rotational alignment during IM nailing because of convenience. It is mentioned in the AO Principles for Fracture Management [10] along with other techniques of rotational assessment. The principle described by Krettek et al. [11] works by assuming presences of variation in cortical thickness in an oval shaped cross-section. When a rotational deformity is present between the fragments, mismatch of cortical thickness (CT) and femoral diameter (FD) is observed on radiograph. However, studies critically looking into the accuracy of this method are lacking, it is believed that CSSDDS is operator dependent and less sensitive (Figs. 1 and 2) [12,13].

The aim of our study was to experimentally determine the optimal C-arm position, threshold values and sensitivity of CSSDDS in picking up rotational malalignment in the femur diaphysis using anatomical data and a simulated model.

Methodology

Radiological data was retrospectively collected from a consecutive patient group who received CT scans of the thigh for acute soft tissue infections. All patients had no bony pathology or fractures. The average age was 54 (15–86). There were 10 males and 9 females. Three patients had bilateral femurs included. From 22 femurs, three axial CT slices were collected at the mid diaphysis,

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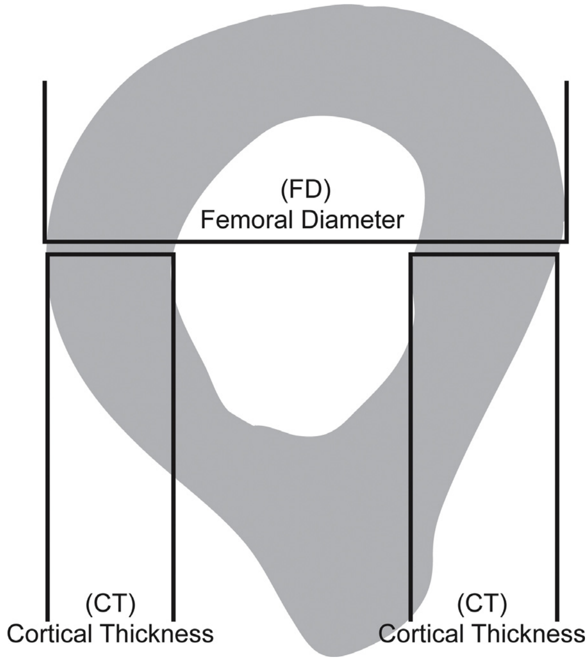

Fig. 1. Defining cortical thickness (CT) and femoral diameter (FD).

4 cm proximal and 4 cm distal to this level. The scans did not cover the whole length in 6 femurs. As a result a total of 55 cross-sectional images were obtained.

We used a software edge detection algorithm (Adobe Master Effects CS5) to circumferentially outline the inner and outer cortical surfaces. Both the cortical thickness (CT) and femoral diameter (FD) were computed per degree of rotation, in other words having 360 measurements along the whole circumference. Rotational positions were standardized by taking the linea aspera as the mid-posterior anatomical references so that variations in patient positioning were standardized.

In the first step, the inner and outer cortical outlines were used to calculate an average femur cross-section for descriptive analysis. In the second step, the changes in CT and FD for each femur cross-section was calculated by subtracting the initial value from the final value for specific rotational differences, simulating a CSSDDS mismatch. A large number of comprehensive scenarios were created, with all femoral cross-sections simulated to receive from 1 to 45 degrees of malrotation. For CT, results were mapped into twelve sectors using clock positions on a femur cross-section for easy understanding, with 3, 6, 9 and 12 o'clock position representing the lateral, posterior, medial and anterior cortices respectively. For FD, results were represented according to the axis, measured starting from sagittal axis in 30° steps, with 90° representing the coronal/medio-lateral diameter and 180° representing the sagittal/anteroposterior diameter. Using a linear regression model, the amount of CT and FD mismatch in mm per degree of rotation was determined (Fig. 4).

In the final step, the overall sensitivity for CSSDDS was determined from the mathematical model. All simulated data were then reanalyzed against a range of preset threshold values to obtain the true positive (CSSDDS larger than threshold) and false negative values (CSSDDS smaller than threshold). The data was then used to calculate the sensitivity of CSSDDS for all given scenarios. Statistical analysis was performed using SPSS Statistics Software (IBM Corporation, NY, USA). Mean values were presented with 95% confidence intervals.

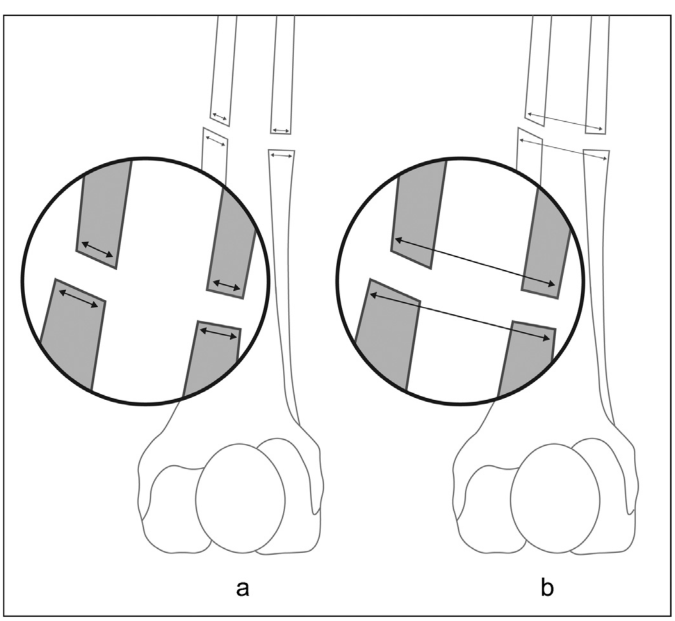

Fig. 2. Excerpt from Krettek's original article on (a) cortical step sign: mismatch in cortical thickness in the presence of malrotation and (b) diameter difference sign: mismatch in diameter in the presence of malrotation.

Results

Dimensions of the average femur

With 360 inner and outer cortical measuring points taken from 55 segments, 79,200 measurement points were obtained. In the mathematically reconstructed average femur, the cortical width was significantly thicker posteriorly (8.2 mm, 95%CI: 7.6–8.8) at the linea aspera, and thinner anteriorly (5.0 mm, 95%CI: 4.7–5.3). The medial (6.8 mm, 95%CI: 6.4–7.3) and lateral cortices (6.5 mm, 95%CI: 6.1–6.9) were comparable. The sagittal diameter of the femur was significantly wider (30.5 mm, 95%CI: 31.0–32.0) then the coronal diameter (27.4 mm, 95%CI: 26.9–27.9). The cross-section had an 'inverted water drop' shaped outline (Fig. 3).

Changes in CT and FD in relation to rotation

Using a linear regression model, changes in CT and FD occurred most remarkably around the linea aspera. Corresponding to this, the slope coefficients for CT for the 5th and 6th o'clock sectors were 0.053 mm/degree (95%CI: 0.053–0.054) and 0.052 mm/degree (95%CI: 0.051–0.052) respectively, and less than 0.034 mm/degree (95%CI: 0.034–0.034) at all other positions. For FD, the slope coefficient was 0.103 mm/degree (95%CI: 0.102–0.103) within a 30° arc around the sagittal axis and less than 0.053 mm/degree (95%CI: 0.052–0.054) at all other locations. All above differences were statistically significant. This forms the basis for focusing on the linea aspera transitional zone in determining the sensitivity of CSSDDS at the next step (Table 1, Figs. 5 and 6).

Sensitivity

Scenario analysis was performed from previous data. To simulate an actual fluoroscopic image, the corresponding thickness differences of two cortices and the diameter difference were analyzed together so that the maximum step mismatch is determined. The sensitivity of detecting *r* (from 1 to 45) degrees of rotation with a CSSDDS threshold of *t* (from 0.3 to 1.5) mm was determined for 180 possible C-arm positions in all 55 femur cross-sections. For each unique *r* and *t* values, 9900 distinct scenarios were available for statistical analysis and in total there were