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Intra-Operative Rotational Alignment Control Using ISO-C 3D in Comparison to Torsion CT Scan: A Cadaveric Study

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Abstract

Introduction: Femur shaft fracture is relatively common and usually treated operatively. Among the different post-operative complications is rotational malalignment, which can affect the patient's gait, and quality of life both cosmetically and physically.

To assess the femoral torsion, a post-operative axial CT or MRI scan of both limbs is performed. However, applying the Linea aspera method as a reference point together with a mobile 3D C-arm image may provide feasible intra-operative recognition and correction.

Materials and Methods: 21 tissue free femora were scanned twice with CT and Iso-C-3D after mid-shaft osteotomy and 6 different angles of malrotation (internal and external rotations at 10, 20 and 30 degrees). The degree of malrotation after both scans was then compared.

Results: The data gained from Iso-C 3D scans and applying the linea aspera method showed high intra and inter-observer reliability without any significant difference compared to the gold standard (axial CT scans).

Conclusion: Intra-operative 3D scans to assess the rotational malalignment provides a reliable method that can be used when available in cases of transverse and short oblique fracture of the femur and especially in cases of bilateral fracture.

Keywords: *Iso- C 3D; Linea Aspera; Femoral Torsion*

Introduction

The estimated incidence of femoral fractures is 21/100,000 yearly [1], where motor vehicle accidents, crush injuries and fall from height are the most common causes in the young age group [2]. The role of conservative therapy is limited and mainly considered for children under 4 years, whereas the three main methods of management are: intra-medullary nails, plate and screws, and external fixators [3]. Many complications have been reported after operative treatment of femoral shaft fractures including infection, compartment syndrome, pseudarthrosis and implant failure [3]. One of the most important and preventable complications is post-operative malrotation.

The normal femoral torsion lies between -10.8 degrees (retroversion) and 22.1 degrees [4].

Krettek., *et al*. described the 5 different stages of correcting rotational malalignment in chronological order. The easiest and best outcome is prevention followed by intra-operative correction. After that, post-operative correction before the fracture has healed and afterwards (before any symptoms develop). The worst outcome is correction after the fracture has healed with development of symptoms [5]. Therefore, intra-operative recognition of malrotation is very critical.

Femoral torsion malalignment especially for an increased external rotation has both clinical and cosmetic drawbacks manifest as pain in the hip and knee joint associated with decreased range of motion together with osteoarthritis and lower functional scores (Harris Hip score, Oxford knee score, Lysholm knee scale and Western Ontario and McMaster University osteoarthritis index) [6-8].

The gold standard in identifying the rotational difference is by obtaining axial scans of the femoral neck and condyles and comparing them with the non-injured side. This can be done with CT or MRI [9]. Many radiological and clinical methods aid the surgeon intra-operatively to avoid such serious complications [5,10].

The mobile isocentric C-arm (Siremobil ISO-C 3D, Siemens, Erlangen, Germany) is a C-arm image intensifier with the ability to reconstruct 3D images that has been used in many fields in orthopedic surgery, especially in the assessment of intra-articular fractures [11,12].

Iso-C 3D has already been tested for its reliability in assessing the intra-operative femoral ante-torsion. In a cadaveric study of 5 fresh frozen human cadavers that there was no significant difference between Iso-C 3D and the multi-slice CT scanner when performing the same method for measuring femoral anteversion [13].

In the present work, the accuracy of using a mobile image intensifier with a 3D CT function (ISO-C 3D) applying the linea aspera method, which was previously described by our group [14], was compared with the standard axial CT images technique described above in measuring femoral torsion.

Aim of the Study

To compare the efficiency of using intra-operative 3D scans of the fractured segments with the gold standard CT torsion scan. (a cadaveric study).

Materials and Methods

Our group was able to establish a new device (rotational fixator/goniometer) through which the desired rotational correction can be accurately measured and achieved [15]. This fixator was used to achieve the desired rotational malalignment in this study.

After acquiring the institutional board's approval, twenty-one soft tissue free femora (12 left and 9 right) from human adult cadavers were used in this study. The same procedure was performed on each specimen:

1. CT scans were performed to determine the anatomical anteversion of each specimen before beginning the measurement. This was followed by inserting two parallel schanz screws perpendicular to the long axis of the intact femur using a fixed drill sleeve and connected with an external fixator rod in the standard fashion.
2. A mid-shaft horizontal osteotomy was performed with a powered saw in controlled fashion. The femora were supinely positioned with their longitudinal axes for scanning. Each femur was scanned twice (CT and Iso-C 3D) after applying an induced malrotation degree (10, 20, 30 internal and external rotation). The malrotation degree was controlled using a rotational goniometer. After that the schanz screws were connected together with a carbon rod. The conventional multi-slice CT scanner (LightSpeed QX/I CT, GE Healthcare, VA, USA - 1,25 mm sections) was used followed by a 3D Scan with a 3D C-Arm system (Siremobil ISO-C 3D, Siemens, Erlangen, Germany).
3. All scanned images were electronically saved for further analysis. Measurements were performed using Visage 7 (Visage Inc, USA).
4. Radiological analysis was performed using the linea aspera method [14] and compared to the torsion CT using the Jarrett [16] method, where the femoral neck anteversion was measured on a single axial image, reformatted from coronal images, through a line drawn connecting the center of the head and center of the greater passing through the center of the femoral neck. The measurements were done by two non-dependent board-certified surgeons and the mean value was utilized in assessing the data.

Figure 1: *Application of rotational goniometer to control the rotational angle after osteotomy.*

Figure 2: *Scanning of the femora using CT.*

Statistical analysis

Statistical analysis was performed with a paired student t-test (α = 0.05) to compare the mean difference between the two measurement methods. Statistical analysis was done with SPSS V26 (IBM, Armonk, New York).

Results

Twenty-one femora were examined. There were 12 left and 9 right femora. Each sample was measured by 2 different investigators (A and B). In the native CT examination before the osteotomy, the native femoral anteversion of examiner A gave a mean of -14.99, a standard deviation (SD) of 6.38 and a range of (-28 to -6). In comparison, examiner B obtained a mean of -14.32, a SD of 7.01 and a range of (-29.2 to 0.1). For more detail, see table 1.

	Native_CT.A	Native_CT.B
N	21	21
Mean	-14.99	-14.3238
Std. Deviation	6.387	7.01811
Minimum	-28	-29.20
Maximum	-6	0.10

Table 1: *Demonstrating the mean femoral anteversion in the 21-sample measured by both examiners.*

There was a non-significant difference between examiner A and examiner B in the 12 - rotation measurement. For more detail, see table 2.

Pairs	Torsion CT- ISO-C 3D (n = 21)	Mean	Std. Deviation	95% confidence interval of the difference		P. Value
				Lower	Upper	
1	Torsion CT IR.10° Exam. A/B	-1.28	4.56	-3.36	0.79	0.212
2	Torsion CT IR.20° Exam. A/B	-0.51	4.55	-2.58	1.56	0.611
3	Torsion CT IR.30° Exam. A/B	-0.98	4.12	-2.86	0.89	0.287
4	Torsion CT AR.10°Exam. A/B	-1.27	4.15	-3.16	0.61	0.176
5	Torsion CT AR.20°Exam. A/B	-1.37	3.08	-2.77	0.02	0.055
6	Torsion CT AR.30°Exam. A/B	0.2	4.39	-1.79	2.19	0.837
7	ISO-3D IR.10° Exam. A/B	0.72	3.42	-0.82	2.28	0.341
8	ISO-3D IR.20° Exam. A/B	0.91	4.43	-1.10	2.93	0.356
9	ISO-3D IR.30° Exam. A/B	0.42	5.30414	-1.99	2.83	0.718
10	ISO-3D AR.10° Exam. A/B	0.81	4.6427	-1.29	2.93	0.428
11	ISO-3D AR.20° Exam. A/B	1.09	3.73951	-0.61	2.79	0.196
12	ISO-3D AR.30° Exam. A/B	1.5	4.9965	-0.77	3.77	0.184

Table 2: *Demonstrating the difference in each measurement performed by both examiners.*

The compared method showed no significant difference between Iso-C 3D and rotational difference CT as can be seen in table 3 below.

	IR 10°	IR 20°	IR 30°	ER 10°	ER 20°	ER 30°
Investigator A	p = 0.267 (95% CI -1.58 to 5.42)	p = 0.229 (95% CI -1.69 to 6.68)	p = 0.102 (95% CI -0.87 to 8.94)	p = 0.233 (95% CI -1.90 to 7.36)	p = 0.181 (95% CI -1.20 to 5.99)	p = 0.079 (95% CI -0.41 to 6.85)
Investigator B	p = 0.753 (95% CI -3.14 to 4.27)	p = 0.368 (95% CI -2.18 to 5.64)	p = 0.175 (95% CI -1.58 to 8.16)	p = 0.366 (95% CI -3.16 to 8.21)	p = 0.356 (95% CI -3.06 to 8.14)	p = 0.282 (95% CI -1.60 to 5.23)

Table 3: *p-values listed for all measurements comparing Torsion CT and Iso-3D with associated confidence level separated by investigator.*

The scatter of the ISO-CT measurements and the measurements with the rotational CT of both examiners are shown as a box plot separated for the left and right side. For more detail, see figure 3.

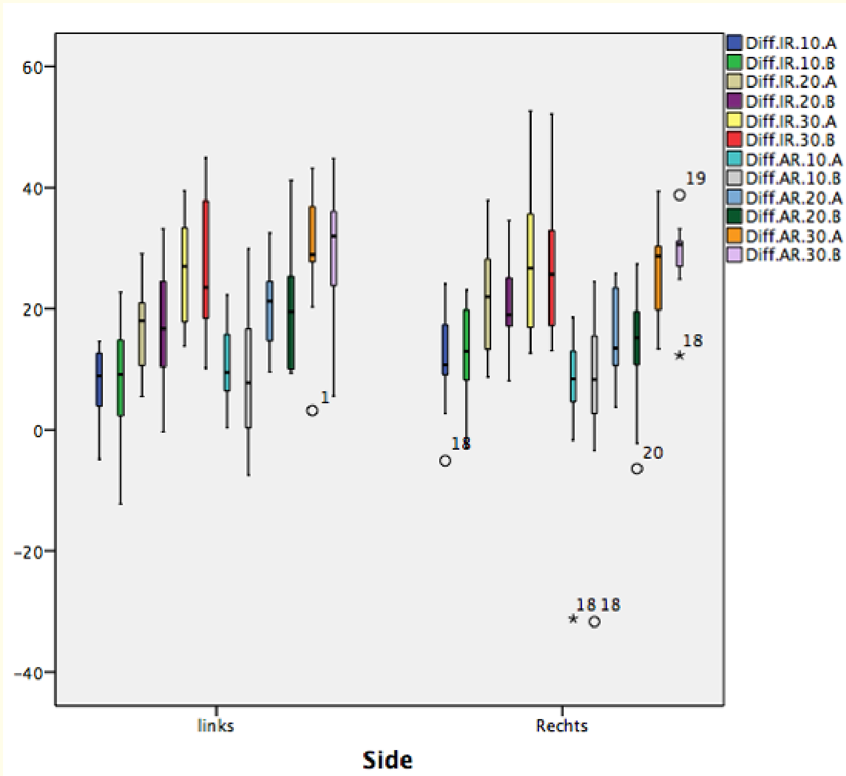

Figure 3: *Demonstrating the measurement by applying both methods done by the examiners (A and B).*

Discussion

The present study was done on 21 femora to evaluate the clinical application of the linea aspera method using 3D-C-arm in assessing the femoral torsion in comparison to the gold standard axial CT scans.

Twelve different angles of rotation after femoral osteotomy were measured twice and compared with the standard torsional CT scan. The obtained data was equally distributed, and it showed a high inter-observer and intra-observer reliability in all 12 compared measurements. It was found that the difference between ISO-C 3D measurements and axial CT was non-significant in all three different internal and external rotation angles.

When using the contralateral (uninjured side) as a reference to identify the femoral torsion, Croom WP., *et al*. found in their recent study of one hundred and sixty-four healthy subjects of different age, sex and ethnic group that 17.7% of the subjects showed a difference version ≥ 10 degrees, while 4.3% had version difference ≥ 15 degrees [17].

Rotational malalignment after operative therapy - especially with intramedullary nails - is not uncommon. The results of Jaarsma., *et al*. showed that 21/76 (28%) of their series had a rotational difference of ≥ 15 degrees [7], while Karaman., *et al*. found that 10/24 (41,7%) have a rotational malalignment of ≥ 10 degrees [8]. Patients with a rotational difference of more than 10 degrees were symptomatic and showing a significantly lower LKS, WOMAC knee and WOMAC hip scores compared to patients without rotational difference [8].

Kaiser., *et al*. compared 6 different techniques in assessing the femoral torsion using axial CT slices on 52 femora Their results show a preferable intra-observer and inter-observer using oblique or superimposed slices. It is important to remember that different techniques would give different values [9,18]. In our study, the Jarrett axial oblique technique was applied in measuring the femoral torsion [16].

In clinical usage, regardless of the technique used to measure the femoral torsion on the affected side, the noteworthy is the ante-torsion difference to the non-affected side and this can only be evaluated by scanning the non-affected side. A difference of up to 15 degrees was tolerated by many authors before the need for a corrective procedure [7,19].

Stübig., *et al*. used the linea aspera as a reference point after the femora had been scanned with ISO-C-3D to correct the malrotation intra-operatively. Their work on 11 intact femora after mid-shaft osteotomy and fixing each femur in 6 different rotation angles has been shown to provide accurate and reliable results when compared with the use of a goniometer [14].

When comparing the radiation exposure after conventional CT scans and Iso-C 3D, Gösling., *et al*. [20] found in all scanning modalities with ISO-C 3D a significantly lower dose length produced (7,9 - 22,7 mGy cm) compared to CT (131 mGy cm).

Conclusion

Intra-operative estimation of the torsional difference using 3D scanning is a useful accessory tool with reliable results and should be used when available in cases of transverse and short oblique fracture of the femur. It is best applied in bilateral fractures, where the linea aspera acts as a reference point to determine the correct torsion. Not only does it save the patient the radiational hazards from scanning the hip and the knee joint on both sides, but it also averts the possible reoperation to correct the post-operative rotational difference. Nevertheless, this method might have a limited role in comminuted fractures.

Conflict of Interest

Each author declares that he has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article. The ethical committee of the Hannover Medical School approved the study.

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