Orthopaedics & Traumatology: Surgery & Research 105 (2019) 999–1004

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Femoral neck shortening after internal fixation of Garden I fractures increases the risk of femoral head collapse

Léo Nanty , François Canovas , Thibaut Rodriguez , Patrick Faure , Louis Dagneaux *

Département de Chirurgie Orthopédique et Traumatologie, Unité de Chirurgie du membre inférieur et du rachis, Hôpital Lapeyronie, CHRU de Montpellier, 351, avenue Gaston-Giraud, 34295 Montpellier cedex 5, France

ARTICLE INFO

Article history:
Received 19 July 2018
Accepted 5 May 2019

Keywords:
Femoral neck fracture
Coxa valga
Femoral neck impaction
Garden I
Avascular necrosis
Femoral head

ABSTRACT

Background: Arthroplasty has not been proven superior over internal fixation for the treatment of non-displaced femoral neck fractures. However, internal fixation has been followed by high rates of revision for mechanical complications and of femoral neck impaction within the first postoperative year. The objective of this study was to determine whether femoral neck impaction was associated with avascular necrosis (AVN).
Hypothesis: Fracture healing with femoral neck shortening by impaction after internal fixation of a femoral neck fracture is associated with AVN.
Material and methods: A single-centre retrospective study in patients with Garden I fractures managed by screw fixation was performed to compare outcomes in the groups with and without femoral neck impaction. Follow-up radiographs were assessed for evidence of the femoral neck impaction during fracture healing. The occurrence of AVN was the primary evaluation criterion. The secondary evaluation criteria were risk factors for impaction and complications.
Results: Of the 75 included patients, 9 (12%) experienced AVN. Impaction was significantly associated with AVN ($p = 0.02$; relative risk, 4.38). Significant risk factors for impaction were a higher body mass index ($p = 0.0003$) and valgus-impacted fracture reduction between the radiographs at baseline and immediately after surgery ($p = 0.0001$).
Discussion: Femoral neck impaction was a significant risk factor for AVN after screw fixation of Garden I fractures. Valgus-impacted fracture reduction must receive careful attention during fixation. We suggest static internal fixation if the impaction is reduced on a traction table and advise caution when using parallel screws. The diagnostic and therapeutic strategy proposed here deserves to be evaluated in a prospective study.
Level of evidence: III, retrospective comparative study.

1. Introduction

The incidence of femoral neck fractures is rising in France and around the world [1]. Efforts to decrease the morbidity and mortality associated with femoral neck fractures include preventive measures and the application of multimodal enhanced recovery protocols. Nonetheless, the poor functional outcomes and high mortality rates associated with femoral neck fractures in elderly patients continue to raise major challenges.

Current recommendations for the treatment of Garden I and II femoral neck fractures are in favour of internal fixation rather than arthroplasty [2,3]. This reference standard treatment produces fairly good functional outcomes across all age groups [4,5]. Nevertheless, about 20% rates of revision for non-union, secondary displacement, or avascular necrosis (AVN) of the femoral head have been reported after internal fixation [6–8]. Few data are available about the specific case of valgus-impacted femoral neck fractures (Garden I), which are usually pooled in published English-language studies with strictly non-displaced fractures (Garden II), as the management strategy and complication rates are closely similar [3].

This uncertainty about the optimal surgical strategy indicates a need for identifying outcome predictors, with the goal of minimising the surgical revision rate. Recent studies have demonstrated associations linking various radiographic parameters to the occurrence of complications. Zhang et al. reported that preoperative radiographic findings correlated closely with the short-term outcomes of femoral neck fractures [9]. Weil et al. drew attention to the

* Corresponding author.
E-mail address: louisdagneaux@gmail.com (L. Dagneaux).

https://doi.org/10.1016/j.otsr.2019.05.009
1877-0568/

occurrence during the first postoperative year of cervical impaction responsible for femoral neck shortening and screw pull-out [10]. Identifying risk factors for femoral neck impaction should therefore result in optimisation of current surgical practices.

The objective of this study was to determine whether femoral neck impaction was associated with AVN. The hypothesis was that fracture healing with femoral neck shortening by impaction after internal fixation of a valgus-impacted femoral neck fracture is associated with AVN.

2. Material and method

2.1. Patients

We conducted a single-centre retrospective comparative study of consecutive patients with valgus femoral neck fractures (Garden I) managed surgically in our department between 2006 and 2016. Exclusion criteria were contralateral femoral neck fracture and pathological fracture. We also excluded patients who were lost to follow-up or died within the first postoperative year.

2.2. Operative technique

Triple-screw fixation using cannulated screws (6.5 ASNIS, Stryker, MI, USA; and 6.5 A0, Synthes, Solothurn, Switzerland) was performed in all patients. The patient was installed on a traction table and given general anaesthesia or spinal anaesthesia. Some surgeons used a dynamic construct consisting in three parallel screws, whereas others created a static construct by having one screw diverge from the other two (Fig. 1). Depending on the surgeon, weight bearing was started during the immediate postoperative period or after a period of up to 6 weeks.

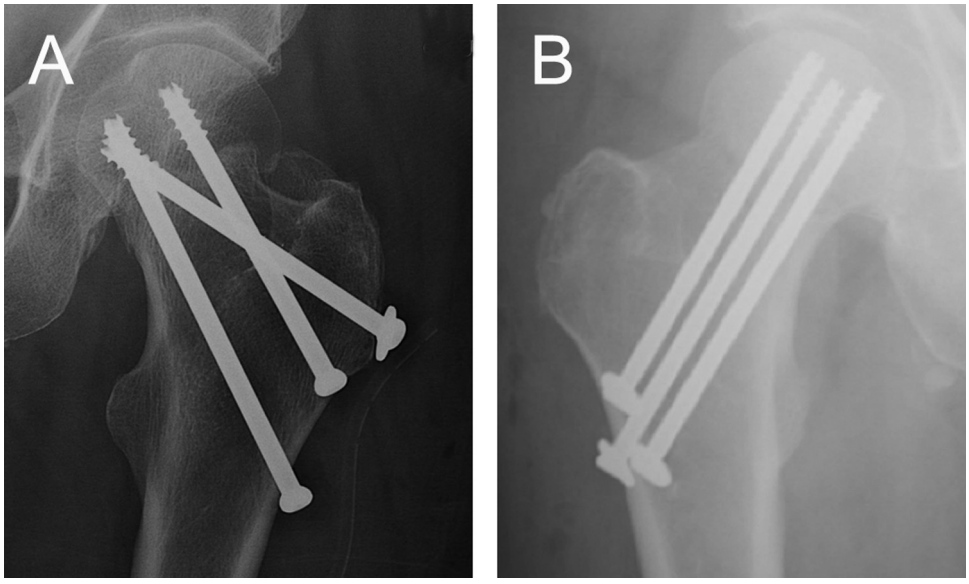

Fig. 1. Internal fixation using three cannulated compressive screws to treat femoral neck fracture: static transverse (A) and dynamic parallel (B) configurations.

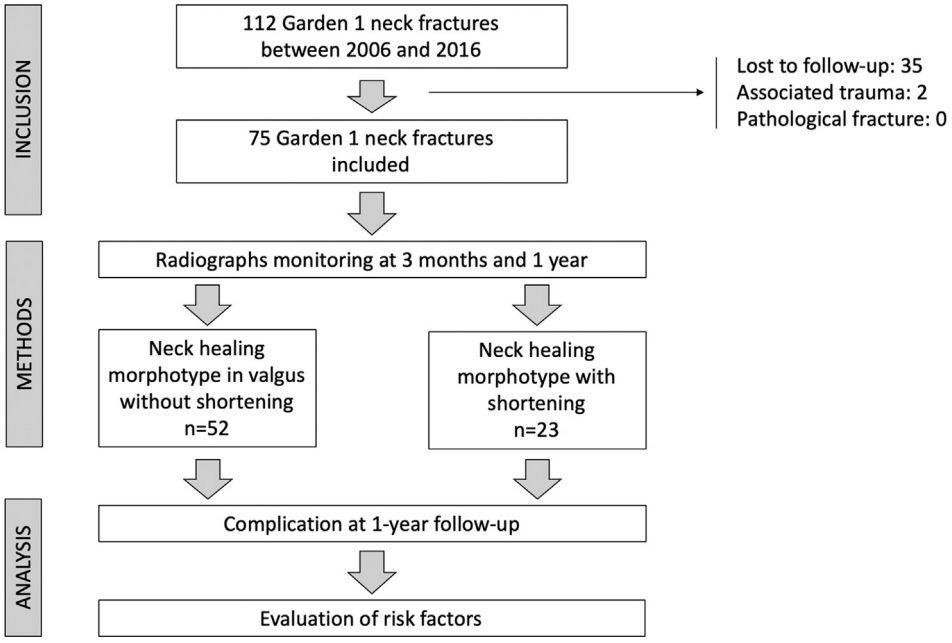

Fig. 2. Flow diagram.

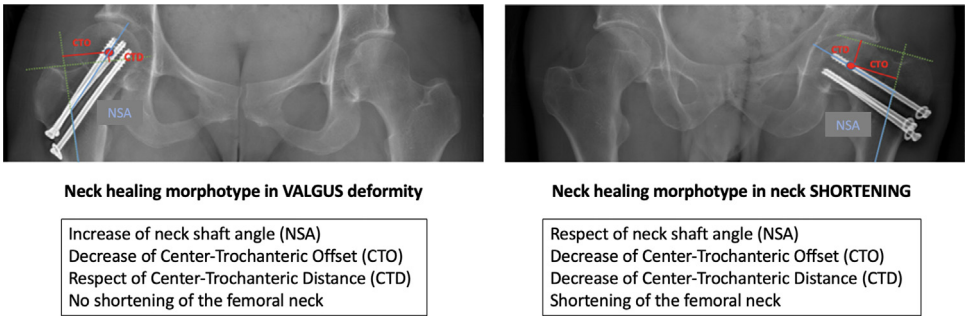

Fig. 3. Antero-posterior pelvic radiographs illustrating the two healing morphotypes of Garden I femoral neck fractures: valgus without impaction (A) and impaction inducing femoral neck shortening (B).

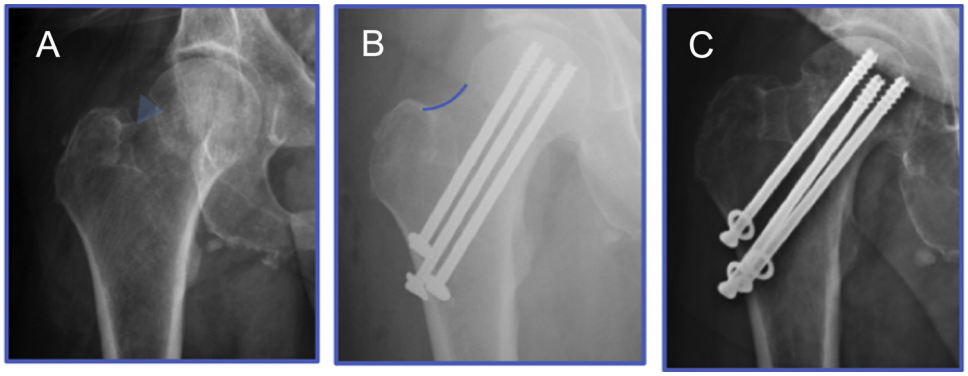

Fig. 4. Antero-posterior radiographs illustrating the preoperative impaction (blue triangle) typically seen in Garden I femoral neck fractures (A), valgus-impacted fracture reduction (blue line) visible on the immediate postoperative radiograph (B) and impaction with neck shortening and screw pull-out 1 year after surgery (C).

2.3. Radiographic assessment

The patients were divided into two groups based on the radiographic findings 3 months after surgery. An antero-posterior supine radiograph of the pelvis obtained at the same centre was evaluated by an independent observer (LN), who compared the neck-shaft angle and neck length on the two sides. The results served to classify the patients into two groups, with valgus but no impaction and with impaction, respectively. Fig. 2 is the flow diagram. The same observer evaluated the follow-up radiographs taken 3 and 12 months after surgery and used several parameters to compare the two sides (Fig. 3), as follows:

- femoral neck shortening caused by impaction was measured on an AP radiograph, starting 3 months after surgery. The distance between the centre of the femoral neck and the intersection of the neck axis and anatomical shaft axis was determined, and the value was compared to that on the other side. In patients with screw pull-out suggesting postoperative impaction, the femoral neck shortening index was computed as follows: ([length on the operated side – length on the normal side]/length on the normal side). An index value greater than 0.2 has been found reliable as an indicator for impaction [11,12];
- centre-trochanteric offset (CTO) and centre-trochanteric distance (CTD) were measured. CTO reflects the height of the greater trochanter and CTD reflects lateral offset relative to the centre of the femoral head [13];
- femoral head diameter and sphericity were assessed to detect AVN;
- the neck-shaft angle (CC'D) was determined to confirm that neck healing occurred in valgus.

2.4. Primary evaluation criterion and risk factors

The primary evaluation criterion in both groups was the occurrence of AVN. We also recorded all other complications, notably aseptic non-union. The secondary evaluation criteria were the risk factors potentially associated with complications, among the following: patient-related risk factors (age, gender, body mass index [BMI], and risk factors for osteoporosis), fracture-related factors (type of trauma and orientation of the fracture line); and surgery-related factors (static vs. dynamic screw configuration, immediate vs. delayed weight bearing, and intraoperative Valgus-impacted fracture reduction during patient installation visible on the radiograph taken immediately after surgery) (Fig. 4). Table 1 lists the main features of the study patients.

2.5. Statistical analysis

The Chi^2 test was chosen to compare qualitative variables between the groups with vs. without impaction when the underlying assumptions were met and Fisher's exact test otherwise. Quantitative variables were compared by applying Student's *t*-test when appropriate and the Wilcoxon–Mann–Whitney test otherwise. The statistical tests were performed using SAS version Cary, NC, USA.

3. Results

Multivariate analysis, impaction was significantly associated with complications (odds ratio: 9.20; 95% confidence interval: 1.022; 82.736; $p = 0.048$), independently from the other statistically significant variables listed below. The relative risk associated with impaction was 4.385.

Table 1
Main features of the study patients in the groups with and without postoperative impaction after healing of a Garden I femoral neck fracture.

	Total $n=75$	Valgus without impaction $n=52$	Impaction $n=23$	p-value
Patient-related factors				
Age, years, mean ± SD	66 ± 15.4	66.3 ± 15.5	65.3 ± 15.3	0.9501
Body mass index, mean ± SD	22.1 ± 2.7	21.0 ± 2.8	22.8 ± 2.61	0.003
Females, *n* (%)	56 (74%)	42 (80%)	14 (60%)	0.1237
Alcohol use, *n* (%)	6 (8%)	4 (8%)	2 (9%)	1
Tobacco use, *n* (%)	14 (19%)	8 (12%)	6 (36%)	0.18
Long-term glucocorticoid therapy, *n* (%)	8 (10%)	5 (10%)	3 (14%)	0.68
Screw configuration				
Dynamic, *n* (%)	60 (80%)	40 (66%)	20 (33%)	0.3155
Static, *n* (%)	15 (20%)	12 (80%)	3 (20%)	
Weight bearing				
Immediate, *n* (%)	47 (63%)	33 (70%)	14 (30%)	1
Delayed, *n* (%)	27 (36%)	19 (70%)	8 (30%)	
Time from injury to surgery				
< 24 h, *n* (%)	44 (59%)	30 (68%)	14 (32%)	0.91
> 24 h, *n* (%)	33 (41%)	22 (66%)	9 (33%)	
Intraoperative reduction				
Yes, *n* (%)	11 (15%)	1 (9%)	10 (91%)	0.001
No, *n* (%)	60 (85%)	47 (78%)	13 (22%)	
Pauwels classification				
I, *n* (%)	10 (13%)	8 (80%)	2 (20%)	0.45
II, *n* (%)	41 (55%)	30 (73%)	11 (27%)	
III, *n* (%)	11 (32%)	6 (54%)	5 (46%)	

We included 75 patients, 56 women and 19 men, with a mean age of 66.0 ± 15.4 years and a mean BMI of 22.1 ± 2.7 kg/m^2. The follow-up radiographs showed coxa valga without impaction in 52 patients and impaction in 23 patients after neck healing.

The overall complication rate was 12%. AVN occurred in 9 patients. The complication rate was higher in the group with vs. without impaction (26.0% and 5.7%, respectively). Impaction was significantly associated with a higher complication rate ($p = 0.0206$). BMI was significantly higher in the group with impaction ($p = 0.003$). Osteoporosis risk factors were not significantly different between the two groups. Fracture line orientation was not associated with impaction.

Valgus-impacted fracture reduction during surgery was nearly always followed by femoral neck impaction during bone healing ($p = 0.001$). These reduced fractures were generally treated using a dynamic parallel screw configuration. There was no direct significant association between intraoperative reduction and the risk of complications ($p = 0.068$). Impaction was not significantly associated with time from injury to surgery, time from surgery to weight bearing, or type of construct.

4. Discussion

To our knowledge, this is the first study of postoperative impaction and risk factors for postoperative complications in patients with Garden I femoral neck fractures. Shimizu et al. reported an association between preoperative impaction and the risk of mechanical complications after internal fixation of Garden I and II fractures but did not assess the risk of AVN over time [14]. Our findings established that impaction after internal fixation of Garden I fractures is a significant risk factor for the development of AVN within the first postoperative year. They also confirm that reduction of the impaction and greater body weight are associated with a higher risk of postoperative impaction. Thus, postoperative impaction of the femoral neck deserves to be viewed as a complication of impacted femoral neck fractures, although these are often described as relatively innocuous.

Our study has several limitations. The design was retrospective, and the limited statistical power due to the small sample size may have resulted in some associations being missed. To demonstrate a direct link between Valgus-impacted fracture reduction and AVN, 207 patients would be required. This fact explains the lack of significant findings from our univariate and multivariate analyses. The radiographic follow-up relied solely on an antero-posterior pelvic radiograph, which was effective in detecting impaction and valgus but could not show posterior tilt of the femoral head. However, slice imaging would not have been warranted in patients receiving standard care in the absence of complications. Finally, the 25% patient attrition rate raised challenges in analysing the clinical data.

4.1. Postoperative femoral neck impaction as a risk factor

In a study of 228 patients, Zhang et al. found that outcomes were affected by both the occurrence of secondary impaction and the degree of posterior tilt of the femoral head [9]. They did not seek to identify risk factors for impaction, and they pooled displaced and non-displaced fractures. A previous study established that femoral neck shortening influenced postoperative hip function [15]. Our work provides the further information that the risk of complications, and therefore the morbidity rate, are affected by femoral shortening. Previous studies also confined their evaluation of impaction to the coronal plane; no 3D data were obtained. Among risk factors in other planes, posterior tilt of the femoral head was associated with the risk of complications in a study of 113 patients conducted by Palm et al. [16]. In contrast, in 382 patients, J. Lapidus et al. found no significant association of complications with posterior tilt [6]. We believe that computed tomography (CT) should be used in the future to obtain a more comprehensive risk factor assessment, with the goal of preventing AVN during the first postoperative year.

4.2. Risk factors for femoral neck impaction

Many studies have sought to identify risk factors for complications after internal fixation of femoral neck fractures, which often require revision surgery to perform arthroplasty. These risk factors include patient dependency, chronic alcohol abuse, and long-term glucocorticoid therapy [17–21]. A longer time to surgery is often blamed for the development of mechanical complications but has not been shown to increase the risk of impaction [21].

In contrast, few studies focussed on identifying risk factors for femoral neck impaction. Higher BMI was associated with

impaction, suggesting possible limitations of the dynamic screw configuration. Our study suggests that intraoperative valgus-impacted fracture reduction should be taken into account when devising the treatment strategy. We believe that excessive traction on the operating table may reduce the initial valgus deformity. Confirmation of these results would suggest that static screw fixation might prevent femoral neck impaction in patients with risk factors such as overweight or intraoperative Valgus-impacted fracture reduction. Neither osteoporosis nor early weight bearing were significantly associated with impaction in our population. We suggest that the advanced age of our patients and early weight bearing in 63% of cases may have biased the evaluation of these factors.

We found no published biomechanical studies comparing static vs. dynamic screw fixation regarding their potential links with impaction and complications. Although a triangular configuration of triple-screw constructs has been found superior over linear configurations [22], no reference biomechanical data are available for validating the construct used. Alternatives to triple-screw fixation in a parallel configuration have been studied, including oblique constructs. Thus, Filipov et al. reported that a static construct of three medially diverging screws did not significantly affect the risk of AVN [23]. However, postoperative impaction was not considered in their study. In our study, impaction after static screw fixation occurred in a single patient, possibly due to insufficient posterior reduction not visible in the coronal plane. All the other cases of impaction occurred in patients managed using dynamic constructs. Weil et al. showed that partially threaded cannulated screws were associated with higher impaction rates than fully cannulated threaded screws [10].

4.3. Clinical implications and future prospects

Although intraoperative valgus-impacted fracture reduction was not significantly associated with the occurrence of complications in our study, due to the limited statistical power and to methodological choices, we believe that trauma surgeons should be aware of the deleterious effects of valgus-impacted fracture reduction. We thus advocate static screw fixation if the impaction is reduced on a traction table (as used for Garden II and displaced fractures in our department). We also suggest that caution is in order regarding the resumption of weight bearing if the patient is overweight. There may therefore be grounds for challenging the English-language literature advocating the same treatment for Garden I and II fractures. We believe that preoperative CT scanning is crucial to obtain a 3D evaluation of the valgus deformity by providing information on parameters that are not considered in the Garden classification, such as posterior tilt of the femoral head. Hoelsbrekken and Dolatowski described the influence of hip position during radiograph acquisition on the values of radiographic parameters [24]. Despite the small margin of error in their study, which did not seem to produce clinically relevant variations in the evaluation of femoral neck fractures, their in vitro data may not be applicable in vivo, since obtaining properly angled lateral radiographs in the setting of emergency trauma care is currently challenging. The advent of low-dose CT may prove able to provide reliable assessments of hip injuries in the future. Our findings deserve to be further evaluated by a prospective study to confirm the association linking femoral neck impaction to AVN, as well as to assess the consequences of femoral neck impaction and valgus angulation on functional outcomes and patient mobility [5,15].

5. Conclusion

Postoperative femoral neck impaction after internal fixation of Garden I fractures was associated with a higher risk of AVN. Although the angulation of the femoral neck results in valgus malunion, operative valgus-impacted fracture reduction during dynamic screw fixation is inadvisable, as it was also associated with postoperative impaction.

Disclosure of interest

F.C. is an educational consultant for Zimmer GmbH but has no competing interest.

LD, LN, TR, and PF declare that they have no competing interest.

Funding

None.

Contribution of each author

LD conceived and designed the study; collected and assembled the data; analysed and interpreted the data; drafted the manuscript; critically revised the manuscript for important intellectual content; provided statistical expertise; provided administrative, technical, and logistic support (university centre); and approved the final version of the manuscript.

LN and TR analysed and interpreted the data; drafted the manuscript; critically revised the manuscript for important intellectual content; provided statistical expertise; and approved the final version of the manuscript.

PF and FC: conceived and designed the study; critically revised the manuscript for important intellectual content; and approved the final version of the manuscript.

References

[1] Les modalités de prise en charge des fractures du col du fémur en France de 1998 à 2009. Études et résultats, DRESS Nº 774 Décembre 2011, n.d.
[2] Reina N, Bonnevialle P, Rubens Duval B, Adam P, Loubignac F, Favier T, et al. Internal fixation of intracapsular proximal femoral fractures in patients older than 80 years: still relevant? Multivariate analysis of a prospective multicentre cohort. Orthop Traumatol Surg Res 2017;103:3–7.
[3] Chirurgie des fractures de l'extrémité proximale du fémur chez les patients âgés. Recommandation de bonne pratique SOFCOT/HAS Décembre 2016, n.d.
[4] Buord J-M, Flecher X, Parratte S, Boyer L, Aubaniac J-M, Argenson J-N. Garden I femoral neck fractures in patients 65 years old and older: is conservative functional treatment a viable option? Orthop Traumatol Surg Res 2010;96:228–34.
[5] Noda M, Saegusa Y, Takahashi M, Kuroda Y, Takada Y, Yoshikawa C, et al. Diminished abductor muscular strength in patients with valgus-impacted femoral neck fractures treated by internal fixation: clinical study and biomechanical considerations. J Orthop Surg 2017;25:1–6.
[6] Lapidus LJ, Charalampidis A, Rundgren J, Enocson A. Internal fixation of garden I and II femoral neck fractures: posterior tilt did not influence the reoperation rate in 382 consecutive hips followed for a minimum of 5 years. J Orthop Trauma 2013;27:386–90.
[7] Rogmark C, Flensburg L, Fredin H. Undisplaced femoral neck fractures—no problems? A consecutive study of 224 patients treated with internal fixation. Injury 2009;40:274–6.
[8] Do LND, Kruke TM, Foss OA, Basso T. Reoperations and mortality in 383 patients operated with parallel screws for Garden I–II femoral neck fractures with up to ten years follow-up. Injury 2016;47:2739–42.
[9] Zhang YL, Zhang W, Zhang CQ. A new angle and its relationship with early fixation failure of femoral neck fractures treated with three cannulated compression screws. Orthop Traumatol Surg Res 2017;103:229–34.
[10] Weil YA, Qawasmi F, Liebergall M, Mosheiff R, Khoury A. Use of fully threaded cannulated screws decreases femoral neck shortening after fixation of femoral neck fractures. Arch Orthop Trauma Surg 2018;138:661–7.
[11] Guenoun B, Zadegan F, Aim F, Hannouche D, Nizard R. Reliability of a new method for lower-extremity measurements based on stereoradiographic three-dimensional reconstruction. Orthop Traumatol Surg Res 2012;98:506–13.
[12] Marmor M, Nystuen C, Ehemer N, McClellan RT, Matityahu A. Accuracy of in situ neck-shaft angle and shortening measurements of the anatomically reduced, varus malreduced and shortened proximal femur: can we believe what we see on the postoperative films? Injury 2012;43:846–9.

[13] Anderson LA, Gililland JM, Pelt CE, Peters CL. Subcapital correction osteotomy for malunited slipped capital femoral epiphysis. J Pediatr Orthop 2013;33:345–52.
[14] Shimizu T, Miyamoto K, Masuda K, Miyata Y, Hori H, Shimizu K, et al. The clinical significance of impaction at the femoral neck fracture site in the elderly. Arch Orthop Trauma Surg 2007;127:515–21.
[15] Zlowodzki M, Brink O, Switzer J, Wingerter S, Woodall J, Petrisor BA, et al. The effect of shortening and varus collapse of the femoral neck on function after fixation of intracapsular fracture of the hip: a multicentre cohort study. Bone Jt J 2008;90:1487–94.
[16] Palm H, Gosvig K, Krasheninnikoff M, Jacobsen S, Gebuhr P. A new measurement for posterior tilt predicts reoperation in undisplaced femoral neck fractures: 113 consecutive patients treated by internal fixation and followed for 1 year. Acta Orthop 2009;80:303–7.
[17] Manohara R, Liang S, Huang D, Krishna L. Cancellous screw fixation for undisplaced femoral neck fractures in the elderly. J Orthop Surg 2014;22:282–6.
[18] Gjertsen J-E, Fevang JM, Matre K, Vinje T, Engesæter LB. Clinical outcome after undisplaced femoral neck fractures: a prospective comparison of 14,757 undisplaced and displaced fractures reported to the Norwegian Hip Fracture Register. Acta Orthop 2011;82:268–74.
[19] Han SK, Song HS, Kim R, Kang SH. Clinical results of treatment of garden type 1 and 2 femoral neck fractures in patients over 70-year old. Eur J Trauma Emerg Surg 2016;42:191–6.
[20] Duckworth AD, Bennet SJ, Aderinto J, Keating JF. Fixation of intracapsular fractures of the femoral neck in young patients: risk factors for failure. J Bone Jt Surg Br 2011;93:811–6.
[21] Wang T, Sun J-Y, Zha G-C, Jiang T, You Z-J, Yuan D-J. Analysis of risk factors for femoral head necrosis after internal fixation in femoral neck fractures. Orthopedics 2014;37:e1117–23.
[22] Selvan V, Oakley M, Rangan A, Al-Lami M. Optimum configuration of cannulated hip screws for the fixation of intracapsular hip fractures: a biomechanical study. Injury 2004;35:136–41.
[23] Filipov O, Stoffel K, Gueorguiev B, Sommer C. Femoral neck fracture osteosynthesis by the biplane double-supported screw fixation method (BDSF) reduces the risk of fixation failure: clinical outcomes in 207 patients. Arch Orthop Trauma Surg 2017;137:779–88.
[24] Hoelsbrekken SE, Dolatowski FC. The influence of the hips position on measurements of posterior tilt in a valgus-impacted femoral neck fracture. Injury 2017;48:2184–8.