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Analysis of the Radiological Anatomy of the Proximal Femur after the Intramedullary Nailing of Trochanteric Fractures

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Abstract

Background. Despite the high rate of the intramedullary osteosynthesis of proximal femur fractures, the incidence of implant-associated complications exceeds 50%. Poor reduction and incorrect implant positioning significantly increase the risk of mechanical complications and the frequency of unsatisfactory treatment outcomes.

The aim of the study was to evaluate various fragment positions after the intramedullary nailing of proximal femur fractures using the developed radiological criteria for assessing the quality of reduction, and to determine the association between the quality of the restoration of the proximal femur, implant position and fracture type.

Methods. In a retrospective single-center study we analyzed the primary X-rays of 108 patients with type 31A fractures. Radiological criteria were preliminarily defined. According to them, the position of the fragments and implants was considered satisfactory if the value of the neck-diaphyseal angle was more than 125°, anteversion did not exceed 20°, medial diastasis was not more than 10 mm, and there were no negative medial support, no femoral neck lengthening of more than 10 mm compared with the healthy side, and no penetration of the blade into the joint. Patients were divided into three groups according to the fracture type. We analyzed and compared the proportions of satisfactory and unsatisfactory radiological results within the groups and between them.

Results. Satisfactory reduction was noted in 83 patients (76.9%) out of 108, unsatisfactory — in 25 patients (23.1%), and 16 patients (14.8%) had incorrect implant position. Patients with type 31A1 fractures were 3.5 times less likely to have an unsatisfactory reduction than patients with type 31A2 fractures (OR 3.511; 95% CI 1.202-10.261) and 6.7 times less likely to have an unsatisfactory reduction than patients with type 31A3 fractures (OR 6.714; 95% CI 1.685-26.752). The probability of incorrect implant positioning was 6 times higher in type 31A3 fractures than in type 31A1 fractures (OR 6.000; 95% CI 1.410-25.528).

Conclusion. To improve the quality of surgical treatment, it is worth paying an increased attention to the quality of the achieved reduction, implant selection, technical peculiarities of the fixation of types A2 and A3 fractures, improvement of preoperative planning algorithms, as well as development of criteria for intraoperative radiological assessment of the quality of the restoration of the proximal femur anatomy.

Keywords: pertrochanteric fracture, proximal femoral nail, osteosynthesis complications, preoperative planning, intramedullary osteosynthesis.

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Анализ рентгенологической анатомии проксимального отдела бедренной кости после интрамедуллярного остеосинтеза переломов вертельной зоны

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Реферат

Введение. Несмотря на распространенность интрамедуллярного остеосинтеза при переломах вертельной области бедренной кости, доля осложнений, связанных с имплантатами, превышает 50%. Некачественная репозиция и некорректное положение имплантата значительно повышают риск развития механических осложнений и частоту неудовлетворительного исхода лечения пациентов.

Цель исследования — оценить варианты положения отломков после фиксации вертельных переломов проксимальным бедренным стержнем на основании разработанных рентгенологических критериев оценки качества репозиции и определить зависимость качества восстановления анатомии проксимального отдела бедренной кости и положения имплантатов от типа перелома.

Материал и методы. В ретроспективном одноцентровом исследовании проанализированы первичные рентгенологические результаты лечения 108 пациентов с переломами типа 31А. Были сформулированы рентгенологические критерии, согласно которым положение отломков и имплантатов признавали удовлетворительным при условии величины шеечно-диафизарного угла более 125°, антеверсии — не более 20°, величины медиального диастаза — не более 10 мм, отсутствия отрицательной медиальной опоры, отсутствия удлинения шейки бедренной кости более 10 мм в сравнении со здоровой стороной, отсутствия пенетрации шеечного винта в сустав. Пациенты были разделены на три группы в зависимости от типа перелома. Мы проанализировали и сравнили доли удовлетворительных и неудовлетворительных рентгенологических результатов в группах и между группами.

Результаты. Удовлетворительная репозиция отмечена у 83 пациентов (76,9%) из 108, неудовлетворительная — у 25 пациентов (23,1%), у 16 пациентов (14,8%) отмечено некорректное положение имплантатов. У пациентов с переломами типа 31А1 вероятность неудовлетворительной репозиции в 3,5 раза ниже, чем у пациентов с переломами 31А2 (ОШ 3,511; 95% ДИ 1,202–10,261), и в 6,7 раз ниже, чем при переломе типа 31А3 (ОШ 6,714; 95% ДИ 1,685–26,752). Вероятность некорректного положения имплантата в 6 раз выше при переломах типа 31А3, чем при переломах типа 31А1 (ОШ 6,000; 95% ДИ 1,410–25,528).

Заключение. Для повышения качества хирургического лечения необходимо уделять повышенное внимание качеству достигнутой репозиции, выбору имплантата, техническим особенностям его установки при переломах типов А2 и А3, улучшению алгоритмов предоперационного планирования, а также детальной разработке критериев интраоперационной рентгенологической оценки качества восстановления анатомии проксимального отдела бедренной кости.

Ключевые слова: чрезвертельный перелом, проксимальный бедренный стержень, осложнения остеосинтеза, предоперационное планирование, интрамедуллярный остеосинтез.

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INTRODUCTION

The proportion of fractures in the trochanteric region accounts for 30.0-51.5% of all femoral fractures and 45.0-55.0% of proximal femoral fractures (PFF) [1, 2, 3]. The presence of osteoporosis and concomitant somatic pathology in patients increases the risk of both local and systemic complications [1, 4]. Consequently, the requirements for the quality of osteosynthesis are heightened, as reduced bone mineral density contributes to the failure of fixation [5]. While answers to questions regarding preoperative examination, timing of osteosynthesis, and its pharmacological support are outlined in current clinical guidelines, the problem of the quality of fracture reduction and its impact on treatment outcomes remains insufficiently studied [6, 7, 8, 9].

At the same time, modern scientific literature on the surgical treatment of trochanteric femoral fractures has increasingly focused on the quality of osteosynthesis [9, 10, 11]. The main goal of surgical intervention is the rapid restoration of weight-bearing capacity in the injured limb and, consequently, early patient ambulation to prevent hypostatic complications. According to many authors, this can only be achieved through a high-quality reduction of bone fragments and their stable fixation, i.e., correct hardware implantation [12, 13].

Most modern implants used for the osteosynthesis of trochanteric fractures are dynamic. Their design incorporates the option of dynamic compression under the force of muscle contraction and axial load, which enhances the mechanical stability of fragment fixation and promotes fracture healing. However, this option is only effective when the neck-shaft angle (NSA) is restored, and the axis of the femoral neck and head aligns with the position of the neck screw [14].

The primary method of surgical treatment for trochanteric femoral fractures at the Interdistrict Clinical Hospital of Vsevolozhsk is intramedullary locking osteosynthesis using a proximal femoral nail. This method is universal and indicated for both stable trochanteric (type 31A1) and unstable fractures (types 31A2 and 31A3). The well-studied surgical technique, the possibility of the closed reduction of fragments under fluoroscopic control in most cases, and the high stability of the implant-bone system when the nail is correctly installed make this method the treatment of choice even for patients with reduced bone density [6, 15, 16].

However, despite the advantages of intramedullary osteosynthesis for trochanteric fractures, the rate of implant-related complications following intramedullary nailing with proximal femoral nail exceeds 50% [17]. The most common complication is the cut-out of the neck screw, occurring in 3-16% of cases [10, 11, 15]. Cut-out may be accompanied by varus collapse or medial penetration of the screw into the joint. Another complication is the Z-effect, which is similar in mechanism and causes and is typical for dual-screw nails [18]. Implant fractures, nail migration, locking screw fractures, periprosthetic fractures, as well as malunion and nonunion may indicate biomechanical problems in the bone-implant system. Under axial load, angular deformation increases, and uncontrolled lateral displacement of the neck screw occurs. In foreign literature, this phenomenon is referred to as sliding [15].

Factors such as gender, age, fracture type, and bone quality influence the frequency of unsatisfactory outcomes and should be considered by the operating surgeon, although they are not directly under their control. At the same time, the quality of the operation, appropriate implant selection, and its correct placement are within the surgeon's responsibility and are controlled during preoperative planning and osteosynthesis.

According to several authors, poor reduction and incorrect implant positioning can lead to mechanical complications, reoperations, and unsatisfactory outcomes in patients with trochanteric fractures [8, 9, 10, 11]. The risk of complications can be reduced through intraoperative assessment and timely correction of radiographic parameters [9, 12, 19, 20].

The aim of the study was to evaluate various fragment positions after the intramedullary nailing of proximal femur fractures using the developed radiological criteria for assessing the quality of reduction, and to determine the association between the quality of the restoration of the proximal femur, implant position and fracture type.

METHODS

Study design: a retrospective cohort study. Primary radiological outcomes of 108 patients with trochanteric femoral fractures (type 31A according to the AO classification) who underwent locking intramedullary osteosynthesis with a proximal femoral nail at the Level I Trauma Center of the Interdistrict Clinical Hospital of Vsevolozhsk from January 1, 2022 to December 31, 2022 were analyzed. All operations were performed using a standard technique with closed reduction on an orthopedic table under intraoperative fluoroscopy using a C-arm in both AP and axial views. The study included 78 (72.2%) women and 30 (27.8%) men. The median age was 82.0 years (Q1-Q3: 71-86, min – 30, max – 99).

Patients were divided into groups according to the type of trochanteric fracture. The groups were comparable in terms of gender (p = 0.369) and age (p = 0.554) (Table 1).

Pre- and postoperative X-rays in AP and axial views were analyzed. Based on the literature, the following radiological criteria for assessing the quality of fragment reduction and implant positioning were defined: NSA, femoral neck anteversion, medial contact gap between the femoral neck and metaphyseal zone, type of medial support, and length of the femoral neck and head compared to the healthy limb.

On the X-ray in AP view, the angle between the axis of the femoral head and neck and the anatomical axis of the femoral diaphysis (NSA) was measured. On the axial (lateral) X-ray, the anteversion angle of the femoral neck and head was determined by measuring the angle between the anatomical axis of the femoral diaphysis (mid-diaphyseal line) and the axis of the femoral neck (line passing through the midpoint of the femoral neck) [21].

On the AP view X-ray, the presence of a gap in the medial contact area between the femoral neck and metaphyseal zone was assessed. Its size was determined by measuring the distance between the medial cortex of the distal fragment and the inferomedial cortex of the proximal fragment along a line parallel to the axis of the femoral neck [13]. Additionally, the presence of negative medial support, characterized by the medial cortex of the proximal fragment overlapping laterally to the medial cortex of the distal fragment, was evaluated on the AP view X-ray [12].

Table 1

Characterization of patient groups by gender and age

Fracture type	Number of patients	Age, Me (IQR; min-max)	Gender	
			female	male
A1	53 (49.1%)	80 (69-85; 30-99)	35 (66%)	18 (34%)
A2	42 (38.9%)	83.5 (72.5-87.0; 37-91)	33 (79%)	9 (21%)
A3	13 (12.0%)	83 (70.5-87.0; 59-91)	10 (77%)	3 (23%)
Total	108 (100%)	82 (71-86; 30-99)	78 (72.2%)	30 (27.8%)

Wedge effect [22, 23], characterized by a relative increase in the length of the femoral neck and head, was measured on the X-ray in AP view along a line corresponding to the axis of the femoral neck from the apex of the head to the intersection with the outer cortex of the subtrochanteric region. The relative increase in femoral neck length compared to the contralateral limb was also measured on the AP view X-ray.

Regarding implant positioning, the placement of the neck screw not above the center of the head on AP and lateral X-rays was considered normal. The deviation of the neck screw axis from the central position by no more than the width of its cross-section upward and posteriorly, as well as a lower screw position on the AP view X-ray, was considered acceptable but only for dual-screw systems. A low screw position at the base of the neck in a single-screw system was deemed unsatisfactory.

The length of the neck screw was considered correct if the distance from the proximal end of the screw to the central point of the articular surface of the femoral head was no more than 1.0 cm [8, 24]. Screw positioning resulting in joint penetration, i.e., the screw tip extending beyond the articular surface of the femoral head on AP or axial X-rays, was deemed unsatisfactory. The derotation screw was assessed for being parallel to the neck screw. The length of the derotation screw was only determined in cases of perforation of the articular surface of the femoral head.

Fragment and implant positioning were considered satisfactory if the NSA was greater than 125°, anteversion was no more than 20°, medial diastasis was no more than 10 mm, negative medial support was absent, femoral neck lengthening was no more than 10 mm compared to the healthy limb, and there was no penetration of the neck screw beyond the femoral head. Otherwise, fragment positioning was deemed unsatisfactory.

We analyzed the proportion of satisfactory and unsatisfactory radiological outcomes based on the fracture type. All measurements were performed on a personal computer using the RadiAnt DICOM Viewer software (Medixant, Poland) with the ruler tool.

Statistical analysis

The database was compiled in Microsoft Excel (Microsoft Office 365, Microsoft Inc., USA). Statistical analysis was performed using SPSS Statistics v.27 (IBM, USA).

The distributions of all quantitative variables were assessed for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Based on the results, the null hypothesis was rejected, and the non-parametric Kruskal-Wallis test was used for comparing quantitative variables.

Nominal variables were presented in contingency tables. Their analysis was conducted using the Pearson $\chi 2$ test and the two-proportion Z-test with the Benjamini-Hochberg correction for multiple comparisons. The strength of the association between variables was assessed by calculating Cramer's V. For 2x2 contingency tables, the odds ratio (OR) with a 95% confidence interval (95% CI) was calculated. Relative values are presented as percentages.

RESULTS

Data on the quality of reduction and the correctness of implant positioning are presented in Table 2.

In 5 (9.4%) patients with type 31A1 fractures, incorrect implant positioning was observed. In 2 of these cases, the neck screw was inserted above the axis, and in 3 cases, the screw length was insufficient. Despite the errors in implant positioning, the reduction of fragments was deemed satisfactory in 2 of these 5 patients.

In the group with type 31A2 fractures, incorrect implant positioning was noted in 6 (14.3%) patients: 3 cases of non-parallel insertion of neck screws, 1 case of cartilage perforation in the femoral head, and 2 cases of using a short screw.

The highest number of patients with incorrect implant positioning was found in the group with type 31A3 fractures—5 (38.4%). One patient had a short neck screw, and in one case, the screw perforated the femoral head. In 2 patients, the neck screw was positioned too low, and in one case, it was positioned too high. Notably, only 4 (30.7%) patients in this group received the long version of the nail.

A correlation was found between fracture type and reduction quality: $\chi^2 = 9.473$; $p = 0.009$. The strength of this correlation, based on Cramer's V (V = 0.296) and interpreted according to the recommendations of L.M. Rea and R.A. Parker [25], was considered moderate.

Pairwise comparison of the groups revealed that statistically significantly fewer cases of unsatisfactory reduction were observed in patients with type 31A1 fractures ($p = 0.026$ compared to 31A2 and $p = 0.011$ compared

Table 2

Distribution of patients by fracture type and the quality of fragment reduction according to the radiological criteria

Fracture type	Number of patients	Satisfactory reduction	Unsatisfactory reduction	Incorrect implant positioning
31A1	53 (49.1%)	47 (88.7%)	6 (11.3%)	5 (9.4%)
31A2	42 (38.9%)	29 (69.0%)	13 (31.0%)	6 (14.3%)
31A3	13 (12.0%)	7 (53.8%)	6 (46.2%)	5 (38.4%)
Total	108 (100%)	83 (76.9%)	25 (23.1%)	16 (14.8%)

to 31A3). It was noted that the odds of unsatisfactory reduction were 3.5 times lower in patients with type 31A1 fractures compared to those with type 31A2 fractures (OR 3.511; 95% CI 1.202-10.261) and 6.7 times lower compared to type 31A3 fractures (OR 6.714; 95% CI 1.685-26.752). No statistically significant differences were found between the patients with type 31A2 and 31A3 fractures.

A statistically significant correlation was also found between fracture type and implant positioning: $\chi^2 = 6.985$; $p = 0.03$. The strength of this correlation, based on Cramer's V (V = 0.254) and interpreted according to the recommendations of L.M. Rea and R.A. Parker, was considered moderate.

Pairwise comparison of the groups showed that the patients with type 31A3 fractures had statistically significantly more cases of incorrect implant positioning ($p = 0.027$) compared to those with type 31A1 fractures. The odds were 6 times higher in patients with more severe type 31A3 fractures compared to those with type 31A1 fractures (OR 6.000; 95% CI 1.410-25.528).

We analyzed all 25 cases of unsatisfactory fragment positioning. The most common reduction error was varus positioning of the proximal fragment with a NSA of less than 125°, observed in 17 patients (15.7% of all 108 patients).

The wedge effect, which develops during nail insertion and leads to the lateralization of the diaphyseal fragment and relative lengthening of the femoral neck, was noted in 10 patients (9.3%) (Figure 1). A pathological medial gap between fragments exceeding 10 mm was observed in 7 (6.5%) patients (Figure 2), and negative medial support was noted in 3 (2.7%) patients (see Figure 1). Significant rotational deformity of the femoral neck with increased anteversion of the head was detected in 3 (2.7%) patients.

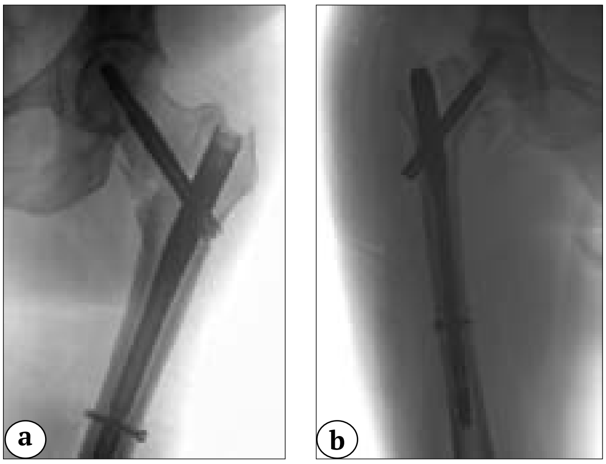

Figure 1. Reduction errors in the osteosynthesis of the proximal femoral fractures:
a — wedge effect, lateralization of the diaphyseal fragment;
b — varus position of the proximal fragment, negative medial support, wedge effect with lateralization of the diaphyseal fragment, incorrect position of the neck screw

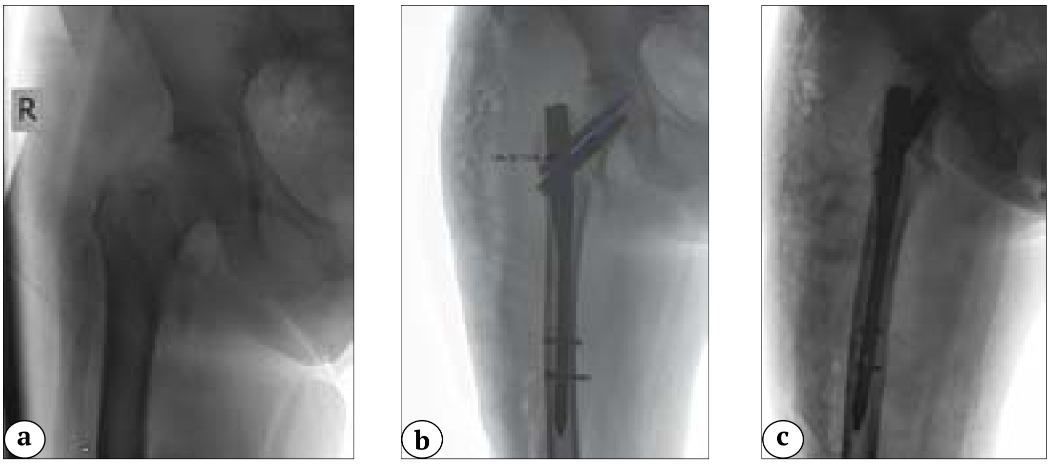

Figure 2. Reverse wedge effect leading to the formation of a pathological calcar gap:
a — initial X-ray; b — X-rays after osteosynthesis;
c — valgus displacement of the proximal fragment, reverse wedge effect

A more detailed analysis of the data from 16 patients with incorrect implant positioning showed that the primary perforation of the femoral head by the neck screw occurred in 2 (1.9%) patients. In one (0.9%) patient with a primary type 31A1 fracture and a short proximal femoral nail, a fracture of the lateral wall extending to the upper third of the diaphysis was identified. In cases where a Gamma nail was used, the neck screw was positioned too high in 3 (2.8%) patients and too low in 2 (1.9%) patients (see Figure 1b). In 6 (5.6%) patients, the implanted neck screw was too short (Figure 3), and in 3 (2.8%) patients, the neck and derotation screws were not parallel on the AP view X-ray.

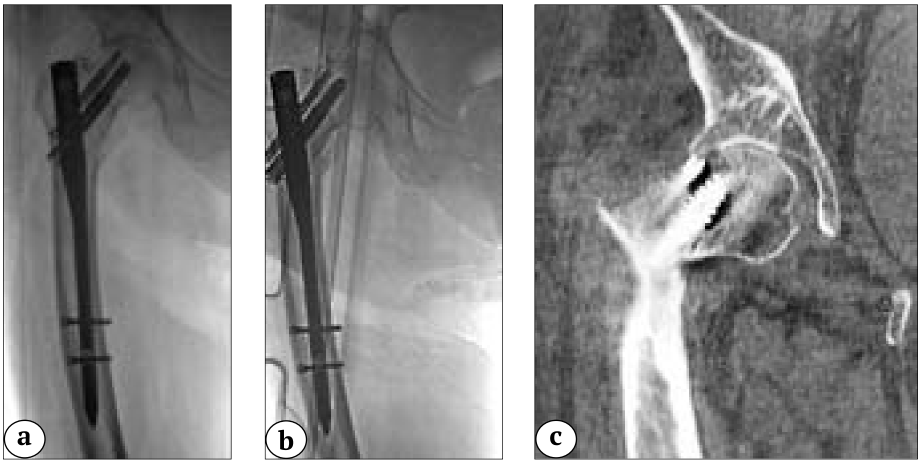

Figure 3. Cut-out of the short neck screw:
a — AP view X-ray after osteosynthesis;
b — AP view X-ray 2.5 months postoperatively;
c — coronal CT 2.5 months postoperatively, demonstrating the cut-out of the neck screw

DISCUSSION

The frequency of mechanical complications in osteosynthesis of trochanteric fractures, such as varus collapse, implant migration and perforation, nonunion, and the need for reoperation, ranges from 4.6 to 12.4% [26] and increases to 30-50% in cases of primary osteosynthesis errors [10, 17]. Therefore, in our opinion, well-performed osteosynthesis promotes early patient mobilization and achieves good treatment outcomes.

Unstable fractures of types 31A2 and 31A3 require increased attention, as the surgical treatment of such patients, as our study has shown, is associated with technical challenges. Implant positioning and the quality of fragment reduction are important indicators of fixation stability and the risk of complications [19].

First and foremost, the correctness of screw positioning in the femoral head is assessed. It is believed that the screw tip should be oriented toward the center of the femoral head in both AP and axial views. In AP view, when using a dual-screw system, the screw can be positioned in the lower third of the head [9, 24]. Many authors use Parker's ratio, determining the percentage ratio of the distance from the base of the femoral head to the screw on the AP view X-ray and from the posterior wall to the screw on the lateral X-ray [27]. Parker's ratio should not exceed 50% [23], which is why the positioning of the neck screw was deemed incorrect in 5 (4.6%) patients in our study (see Figure 3).

In 1995, M.R. Baumgaertner et al. proposed the tip-apex distance (TAD) criterion as the sum of the distances from the apex of the femoral head to the upper end of the neck screw in two views. After examining 198 trochanteric fractures, the authors noted complications in 19 cases (including 16 cut-outs). Based on these findings, it was determined that the TAD value should not exceed 25 mm [8].

P.R. Kuzyk et al. proposed measuring the calcar-referenced tip-apex distance (CalTAD) on the AP view X-ray, which represents the distance from the screw tip to the point where the circumference of the femoral head intersects with a line parallel to the axis of the femoral neck and passing through its base [28]. This approach favors a lower position of the neck screw relative to the central axis of the neck. However, some modern authors have not found a statistically significant correlation between a TAD of less than 25 mm and cut-out, stating that a TAD and CalTAD of less than 20 mm carry the risk of screw penetration into the joint, especially with low screw positioning [11]. In our study, we focused on the position of the neck screw relative to the center of the femoral head and the distance from the proximal end of the screw to the central point of the articular surface of the head, considering a distance of no more than 1.0 cm as normal. If this distance was greater, the screw was deemed too short or its positioning was considered incorrect, which was noted in 6 (5.5%) patients.

In three cases where a dual-screw system was used, the screws in the femoral head were not inserted parallel, which may have been due to instrumentation defects or insufficiently secure fixation of the guide device during channel formation.

The above parameters are important but not the only criteria for assessing the quality of reduction and fracture fixation. As additional criteria, we selected the following parameters for a more comprehensive evaluation of radiological surgical outcomes: NSA and femoral neck anteversion angle. These parameters were determined on AP and axial X-rays. According to L.N. Solomin et al., the average NSA is 130° (124-136°), and the anteversion angle is 170° (165-175°) [21]. For greater objectivity, these values should be compared with those of the healthy limb, which may differ due to individual patient characteristics.

Since many patients lacked X-rays of the healthy joint, we considered a NSA of 125° as the threshold. According to A. Kashigar et al., there is a statistically significant correlation between residual varus deformity and the risk of cut-out [10]. In our study, 17 (15.7%) patients exhibited residual varus deformity of the proximal femur with a NSA of less than 125° after operation, which, in our opinion, most often indicates poorly performed reduction.

According to the literature, the acceptable margin of error for anteversion is 20° [12, 19]. Excessive anteversion is generally associated with non-central positioning of the neck screw on the lateral X-ray, which significantly increases the risk of cut-out [8, 10, 27]. In 3 (2.7%) patients, we noted increased anteversion on the lateral X-ray.

Formation of medial support: positive, neutral, and negative medial support

S.M. Chang et al. proposed the concept of reduction for trochanteric fractures of types 31A1 and 31A2 with positive medial support, which involves eliminating displacement in the area of the contact between the medial cortices of the proximal and distal fragments so that the medial cortex of the proximal fragment is slightly medial to the medial cortex of the distal fragment. During compression between the fragments, the proximal fragment is supported by the distal fragment, preventing excessive displacement of the proximal fragment under the dynamic compression of the neck screw under axial load. Otherwise, if the medial cortex of the distal fragment is medial to the proximal fragment, there will be no support between the fragments. This can lead to uncontrolled medialization of the distal fragment, increased varus deformity, screw migration, and penetration into the joint or cut-out [12].

Neutral support is defined as the position where the medial cortices of the fragments are aligned. The authors tested this concept in a clinical study involving 127 patients. Surgeons achieved reduction with positive medial support in 89 (70%) patients. In 26 (20.5%) patients, reduction was with neutral support, and in 12 (9.5%) patients, it was with negative support. A statistically significant difference was found in the increase in varus deformity up to 8.9° and shortening of the neck up to 6.8 mm in the group with negative medial support. In the group with positive medial support, patients returned to full weight-bearing earlier, experienced less pain, and had better functional outcomes [12].

We consider this concept justified and convenient for use, as the described features are easily distinguishable on intraoperative X-rays. In our study, we also used the principle of negative medial support as one of the indicators of reduction quality. However, unlike the study by S.M. Chang et al., this feature was noted in only 3 (2.7%) patients in our group.

Neck lengthening and diaphysis lateralization: a wedge effect

Wedge effect was first described by M.J. O'Malley et al. in 2015 [22]. It manifests as lateral displacement of the femoral diaphysis and is characterized by an increase in varus deformity during intramedullary nail insertion (see Figure 1a). This results in the lengthening of the femoral neck and increased femoral offset, leading to increased load on the implant-bone system in the trochanteric region that raises the risk of fixation failure and neck screw cut-out. Additionally, varus positioning of the femoral neck can lead to poor reduction of medial support and incorrect screw positioning in the head, which can also contribute to mechanical complications.

Wedge effect is widely discussed in the literature [22, 23, 29] and is relatively common. According to B.A. Butler et al., it is associated with the higher bone density in the superolateral part of the femoral neck compared to the greater trochanter. Therefore, during drilling, the drill and subsequently the nail are displaced laterally [29].

S.H. Yen et al. observed an average decrease in NSA of 4.16° and an increase in femoral offset of 5.5 mm in a group of 113 patients with trochanteric fractures. In the group of patients with subsequent cut-out, the decrease in NSA was 8.9°. The authors also assert that the presence of a lateral wall fracture, as in type 31A3 fractures, is a predisposing factor for progressive varus deformity [23].

In our study, we also noted the presence of wedge effect, i.e., varus deformity and femoral neck lengthening. This radiological sign was observed in 10 (9.3%) patients. Therefore, we recommend carefully monitoring lateral displacement during the implantation of the proximal femoral nail and following the recommendations to perform reduction with slight valgus, medializing the nail entry point, and temporarily holding the fragments with pointed bone clamps during nail insertion [23, 29].

Pathological calcar gap

Y. Zhang et al. described the reverse wedge effect, which may take place in case of intramedullary osteosynthesis for type 31A1 and 31A2 fractures. During implant insertion, impingement occurs between the nail (or drill) and the proximal wall of the neck fragment, leading to internal rotation of the femoral neck and the formation of a gap in the medial contact area (see Figure 2). The authors report that this effect occurs in 7.97% of cases, with an average gap size of 9.2±4.6 mm [20].

Such fragment displacement can lead to incorrect implant positioning, mechanical complications, and delayed fracture healing. H. Song et al., studying this effect, concluded that the calcar gap should not exceed 4.2 mm on the AP view and 3.8 mm on the lateral view. Otherwise, the risk of losing anteromedial support increases, leading to excessive sliding of the femoral head and neck fragment. In the group of patients with the loss of medial support, the average gap on the AP view X-ray was 7.09 mm, and on the lateral X-ray, it was 5.89 mm in 46 cases. During follow-up, varus deformity greater than 10° was noted in 10 (21.7%) patients, and excessive sliding greater than 10 mm was noted in 8 (17.4%) patients [13]. In our study, a pathological calcar gap of 10 mm or more was observed postoperatively on the AP view X-ray in 7 (6.5%) patients.

In intertrochanteric type 31A3 fractures, many authors assess the integrity of the lateral wall and pay attention to its reduction in case of damage, as residual displacement of the lateral wall fragments or iatrogenic fracture can lead to complications [15, 23]. In an earlier study, C.E. Hsu et al. demonstrated that in patients with a lateral wall thickness of less than 20.5 mm, isolated fixation with a dynamic hip screw (DHS) significantly increases the risk of lateral wall fracture and mechanical complications [30].

J. Li et al. proposed a classification of trochanteric fractures based on computed tomography (CT). They divided them into five types depending on the integrity of the lateral wall and the preservation of medial cortical support. The first three types are stable and characterized by varying degrees of medial support involvement with an intact lateral wall. Type IV is characterized by partial, and type V by complete destruction of the lateral wall. Both types are unstable, with a tendency for excessive sliding of the neck screw and medial displacement of the femoral diaphysis. Type IV can be complicated by iatrogenic fracture of the lateral wall during reduction and implant insertion, which exacerbates instability [26].

S. Babhulkar et al. proposed their own classification of unstable fractures that require careful planning and mandatory preoperative CT to clarify the morphology and type of lateral wall fracture, posterior intertrochanteric fragment (posterior wall), and lesser trochanter fragment (medial column). During osteosynthesis, the authors recommend accurately reducing these fragments and fixing them with additional cerclage wires [15].

In our study, two patients with type 31A3 fractures had significant residual displacement of the greater trochanter fragment, with the neck screw passing through the fracture line of the lateral wall. In another 4 patients, the neck screw was inserted through the intertrochanteric fracture line, but no primary displacement of the greater trochanter fragment was observed. Subsequently, two of these patients experienced cut-out, requiring reoperation.

In one case, correcting osteotomy with repeated osteosynthesis using a dynamic condylar screw (DCS) was performed 6 months after the initial operation. In the second case, at 7 months post-osteosynthesis, the intramedullary nail was removed, followed by total hip arthroplasty. Another patient had an iatrogenic lateral wall fracture without significant fragment displacement.

It is also worth noting that only 4 of the 13 patients with type 31A3 fractures received the long version of the intramedullary nail. While this is not a violation of the technique, there are publications describing the advantages of the long version of the proximal femoral nail for type 31A3 and 31A2.3 fractures, as well as in cases of a wide medullary canal and the presence of a large coronal lateral wall fragment [31].

Thus, the analyzed group of patients with trochanteric femoral fractures is sufficiently representative and comparable in terms of gender, age, and fracture characteristics to the groups studied by other authors [13, 20, 24]. The surgical method used in our study complies with current clinical guidelines.

X-ray analysis showed that a significant proportion of patients (23.1%) had unsatisfactory fragment and implant positioning. There was also a progressive deterioration in reduction quality and an increase in unsatisfactory outcomes with increasing fracture severity. Thus, the proportion of unsatisfactory radiological outcomes of primary osteosynthesis in unstable type 31A2 and 31A3 fractures was significantly higher than in type 31A1 fractures.

In the largest group of patients with type 31A1 fractures, the frequency of reduction and implant positioning errors was relatively low and was observed in only 6 patients (11.3%). This is likely due to the fact that type A1 fractures are considered stable, as they are not accompanied by significant fragmentation or displacement of fragments, and closed reduction through traction and internal rotation in most cases restores the anatomy of the neck, head, and metaphyseal zone of the femur. Inaccurate reduction may be associated with an incorrect entry point of the nail, lateralization of the diaphyseal fragment, and the formation of a wedge effect [22] or with errors in preoperative planning and improper selection of implant sizes.

In the group of 31A2 fractures, the frequency of intraoperative errors is significantly higher than in 31A1 fractures, reaching 31%. This is due to the instability of the fracture, given its comminuted nature and significant fragment displacement. All types of errors identified in the study are observed in this patient group. These errors may be related to imprecise fragment reduction, leading to residual angular deformity due to inadequate traction, as well as uncorrected rotation of the proximal fragment, which manifests as residual varus positioning of the femoral neck and the formation of negative medial support. Under subsequent axial loading, this may result in varus collapse, implant penetration, and migration.

Thus, the improper reduction of fragments leads to incorrect implant positioning. At the same time, implant placement without considering the described effects may also lead to fragment displacement, improper fixator positioning, disruption of the dynamic stabilization mechanism, and fracture nonunion.

In our study, the error rate in the group of patients with 31A3 fractures was also high, reaching 46.2%. This is not only due to the difficulties of reduction but also to errors in implant selection and placement techniques. Similar to 31A2 fractures, significant displacement of bone fragments may progress during the implantation of the intramedullary nail and femoral locking screw, which often cause fragment migration as they pass through the fracture line. The broader use of direct closed or minimally open reduction methods with temporary fixation using bone clamps, wires, or cerclage before reaming the medullary canal and inserting the nail may improve the final position of the fragments.

According to the literature, in 31A3 fractures, the use of a long version of the proximal femoral nail is recommended, as it provides greater fixation stability and resistance to axial loads compared to the short version, helping to prevent complications such as the pendulum effect. In cases of a wide medullary canal, pathological nail toggling within the canal may occur, leading to pathological mobility of the neck screw and its external migration [31].

CONCLUSION

The application of intraoperative radiological criteria for assessing the quality of the restoration of the proximal femur has led to the conclusion that, in case of 31A2 and 31A3 fractures, special attention should be paid to the quality of achieved reduction, implant selection, and technical aspects of its placement. Along with improving preoperative planning algorithms, this will help to achieve better surgical treatment outcomes.

DISCLAIMERS

Author contribution

Maiorov B.A. — study concept and design; data acquisition, analysis and interpretation.

Belen'kiy I.G. — study concept and design, drafting and editing the manuscript.

Sergeev G.D. — data acquisition, analysis and interpretation; drafting and editing the manuscript.

Endovitskiy I.A. — data acquisition, analysis and interpretation.

Sergeeva M.A. — drafting and editing the manuscript.

Isakhanyan D.A. — data acquisition, analysis and interpretation.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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