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Trochanteric fractures treated by internal fixation using short intramedullary nails: does the visual intraoperative estimation of the Tip-Apex Distance (TAD) concur with its digital postoperative measurement?

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Abstract

Introduction: The tip-apex distance (TAD) is the only predictor for mechanical failure after internal fixation of trochanteric fractures. The main objective of our study was to assess whether the intraoperative visual estimation of the TAD concurred with the measurement taken on postoperative digital X-rays. We hypothesized that there was a good concordance between these 2 different methods of measurement.

Materials and Methods: Patients with an isolated trochanteric fracture were included in our study. A hardcopy of the intraoperative X-rays were printed, and the TAD was calculated manually. Radiological and clinical follow-ups were scheduled at 6 weeks, 3 months and 6 months during which numerical measurements of the TAD were taken. We also recorded the fracture type (AO/OTA classification), degree of osteoporosis (Singh index), surgeon experience, age and ASA score.

Results: A total of 98 patients were included in our study. Of these, 70 had a 6-month follow-up and interpretable postoperative X-rays. The mean age was 87 years, with

77.14% women and a mean ASA score of 3. The coefficient of concordance between the intra and postoperative TAD was 0.7202 (95% CI = 0.4905-0.9499). The secondary displacement rate was 3.28%. The univariate analysis showed no statistically significant association between an intraoperative TAD > 25 mm and fracture type ($P = .7290$), degree of osteoporosis ($P = .5701$) and surgeon experience ($P = 1$).

Discussion/Conclusions: There was a high degree of concordance between intraoperative visual estimation of the TAD and its measurement on postoperative digital X-rays. The treatment of unstable fractures in osteoporotic bone by junior surgeons was not a risk factor for intraoperative TAD > 25 mm. It is therefore important to educate young surgeons on the concept of TAD and its intraoperative visual estimation technique as it ensures that the cephalic screw is positioned properly during the fixation of trochanteric fractures.

Level of Evidence: II

Keywords: tip-apex distance, concordance of measurements, TAD, pertrochanteric fracture, secondary displacement.

Introduction

One in 5 women and 1 in 10 men will suffer a proximal femoral fracture, from whatever cause, at some point in their lifetime [1, 2]. In France, it is estimated that 70,000 fractures occur every year, with only 30 to 40% of patients recovering their previous functional status [3]. These fractures can be life-threatening for the elderly and can affect functional prognosis in young patients.

Almost 60% of these are trochanteric fractures and the preferred surgical treatment for patients over the age 70 is internal fixation [4–6]. Its main complication is secondary displacement, characterized by “collapse of the neck-shaft angle into varus, leading to the extrusion, or so-called cutout, of the screw from the femoral head” [7]. This complication is not uncommon, since its incidence can reach 16% [3, 8]. The important consequence for patients is that the 1-year mortality rate can be as high as 63% [9–11].

A radiographic measurement called the tip-apex distance (TAD), initially described by Baumgaertner et al, seems to be the only predictor of mechanical failure after internal fixation [8, 10, 12–19]. A TAD > 25 mm is a risk factor for secondary displacement. Most operating rooms do not have the technology to perform real-time computerized measurement on X-rays taken during surgery. In these cases, the surgeon must use

another technique and visually estimate the TAD by taking well-defined radiographic landmarks [20]. No study has to date assessed the concordance between the intraoperative visual estimation of the TAD and its postoperative measurement.

Our goal was to answer the following questions:

- 1) Does the TAD visually estimated on intraoperative X-rays concur with the TAD measured on postoperative X-rays?
- 2) Are there pre and intraoperative factors that could explain an intraoperative TAD > 25 mm despite the known consequences of secondary displacements?
- 3) Can an intraoperative TAD < 25 mm result in a secondary displacement rate of less than 5%?

Our study hypothesis was that there was a good concordance between the TAD visually estimated on intraoperative X-rays and the TAD measured on digitized postoperative X-rays.

Materials and methods

This was a prospective, observational, single-center, multi-surgeon cohort study involving patients who were operated in our department of orthopedics and traumatology between May 2019 and November 2019. Our study received a favorable opinion from our hospital's Institutional Review Board (No. 313-2019-79). The study inclusion criteria were: patients older than 70 years at the time of the trauma and an isolated closed trochanteric femur fracture sustained during a mechanical fall.

We recorded the following data during the initial inclusion: age, sex, affected side, and the American Society of Anesthesiology (ASA) score [21].

Surgical technique and implant used

Patients admitted to our hospital's emergency department for trochanteric fractures were treated by internal fixation in the operating room, either under general or locoregional anesthesia, in supine position on an orthopedic table. The fracture was first managed with closed reduction maneuvers under fluoroscopic guidance. The internal fixation was then performed through a lateral approach with a traditional intramedullary internal fixation technique (short standard intramedullary Zimmer

Natural Nail® system: angle 125°, length 215 mm, diameter 10 mm, Zimmer Biomet®, Warsaw, USA).

X-ray data collection and postoperative follow-up

In their initial study, Baumgaertner et al did not mention any specific conditions for performing the image acquisitions necessary to measure the TAD. Variations of the TAD depending on the angle of rotation of the lower limb and position of the image intensifier are well known, but are not the subject of this study [22]. Our goal was not to confirm the validity of the TAD, but to establish that its intraoperative analysis and its postoperative measurement concurred [7, 10, 12, 19, 23–25]. Intraoperative X-rays were therefore taken with the patella facing up in the anteroposterior view and with the fluoroscope tilted 15° in the lateral view to compensate for the natural anteversion of the femoral neck and obtain a precise lateral view of the femoral neck, which minimized rotation errors and improved reproducibility (**Figure 1**). Full-weight bearing was prescribed for all patients in the immediate postoperative period. Immediate postoperative X-rays (D0 or D1) were not used in our study because they could not be performed correctly given the pain. Clinical and radiographic follow-ups were scheduled at 6 weeks, 3 months and 6 months postoperatively with anteroposterior and lateral Lequesne's false profile views of the femoral neck. The postoperative TAD was calculated on computerized X-rays taken 6 weeks postoperatively that were accessed from our picture archiving and communication system (PACS). We searched for any secondary displacements up to 6 months postoperatively, according to Baumgaertner et al's definition [7].

Intraoperative measurement of the TAD

The TAD was defined by Baumgaertner et al in 1995 (**Figure 2**) [7]. It was visually estimated by surgeons on X-rays taken with an image intensifier, according to the technique described by Berstock et al and developed further by Wijeratna et al in 2014 [20, 26]. This technique uses the diameter of the implanted cephalic screw, a known and constant variable (10.5 mm in our study), as the visual reference. If surgeons maintain a distance between the tip of the cephalic screw and the apex of the femoral head that is less than the visual diameter of the cephalic screw, on both the anteroposterior and lateral views, then the TAD will be less than or equal to 25 mm. For the purpose of this

study, we printed hardcopies of these X-rays to quantify this visual estimation using the digital postoperative measurement technique (**Figure 3**).

Postoperative measurement of the TAD

This measurement was carried out on the X-rays taken 6-weeks postoperatively using the PACS digital measurement protocol described by Johnson et al (**Figure 4**) [27]. X-rays were calibrated using the diameter of the implanted cephalic screw (10.5 mm for all patients). Postoperative measurements were performed by a department surgeon (AD) and were reviewed blindly by an independent radiologist (SC). If findings were discordant, then the measurements were reviewed by a third surgeon (AA) and the average of the three measurements was used.

Fracture type, degree of osteoporosis and surgeon experience

The fracture type was determined on the initial X-rays according to the AO/OTA classification and were divided into 2 groups: stable (A1) and unstable (A2, A3) fractures (**Figure 5**) [28]. This analysis was performed independently by 2 department surgeons (AD, AA). Cases were reviewed by a third independent surgeon (TC) whenever consensus could not be reached, and the majority decision was adopted.

The degree of osteoporosis was determined using the Singh index [29]. A diagnosis of osteoporosis was made when the score was less than or equal to 3 (**Figure 6**). Internal fixation of trochanteric fractures is usually performed in the operating room of our hospital by a resident specialized in orthopedic surgery under the direct supervision of a senior surgeon. Surgeon experience was assessed according to the level of surgical training. We therefore divided the 11 residents into 2 groups, depending on whether they were in the first (7 residents) or second (4 residents) half of their residency.

Statistical analysis

The data recorded in an Excel™ spreadsheet (Release 2010, Microsoft, Redmond, USA) and the analyses were carried out using Stata Statistical Software: Release 12 (StataCorp LP, College Station, Texas, USA). The significance level was set at 5%. We first carried out descriptive statistics for the studied variables. The qualitative variables (sex, operated side, fracture type, degree of osteoporosis, surgeon experience, TAD > 25 mm, secondary displacements) were expressed as numbers and percentages. The quantitative variables

(age, ASA score) were expressed as mean, standard deviation and extreme values. To answer our main objective, we assessed the concordance between the 2 methods of measuring TAD using Cohen's kappa (κ). To answer our secondary objectives, the association between the 2 qualitative variables "TAD" and "secondary displacements" was assessed using the Fisher exact test. The association between the dependent variable "TAD > 25 mm" and the independent variables "fracture type," "degree of osteoporosis" and "surgeon experience" was assessed with a univariate analysis using the chi-square test. These variables of interest were then included in a multivariate backward stepwise logistic regression analysis and a Hosmer-Lemeshow test was performed to determine the p-value.

Results

Between May 2019 and November 2019, 178 patients over the age of 70 with a proximal femoral fracture were admitted to our hospital's emergency department. Patient distribution over our study period is depicted in **Figure 7**. A total of 98 patients were included in our study. Of these, 70 were followed for 6 months and had interpretable X-rays (71.5% of patients included). Twenty-eight patients had either a follow-up of less than 6 months or uninterpretable X-rays (28.6%). Therefore, this study took place over a 1-year period: 6-month inclusion and 6-month follow-up.

Detailed patient sociodemographic data are presented in **Table 1**.

Results on the intra and postoperative concordance of the TAD

The mean intraoperative TAD was 19.5 mm (+5.3) [min: 8, max: 34]. Of the 70 patients, 61 (87.15%) had an intraoperative TAD < 25 mm, 6 (8.57%) an intraoperative TAD between 25 and 30 mm and 3 (4.28%) an intraoperative TAD > 30 mm. Of the 10 early deaths, 4 (40%) had an intraoperative TAD > 25 mm (between 25 and 28 mm) and 6 (60%) an intraoperative TAD < 25 mm.

The mean TAD at 6 weeks was 21.3 mm (+5.5) [min: 9, max: 38]. Of the 70 patients who underwent surgery and had interpretable postoperative X-rays, 65 (92%) had concordant intra and postoperative TAD measurements. The coefficient of concordance calculated with Cohen's kappa was 0.7202 (95% CI=0.4905-0.9499). There was

therefore a high degree of concordance between the intraoperative visual estimate of the TAD and its postoperative digital measurement.

Among the 5 patients with inconsistent results, 4 (80%) had a postoperative TAD > 25 mm while the intraoperative TAD was < 25 mm and 1 patient (20%) had an intraoperative TAD > 25 mm and a postoperative TAD < 25 mm.

Factors that may lead to an intraoperative TAD > 25 mm

Of the 98 patients included, 16 had an intraoperative TAD > 25 mm. The univariate analysis showed that there was no statistically significant association between a TAD > 25 mm and fracture type ($P = .7290$), degree of osteoporosis ($P = .5701$) and surgeon experience ($P = 1$) (**Table 2**).

We used a multivariate logistic regression analysis to determine the interaction between the variables and confirm our previous result. There was no significant association between these three factors and an intraoperative TAD > 25 mm (**Figure 8**).

Secondary displacement and TAD

The secondary displacement rate in this study was 3.28%, i.e. 2 patients. All secondary displacements were observed for an intraoperative TAD < 25 mm.

Discussion

Our study's main hypothesis was verified with a "high" degree of concordance between intraoperative visual estimation of the TAD and its postoperative measurement on digital X-rays.

TAD concordance

We did not find any published studies to date that assessed the concordance between intraoperative visual estimation and the measurement performed on postoperative X-rays. The high coefficient of concordance found in our statistical analysis ($k = 0.7202$ [95% CI = 0.4905-0.9499]) enabled us to conclude that the visual estimation of the TAD on intraoperative X-rays was sufficient to obtain a postoperative TAD < 25 mm. A new

tool has recently appeared on the market that can calculate in real time the TAD during internal fixation. This is the Stryker ADAPT® 2.0 computer navigation system, which enables intraoperative adjustments to the TAD and cephalic screw length. The advantage of this system is its accuracy [30], but it also has some major disadvantages. These include cost, the need to acquire its dedicated platform, it is only compatible with Gamma3® nails from Stryker, and it sometimes has problems differentiating between the acetabular wall and the femoral head [31].

Utility and use of TAD

The concept of TAD has significantly improved clinical practice and patient survival, since Baumgaertner et al demonstrated that the secondary displacement rate significantly dropped after it was introduced to surgical teams and that it was the only strong predictor of secondary displacement [12]. However, the optimal position of the cephalic screw remains controversial, with the “center-center” position (centered on the anteroposterior and lateral views) long considered the gold standard [7, 32]. More recently, some authors have demonstrated an equivalent stability with a cephalic screw positioned in the lower third in the anteroposterior view and in the center on the lateral view (“inferior-center” position) [33, 34]. The fact that this new reference tended to increase the TAD led Kuzyk et al to propose a new calcar referenced tip-apex distance (CalTAD), which was calculated on a screw in the “inferior-center” position (**Figure 9**) [35]. This new measurement has not proven itself to be better than the “traditional” TAD in limiting the risk of secondary displacements [36]. We therefore chose to use the “traditional” TAD, which is the most commonly used measurement.

Moreover, our study only included intramedullary nails. However, the TAD was initially calculated for dynamic hip screw plate fixation. Two studies demonstrated the validity of measuring the TAD using intramedullary nails as a predictor for secondary displacement [16, 37].

Factors that may explain an intraoperative TAD > 25 mm

We presumed that an unstable fracture, a high degree of osteoporosis or a lack of surgical experience could explain the intraoperative observation of a TAD > 25 mm. However, our statistical analysis revealed no significant association between these three factors and an intraoperative TAD > 25 mm. These results were consistent with the

literature [8, 10, 13, 14, 16–19]. As for fracture type and degree of osteoporosis, this may be due to our study's low statistical power caused by the too small sample size since this was not the main objective of the study. Although the confidence interval for the odds ratios included 1, these 2 factors were consistent with an influence on the TAD. As for surgeon experience, we think that the non-significant results may be due to the department's educational campaign to inform surgeons about the concept of TAD, the intraoperative visual estimation technique and its impact on the incidence of secondary displacement over the long term.

Secondary displacement

The secondary displacement rate in our study was 3.28%. This rate was consistent with the literature since the reported incidences varied between 0% and 16%, with a mean of 5% [8, 10, 13, 14, 16–19]. A symposium held by the French Society of Orthopedics and Traumatology (SOFOT) in 2018 on the technical and medicolegal implications of internal fixation failures in nearly 1,000 patients revealed a failure rate of 8% with, among other predictors of failure, cephalic screw placement [38]. However, a distinction must be made between secondary displacement with intra-articular extrusion of the fixation device and secondary displacement without extrusion. John et al. demonstrated that TAD is only valid for assessing the risk of secondary displacement with an intra-articular extrusion of the cephalic screw [16]. One possible approach for assessing secondary displacement without extrusion of the fixation may be the analysis of patients with inconsistent intraoperative and postoperative TAD results. As a matter of fact, we noted that 4 patients in our study had an intraoperative TAD < 25 mm and a postoperative TAD > 25 mm, with no subsequent secondary displacement involving extrusion of the cephalic screw. We think that changes in the TAD that occur as the fracture heals could be used to assess secondary displacement without extrusion of the fixation.

Study limitations and strengths

One of our study's limitations is the relatively short follow-up. We chose this time frame because any secondary displacement that occurs after 6 months is no longer just related to the position of the cephalic screw but is also linked to a delayed nonunion.

Another limitation was the high incidence of uninterpretable results (28 patients out of 98 - 28.5%). Finally, the small number of patients included in our study did not give us sufficient statistical power to obtain satisfactory results with the multivariate analysis of the secondary objectives. Indeed, we observed wide confidence intervals for the odds ratios on the graphical representation. However, this was not the main objective of the study and could be addressed in another paper.

The strengths of our study were its unique character, since it had never been studied from this angle before, its prospective design and the homogeneity of the surgical management (intramedullary nails only) which reduced potential biases in the interpretation of results as well as, the reproducibility of X-rays and measurements used, making them comparable.

Conclusion:

Internal fixation using short intramedullary nailing is the preferred treatment for trochanteric fractures and a TAD < 25 mm is currently the only known predictor that decreases the risk of secondary displacement. Our study confirmed the high degree of concordance between the intraoperative visual estimation of the TAD and its postoperative measurement on digital X-rays.

Conflicts of interest: none

Sources of funding: none

Author contributions: AD, AA, SC, TC, PSM participated in project development, data analysis, and drafting and editing of the manuscript.

EA participated in the statistical analysis.

PSM participated in the editing of the manuscript and project supervision.

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Figures and tables

Table 1: Sociodemographic data

Table 2: Association between TAD > 25 mm and fracture type, degree of osteoporosis and surgeon experience.

Figure 1: Illustration of the acquisition of intraoperative lateral X-rays with fluoroscope tilted at 15°.

A: patient positioning
B: X-ray before internal fixation
C: X-ray of screw positioning

Figure 2: Tip-apex distance (TAD) according to Baumgaertner et al, on anteroposterior (Xap) and lateral (Xlat) X-rays, after magnification correction [7].

D_{true} = known cephalic screw diameter as described in the manufacturer's documentation.

D_{ap} = cephalic screw diameter measured on the anteroposterior view.

D_{lat} = cephalic screw diameter measured on the lateral view.

Figure 3: Quantification of the intraoperative visual estimation of the TAD on image intensifier X-rays printed at the end of the procedure.

A and C: anteroposterior and lateral views of the hip after internal fixation.

B and D: tracings of the contours of the femoral head and neck (red dotted lines), lines used to find the apex of the femoral head (red lines), TAD (blue line) and cephalic screw diameter (black line).

Figure 4: Measurement of TAD at 6 weeks on digital X-rays using the reference method described by Johnson et al. [27].

Figure 5: Classification of trochanteric fractures according to AO/OTA [28].

A1: stable fractures, A2-A3: unstable fractures (comminution of lesser trochanter, no medial wall)

Figure 6: Singh index for osteoporosis [29].

Grade 1: Disappearance of all bone trabeculae except the principal compressive group.

Grade 2: No greater trochanter group or principal tensile and compressive group.

Grade 3: Weakening of the principal tensile and compressive group.

Grade 4: Disappearance of the greater trochanter group.

Grade 5: Weakening of the greater trochanter group.

Grade 6: Normal femur.

Figure 7: Study flowchart

Figure 8: Graphic representation of the odds ratios from the multivariate logistic regression analysis.

Figure 9: Illustration of the difference between traditional TAD (left) and the CalTAD (right) proposed by Kuzyk et al [35].

Figure 1:

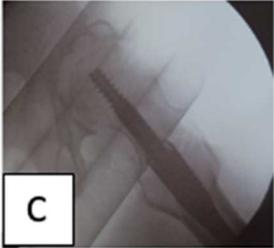
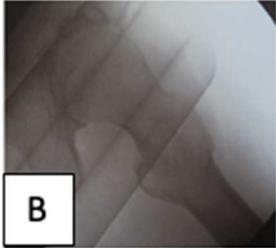


Figure 2:

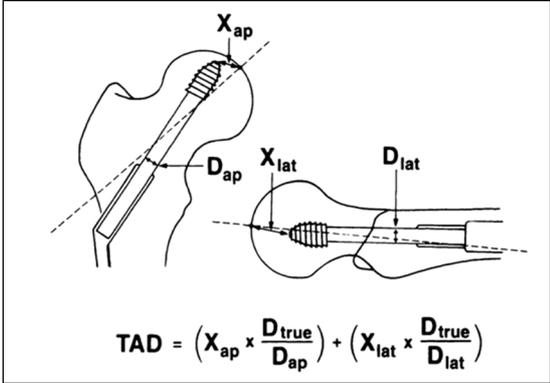


Figure 3:

ANTEROPOSTERIOR	Measured	True
TAD _{AP} (mm)	8	$(8 \times 10.5)/8 = \mathbf{10.5}$
Cephalic screw diameter (mm)	8	10.5

$$\text{TAD}_{\text{total}} = 10.5 + 9.45 = 19.95 \text{ mm}$$

LATERAL	Measured	True
TAD _{lateral} (mm)	9	$(9 \times 10.5)/8 = \mathbf{9.45}$
Cephalic screw diameter(mm)	10	10.5

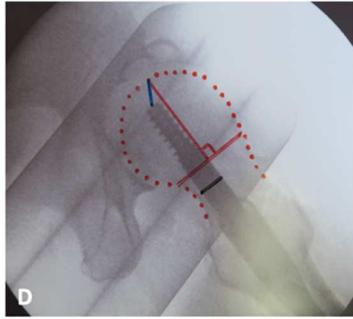
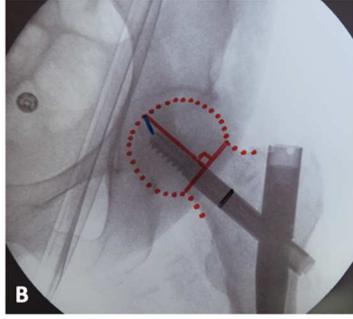
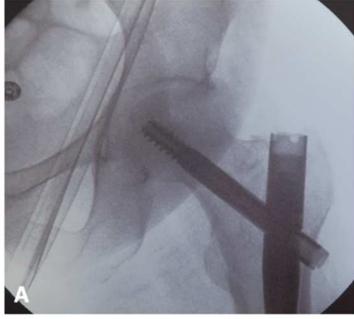


Figure 4:

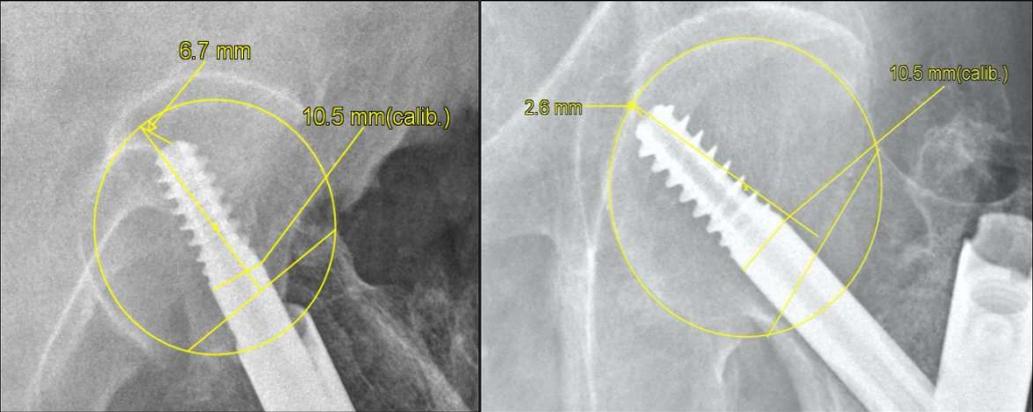


Figure 5:

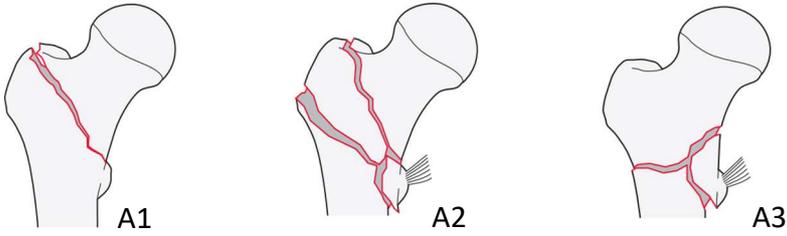


Figure 6:

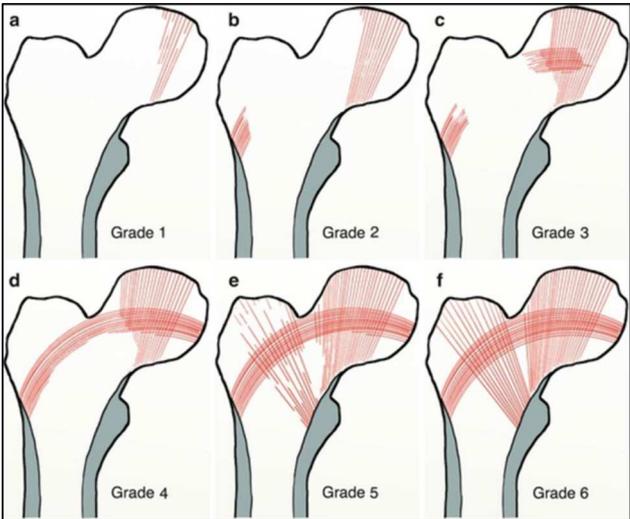


Figure 7:

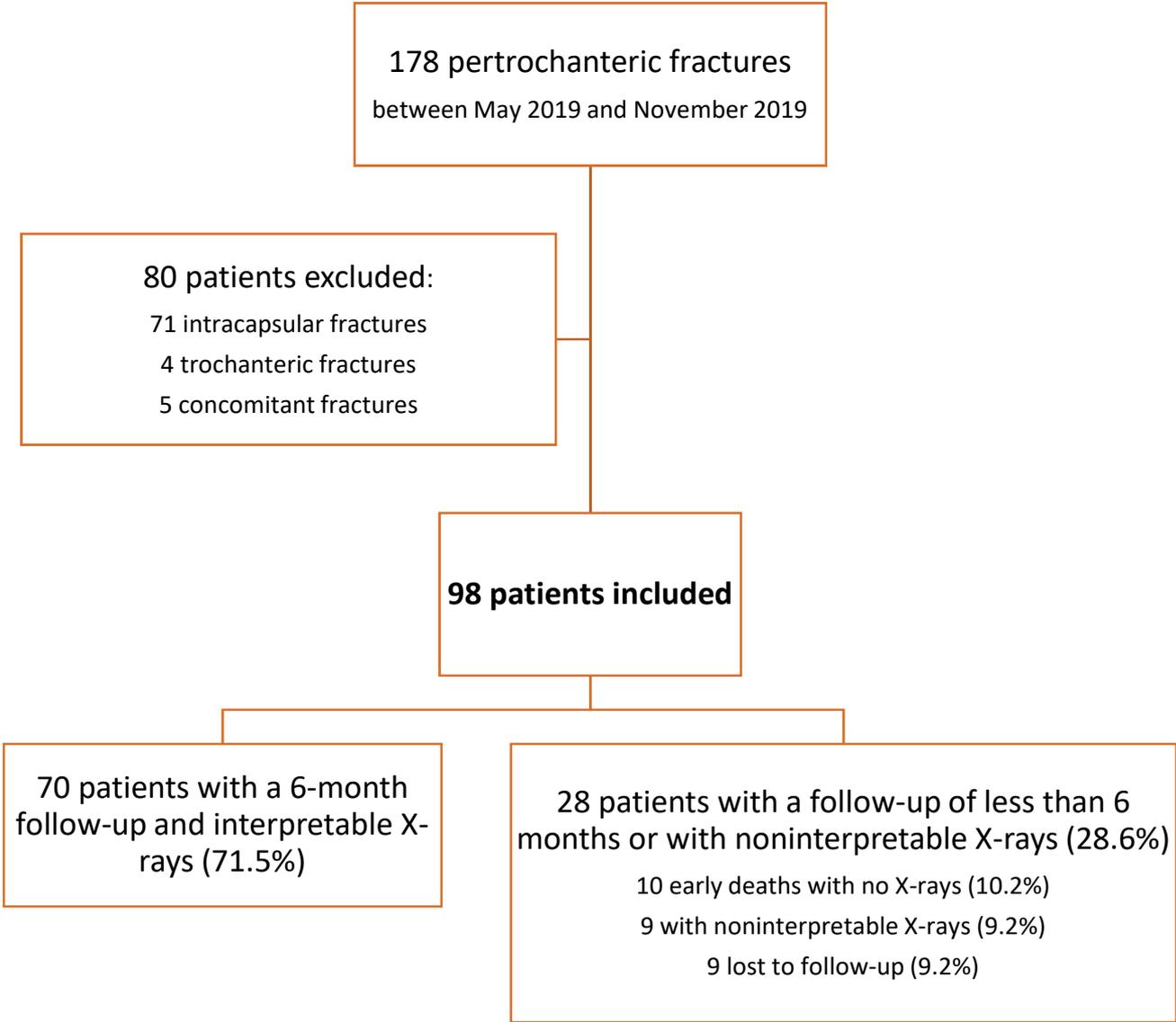


Figure 8:

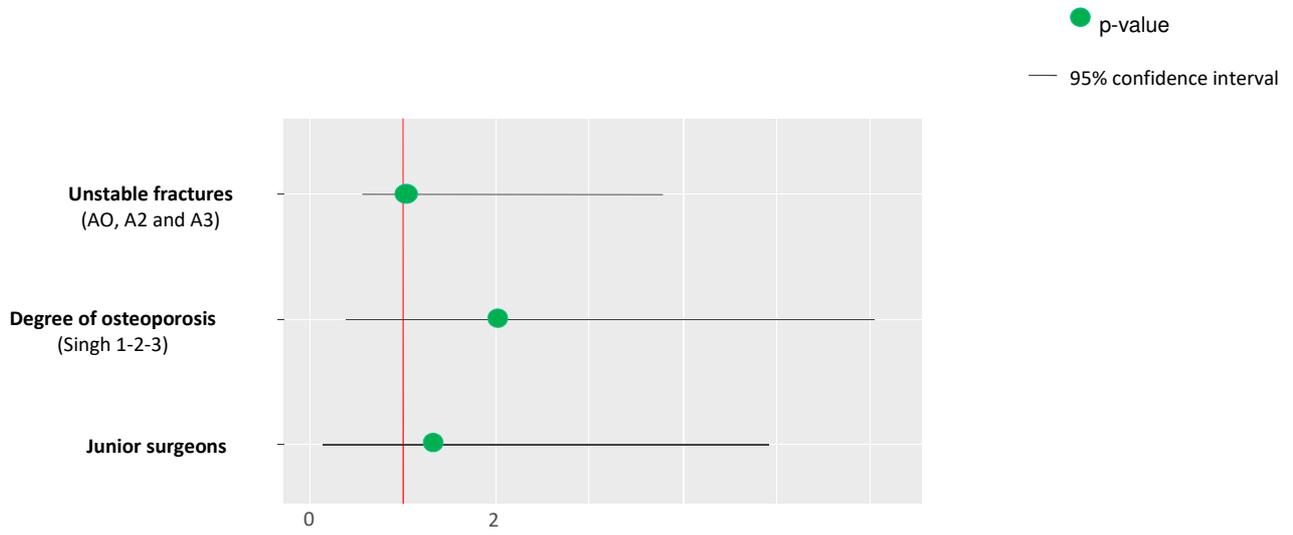


Figure 9:

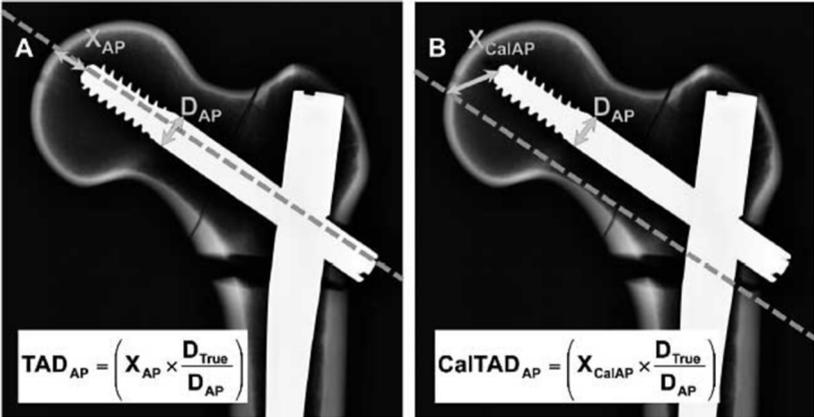


Table 1:

Operated patients with interpretable X-rays		n = 70
Age at the time of the fracture		87 years (+/- 8 years) [min: 70; max: 100]
Sex		
Male		16 (22.86%)
Female		54 (77.14%)
Operated side		
Right		34 (48.5%)
Left		36 (51.5%)
Mean ASA score		3 (+/- 0.81) [min: 1; max: 4]
Type of fracture		
Type 1		29 (41.4%)
Type 2		30 (42.8%)
Type 3		11 (15.8%)
Degree of osteoporosis		
Grades 1-2-3		48 (68.6%)
Grades 4-5-6		22 (31.4%)
Surgeon experience		
Junior surgeon		47 (67.1%)
Senior surgeon		23 (32.9%)

Table 2:

	Number (n)	Percentage (%)	p-value
Type of fracture			.7290
Type A1	7	43.75	
Type A2	5	31.25	
Type A3	4	25	
Degree of osteoporosis			.5701
Grades 1-2-3	12	75	
Grades 4-5-6	4	25	
Surgeon experience			1
Junior surgeon	12	75	
Senior surgeon	4	25	