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Factors influencing femoral neck fracture healing after internal fixation with dynamic locking plate

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Abstract

Introduction The purpose of this study was to determine factors that affect the early failure of femoral neck fracture healing after internal fixation with a dynamic locking plate implant.

Patients and methods Retrospective analysis of all cases of femoral neck fracture (FNF) primarily treated with dynamic locking plate implant from 04/2014 to 04/2017 with a minimum of 6 month follow-up. For the purpose of the study age, sex and time from admission to surgery were retrieved from the hospital medical database. Patient's pre- and postoperative hip radiographs were reviewed by the authors. Radiographically detected fracture healing failure (non-union and screw cut-out) was recorded.

Results For the period of the study, there were 77 consecutive FNF (76 patients) treated with the dynamic locking plate implant. Eight (10%) patients were lost to follow-up, 13 (17%) patients died within 6 months after surgery. Healing failure was identified in 23 (41%) of remaining 56 cases. Three of four (75% failure rate) failures were observed in cases with fair-quality reduction and two of two (100% failure rate) failures were noticed in the case of none telescoping screw located within subchondral bone. Multiple logistic regression showed an increased risk of fracture failure in cases with at least one completely collapsed telescoping screw (OR = 73.2; 95% CI 9.4–568.5, $p < 0.01$), while telescoping screws' location around centre of the femoral head reduces the risk of failure (OR = 14.7; 95% CI 1.6–135.1, $p = 0.02$).

Conclusion In our group of patients, fracture healing failure of the FNF treated with dynamic locking plate reached 41%. This high failure rate was associated with poor fracture reduction, not subchondrally and centrally placed telescoping screws and in the case of complete collapse on at least one of the telescoping screws.

Keywords Femoral neck fracture · Hip screw · Complications · Predictors of failure

Introduction

Treatment of the femoral neck fracture are still under debate and investigation [1, 2]. In the case of nondisplaced femoral neck fracture, internal fixation approach preserving femoral head is accepted at any age of the patient, while, for displaced fracture and older patients, total hip replacement or hemiarthroplasty is recommended [3–6]. Nonetheless, some cases of displaced fractures in older patients can be treated by internal fixation [6, 7]. There are two most commonly used types of internal fixation for the femoral neck fractures: sliding hip screw and the multiple cancellous screws [1]. Dynamic locking plate is a novel implant design which combines advantageous characteristics from both of those implants. It has rotational stability of parallel screws, it allows fracture collapse in the line of femoral neck axis, and it is strong angle-fixed construct as it has screw barrel locked to the lateral femoral plate. Moreover, telescoping of screw occurs only within screw barrel, so there is no screw backing out [5]. In spite of proclaimed improved features of new implant in treatment of femoral neck fracture, recent studies report different results while using this implant [7, 8]. On one hand, studies have been published on reducing non-union, revision, and replacement rate in comparison to other implants; on the other hand, a few analyses have been reported on high cut-out rate [4, 8, 9]. The aim of the present

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retrospective study was to search for possible risk factors for hip fracture healing complications (non-union and screw cut-out) after being treated with dynamic locking plate.

Study design

The retrospective study of prospectively collected data with repeated reviewing of all case radiographs was carried out in trauma surgery department of the university hospital. The local ethics committee reviewed and approved the study protocol.

Study population

All consecutive patients with femoral neck fracture who were primarily treated with dynamic locking plate (Targon Femoral Neck; Aesculap B. Braun, Tuttlingen, Germany) at our department from April 2014 to April 2017 and with a minimum of 6 month follow-up were included into the study.

Data collection

Patients were retrospectively identified from a database of implanted osteosynthetic material. Baseline and follow-up data were acquired from electronic medical records which are stored in the hospital information system (age at admission, sex, mechanism of injury, time from admission to surgery, length of clinical follow-up, and need for any revision surgery). All pre- and postoperative hip radiographs of the study cases were evaluated by the authors who after discussion reached a consensus decision for each case on the type of femoral neck fracture (according to Garden and Pauwels classification), femoral neck bone density according to Singh index, presence of medial femoral neck fragmentation, and quality of the fracture reduction [10–14]. The authors recorded the number of applied telescoping screws, and measured their proper location and anchoring within femoral head, number of maximally extended screws, and number of fully collapsed screws.

Any radiographically identified screw femoral head cut-out, and/or fracture non-union at a minimum of 6 months after the surgery was regarded as failure.

Surgical technique

All surgeries were performed on traction table with two mobile C-arm radiographs in orthogonal views. Fracture reduction was obtained by closed technique, and implantation of internal fixation followed the manufacturer's instructions and already published the description of the procedure [5]. In brief, during surgical procedure, the central guide wire was inserted into the femoral head using alignment jig or aiming guide to lie centrally on both the AP and lateral views. Thereafter, three or four wires were placed parallel to the central guide wire into femoral head. Wires were exchanged for telescopic screws that were locked to the side plate. The plate was secured to the femur with two cortical screws. Final fracture reduction, number of used screws, implant location, and its anchoring within femoral were left to the surgeons' discretion.

After procedure, partial weight bearing as tolerated was allowed for 6 weeks using a walking aids and then full weight bearing was initiated. Patient follow-up, which included AP and lateral radiographs, was scheduled at 6 weeks, 3 months, and 6 months. If fracture was healed next follow-up visit was at the discretion of the patient. Any patient with significant symptoms was followed-up regularly after a 6 month period.

Evaluation of radiograph

All radiographs were calibrated before their evaluation using the known diameter of the shaft of the telescoping screw (Fig. 1). Type of femoral neck fracture was classified according Garden classification into undisplaced or displaced group [10]. Pauwels classification was used to describe the size of fracture line angle to horizontal with critical angles 30° for type I, 50° for type II, and over 50° for grade III [11]. To determine the angle of fracture, line operative or first postoperative radiographs were used. Singh index (SI) of 6 grades was used to estimate presence of bone osteoporosis from 6 (all trabeculae visible) to 1 (only thin principal compression trabeculae visible) [12]. Patients were grouped by two grades according to Singh index into severe osteoporosis group (SI grades 1 and 2), osteoporosis/osteopenia group (SI grades 3 and 4), and minimal/no osteopenia (SI grades 5 and 6). Quality of the fracture reduction was assessed using criteria described by Haidukewych et al. (2004) based on the remaining angulation and displacement into four categories: excellent (< 2 mm of displacement and < 5° of angulation in any plane), good (2–5 mm of displacement and/or 5°–10° of angulation), fair (> 5 to 10 mm of displacement and/or > 10–20° of angulation), or poor (> 10 mm of displacement and/or > 20° of angulation) with one exception [13]. Authors considered valgus angulation up to 15° as a criterion for excellent category (Figs. 2, 3).

If any bone fragment was present in the medial femoral neck cortex, it was considered fragmented [14].

Maximally extended telescoping screws were those which shaft length of the screw was 20 mm. Telescoping screw location within a femoral head was regarded perfect if the centre of the femoral head was located between superior and inferior telescoping screws in anteroposterior (AP) view and between anterior and posterior screws in lateral view (central/central location). The number of

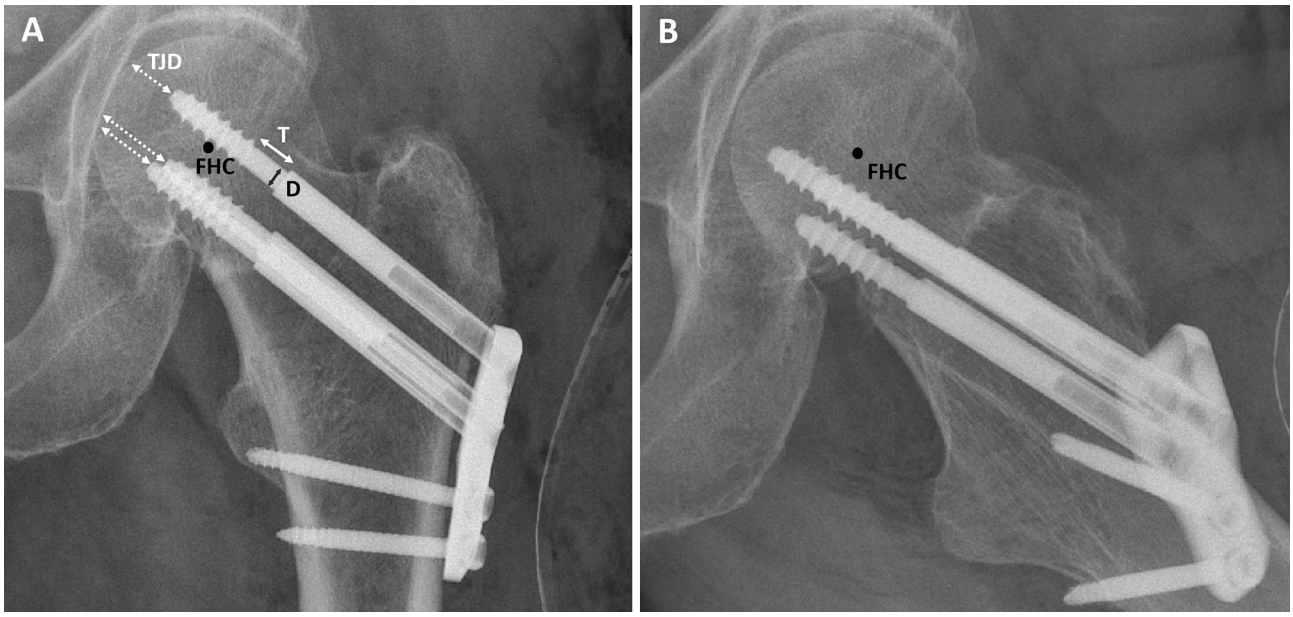

Fig. 1 Known diameter ($D = 4.8$ mm) of telescoping screw shaft was used for calibration. Digimizer Software function "circle to centre" was used to find femoral head centre (FHC). Length of the screw shaft (T) was measured to identify maximally extended screws. Tip screw to joint line distance (TJD) was measured to determine whether screw is adequately anchored within femoral head. FHC lies between superior and inferior screws (**a**) and anteriorly in lateral view (**b**). Final screw position coded as central/posterior

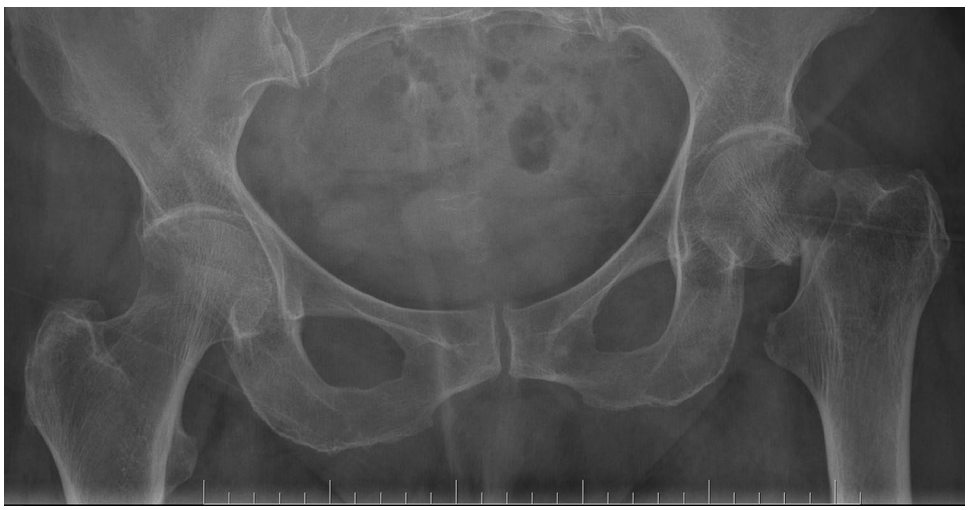

Fig. 2 Plain pelvic radiograph of 78-year-old lady. Radiograph shows displaced femoral neck fracture, with lower femoral neck bone density (Singh index 4) without medial femoral neck fragmentation. Fracture line to horizontal angle (55°) was measured from anteroposterior view after surgery (Fig. 3a)

adequately anchored telescoping screw within femoral head was noted. The telescoping screw was considered adequately anchored if the tip of the screw was in at least one radiographic view in less than 6 mm to the joint line. Telescoping screw was considered fully collapsed if the screw thread was on or within 1 mm of the edge of sliding barrel. The cases with at least one fully collapsed screw were noted. Non-union was defined as the presence of a visible cortical and trabecular fracture line in AP and/or lateral radiographs of the affected hip at a minimum of 6 months. Radiograph measurements were performed on computer using the Digimizer Image Analysis Software (ver. 4.6.1, MedCalc Software, Belgium).

Statistical analysis

Fisher's exact tests or Chi-square test was used to compare differences between categorical variables. Continuous outcomes were assessed by the two-sample *t* test. A multiple logistic regression model with failure as

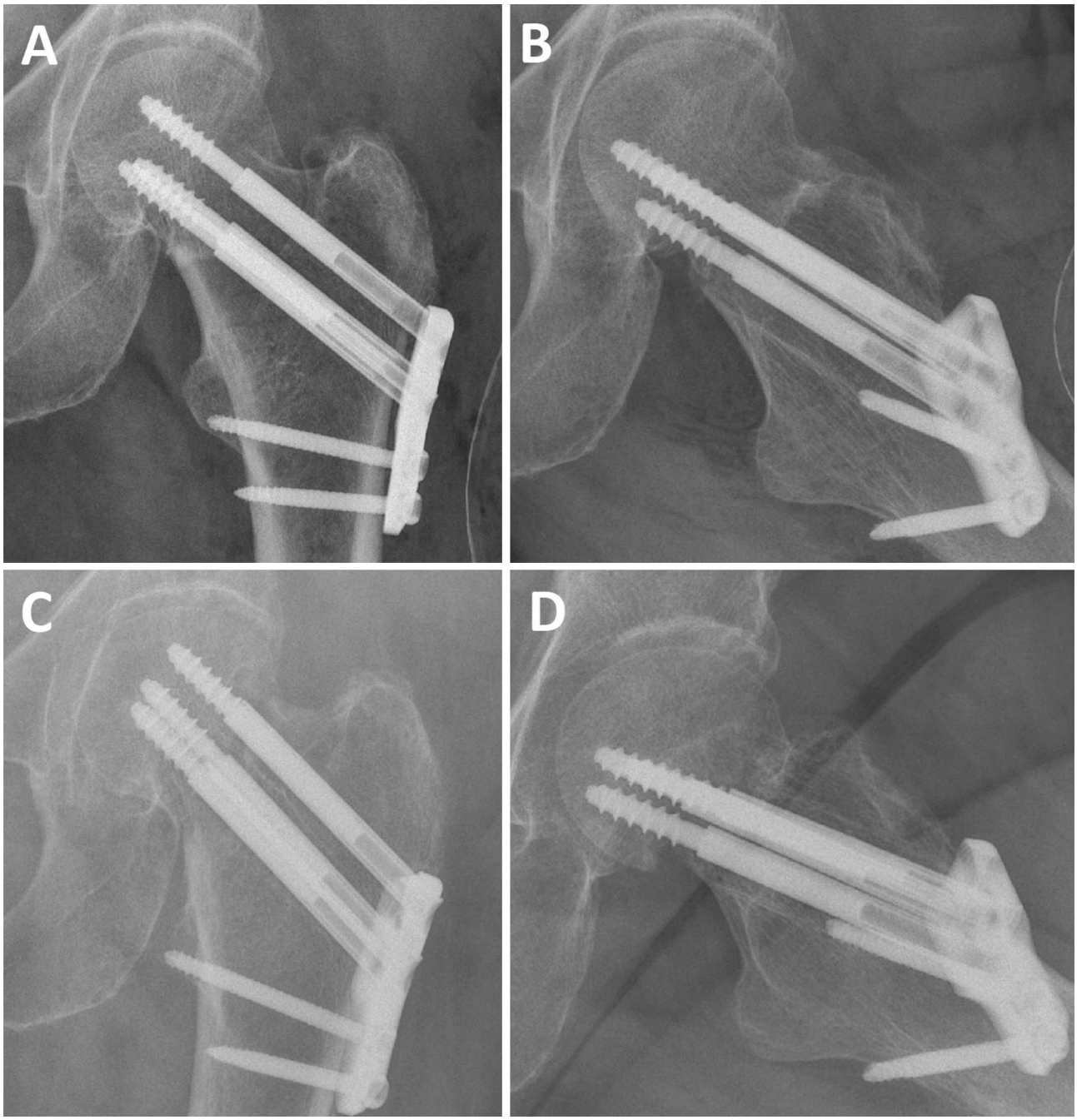

Fig. 3 Radiographs showing excellently reduced fracture in anteroposterior (**a**) and lateral (**b**) views with no screw placed subchondrally. Completely collapsed telescoping screws and femoral neck fracture non-union were seen on radiographs 1 year after surgery (**c, d**)

dichotomous outcome variable, using a forward entry conditional model ($p < 0.05$ for entry and $p > 0.10$ for removal), was performed to determine independent predictors of failure. A p value < 0.05 was considered significant. Statistical analysis was performed using MedCalc version 18.2 (MedCalc Software, Belgium).

Results

Between April 2014 and April 2017, there were 76 patients [mean age 74.4 years (SD 13.5)] treated with for 77 femoral neck fractures with dynamic locking plate implant (Table 1). Thirteen patients (17%; mean age 83.5 years (SD 4.2) years) died within 6 months after surgery and 8 patients [10%;

Table 1 Baseline characteristics of all patients with intracapsular hip fractures treated with dynamic locking plate ($N=77$)

Age	
Mean 74.4 (SD 13.5), range 38–95 years	
< 65 years	19 (25%)
≥ 65 years	58 (75%)
Sex	
Male	23 (30%)
Female	54 (70%)
Fracture displacement (Garden)	
Undisplaced	12 (16%)
Displaced	65 (84%)
Fracture type (Pauwels)	
1	1 (1%)
2	42 (55%)
3	34 (44%)
Femoral neck fragmentation	
Yes	22 (29%)
No	55 (71%)
Osteoporosis (Singh index)	
1–2	12 (16%)
3–4	49 (64%)
5–6	16 (21%)
Admission to surgery	
≤ 24 h	39 (51%)
> 24 h	38 (49%)
Quality of fracture reduction	
Excellent	44 (57%)
Good	29 (38%)
Fair	4 (5%)
Poor	0 (0%)
Telescoping screw location within femoral head	
Centre/centre	20 (23%)
Not in centre/centre	57 (77%)
Number of applied screws	
3	64 (83%)
4	13 (17%)
Number of screws located within subchondral bone	
None	2 (3%)
1	14 (18%)
2	29 (38%)
3 or 4	32 (42%)
Number of screws with maximum extension	
None	15 (19%)
1	28 (36%)
2	22 (29%)
3 or 4	12 (16%)

SD standard deviation

mean age 81.4 years (SD 10.4)] were lost to follow-up. For the purpose of the study, 56 cases (55 patients) remained (Fig. 4).

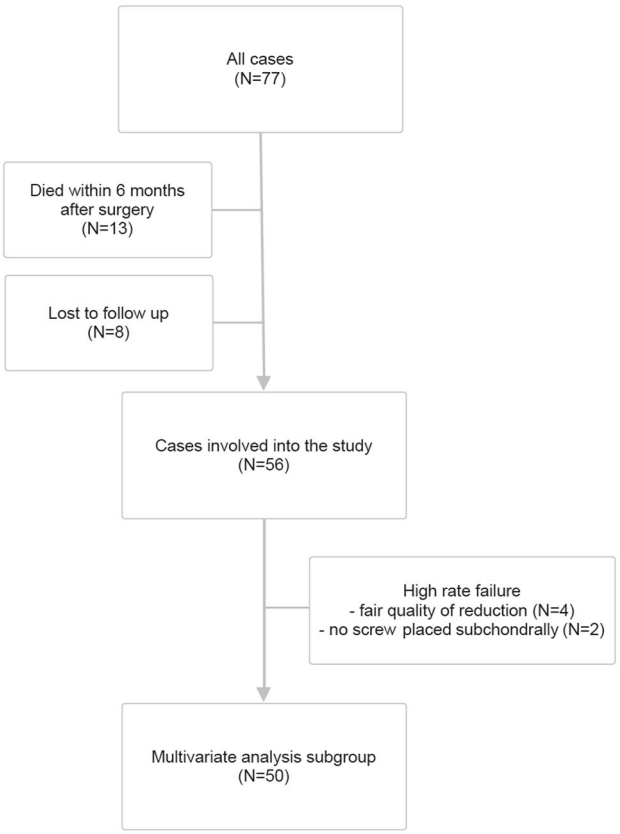

Fig. 4 Flowchart of the study

In the study group, there were found 23 (41%) failures in 56 cases. Four femoral head perforations were seen on average 3 months (SD 1) and 19 non-unions on average 10 months (SD 5) after index procedure. For the purpose of the study, three cases with healed fracture were included into the healed group despite they developed avascular femoral head necrosis 14, 24, and 30 months after surgery.

High failure rates (75%) were observed in cases with fair-quality reduction in which three of four cases failed. The highest failure rates (100%) was noticed in two of two cases in which none telescoping screw located within subchondral bone (Table 2).

After exclusion six cases with high failure rate, we further analyzed subgroup of 50 remaining cases. In this subgroup fracture, healing failure was observed in 18 (36%) and healing in 32 (64%) cases. The mean time to failure was 7.8 (SD 4.1) months and mean follow-up time for healed group was 16.8 (SD 8.3) months. Failure group ($N=18$) differed from healed group ($N=32$) in proportion of cases in which at least one telescoping screw was completely collapsed ($p<0.01$) and in proportion of osteoporotic and severe osteoporotic fractures ($p=0.03$) (Table 3). Despite statistically insignificant, there were differences between the failed and the healed group in a percentage of patients older than 65 years

Table 2 Comparison of baseline characteristics between the failed and the healed group

	Failure ($N=23$)	Healed ($N=33$)	p
Age			
Mean (years)	75.5 (SD 11.5)	68.3 (SD 15.1)	0.06
< 65 years	4	14	0.05
≥ 65 years	19	19	
Sex			
Male	8	9	0.55
Female	15	24	
Fracture displacement (garden)			
Undisplaced	1	7	0.12
Displaced	22	26	
Fracture type (Pauwels)			
1	0	0	0.19
2	10	21	
3	13	12	
Femoral neck fragmentation			
Yes	6	12	0.42
No	17	21	
Osteoporosis (Singh index)			
1–2	5	2	0.10
3–4	16	19	
5–6	4	12	
Admission to surgery			
≤ 24 h	11	19	0.48
> 24 h	12	14	
Quality of fracture reduction			
Excellent	11	18	0.36
Good	9	14	
Fair	3	1	
Poor	0	0	
Screw location within femoral head			
Centre/centre	3	10	0.14
Not in centre/centre	20	23	
Number of applied screws			
3	19	28	1.00
4	4	5	
Number of screws located within subchondral bone			
None	2	0	0.26
1	4	5	
2	6	14	
3 or 4	11	14	
Number of screws with maximum extension			
None	8	7	0.67
1	9	14	
2	4	9	
3 or 4	2	3	
At least one completely collapsed screw			
Yes	21	7	< 0.01*
No	2	26	

Patients with hip fractures treated with dynamic locking plate and least 6 month follow-up ($N=56$)

SD standard deviation

*Statistically significant difference

Table 3 Comparison of baseline characteristics between the failed and the healed group

	Failure ($N=18$)	Healed ($N=32$)	p
Age			
Mean (years)	75.8 (SD 9.8)	69.0 (SD 14.8)	0.09
< 65 years	3	13	0.08
≥ 65 years	15	19	
Sex			
Male	5	9	0.98
Female	13	23	
Fracture displacement (Garden)			
Undisplaced	1	7	0.23
Displaced	17	25	
Fracture type (Pauwels)			
1	0	0	0.22
2	8	20	
3	10	12	
Femoral neck fragmentation			
Yes	5	12	0.49
No	13	20	
Singh index			
1–2	4	2	*0.03
3–4	13	19	
5–6	1	11	
Admission to surgery			
≤ 24 h	9	18	0.67
> 24 h	9	14	
Quality of fracture reduction			
Excellent	9	18	0.67
Good	9	14	
Fair	0	0	
Poor	0	0	
Telescoping screw location within femoral head			
Centre/centre	2	10	0.11
Not in centre/centre	16	22	
Number of applied telescoping screws			
3	14	27	0.70
4	4	5	
Number of telescoping screws located within subchondral bone			
None	0	0	0.50
1	2	5	
2	5	13	
3 or 4	11	14	
Number of telescoping screws with maximum extension			
None	4	7	0.97
1	8	13	
2	4	9	
3 or 4	2	3	
At least one completely collapsed telescoping screw			
Yes	16	6	< 0.01*
No	2	26	

Patients with hip fractures treated with dynamic locking plate without high rate failure cases ($N=50$)

SD standard deviation

*Statistically significant difference

(83% vs 59%, $p=0.08$) and number of displaced fractures (94% vs 78%, $p=0.23$). The proportion of telescoping screws in central/central location in both views also varied between groups (11% vs 31%, $p=0.11$). Central location of telescoping screw in AP view was found in 27 (54%) and inferior location in 17 (34%) cases. In lateral view, there were 23 (46%) cases with central and 22 (44%) with posterior telescoping screw position.

On multivariate analysis, the presence of at least one completely collapsed screw (OR = 73.2; 95% CI 9.4–568.5, $p<0.01$) was identified as predictive factor for fracture healing failure, while telescoping screws' location around centre of the femoral head (OR = 14.7; 95% CI 1.6–135.1, $p=0.02$) reduces the risk of fracture healing failure.

Fourteen patients from failure group ($N=18$) underwent subsequent surgery 3–17 months following index procedure and eleven of them were performed within 1 year. Most of them were conversion to total hip arthroplasty (8 patients), 1 conversion to hemiarthroplasty, 3 hardware removal, 1 hardware removal with excision arthroplasty, and 1 screw exchange.

Discussion

In our study, we found femoral neck fracture healing complications (femoral head cut-out or non-union) in 23 (41%) of 56 cases which is more than published in earlier studies that presented healing complication rate from 2 to 11.8% [4, 9, 15, 16]. In our studied group, dynamic locking plate implant was used for patients with intracapsular femoral fractures at any age and with any fracture dislocation. Therefore, we had higher proportion of displaced (84%) fractures which differs from most of the other studies in which proportion of displaced fractures reached 34–65% [4, 6, 16]. After excluding failures attributed to poor fracture reduction or not subchondral placement of the telescoping screws, the failure rate achieved 36% (18/50) cases. The failure rate 36% is still higher than previously published, but, after we take into consideration our overall high proportion of displaced fractures (84%), our failure rate might be comparable to results of Bieber *et al*. (2014) who reported non-union and cut-out in 11.8% in a cohort involving only 34% of displaced fractures [4]. Moreover, we had greater proportion of patients older than 65 years with displaced fracture than Bieber et al. (88% vs 0%) [4]. Displaced fracture was shown by Parker et al. as a factor increasing non-union. In his study, he found 2.7% risk for non-union in undisplaced fractures compared to 15.4% in displaced fracture group which, after calculation, gives risk ratio of 5.7 (95%CI 1.8–18.3, $p<0.01$) [6].

Our 1 year revision surgery reached 22% (11/50) which is similar to outcome of Griffin et al. who reported 32% risk of revision surgery at 12 months in the group consisted of 80% of displaced intracapsular hip fractures with a cohort mean age of 83 years [7].

As mentioned earlier analysis of our complications revealed that 5 (22%) of 23 failures could be attributed to the surgeon performing the procedure. Patients with a fair fracture reduction reached as high as 75% failure rate. Similar high rate of failures was published by Haidukewych et al., who found three of five (60%) non-unions in the case of fair-to-poor reduction despite reported cohort consisted of younger patients with femoral neck fractures [13]. Alho et al. (1992) showed that imperfect fracture reduction increased three times risk for fracture healing failure [17]. Moreover, not perfectly reduced fracture was recognized by Biber et al. as the main reason for cut-out in his study group of patients treated by dynamic locking plate [4].

To achieve good bone purchase of the telescoping screw, it is critical that screw tip should be placed in subchondral bone [5]. In two of our cases, we did not appropriately place any of the telescoping screws deep in subchondral bone which resulted in 100% fracture healing failure. The exact reason of this technical fault is unknown, because telescoping screws after procedure were not fully extended, so there was still possibility to achieve subchondral screw tip location.

During implantation of dynamic locking plate, it is important to place the central guide wire in the centre of femoral head as the aiming jig, and thus, implantation of telescoping screws fully depends on the location of the guide wire [5]. Good positioning of the guide wire should result in the central location of telescoping screws in both AP and lateral views. In our group of patients, we achieved central/central location of telescoping screws in 12 out of 50 cases (24%). The central/central screws position was found in 31% of healed group but only in 11% of failed group. The central/central position of telescoping screws was found predictor (OR 14.7, 95% CI 1.6–135.1) that reduces the risk of fracture healing failure. Placing telescoping screws in other than central/central location might be in part explained by the learning curve of the surgeons starting to perform the procedure. All of the surgeons had long term experience with sliding hip screw procedure in which insertion of guide wire in AP view was considered correct, if the wire was located slightly inferior to femoral head centre, which might be the reason of inferior location of telescoping screws in 34% [18]. We noticed other than the central location of telescoping screws in a lateral view is 54%. Explanation of this might be partly by the bending of the central guide wire during advancing it into the femoral head which was experienced by some surgeons. During the placing of the wire into the central location of the femoral head, when the wire was passing through the femoral neck and the head, it slightly diverged from the straight path due to its minimal bending which was left unnoticed. As telescoping screws were keeping a straight

path while advancing through the femoral neck and head, it resulted not within the central location of the screw within femoral head (Fig. 5).

Sliding is important feature of the implant as it allows controlled impaction of the fracture. The implant should also have a sufficient sliding capacity, because the femoral neck can collapse more than 10 mm [19]. Based on the amount of screw extension, sliding capacity of the telescoping screws is from 10 up to 20 mm [5]. Telescoping screws slide as one unit in a dynamic locking plate, so, if one of the screws fully collapses earlier than the others, the implant becomes a combination of rigid and dynamic fixed angle implant. In our series, we noticed this situation in 89% of all failures, while only in 19% of healed group. Reason for this situation might be an excessive collapse across fractures and unevenly extended telescoping screws that allowed premature complete collapses on some of the screws. We can only speculate whether equally extended telescoping screws would lead to less fracture healing complications.

The present study has some limitations. It has retrospective character and being conducted at a single centre. The small number of patients could be the main reason that the difference between age and number of displaced fractures did not reach statistical significance between the failed and the healed group. Finally the location of telescoping screw within femoral head was hard to determine in the lateral

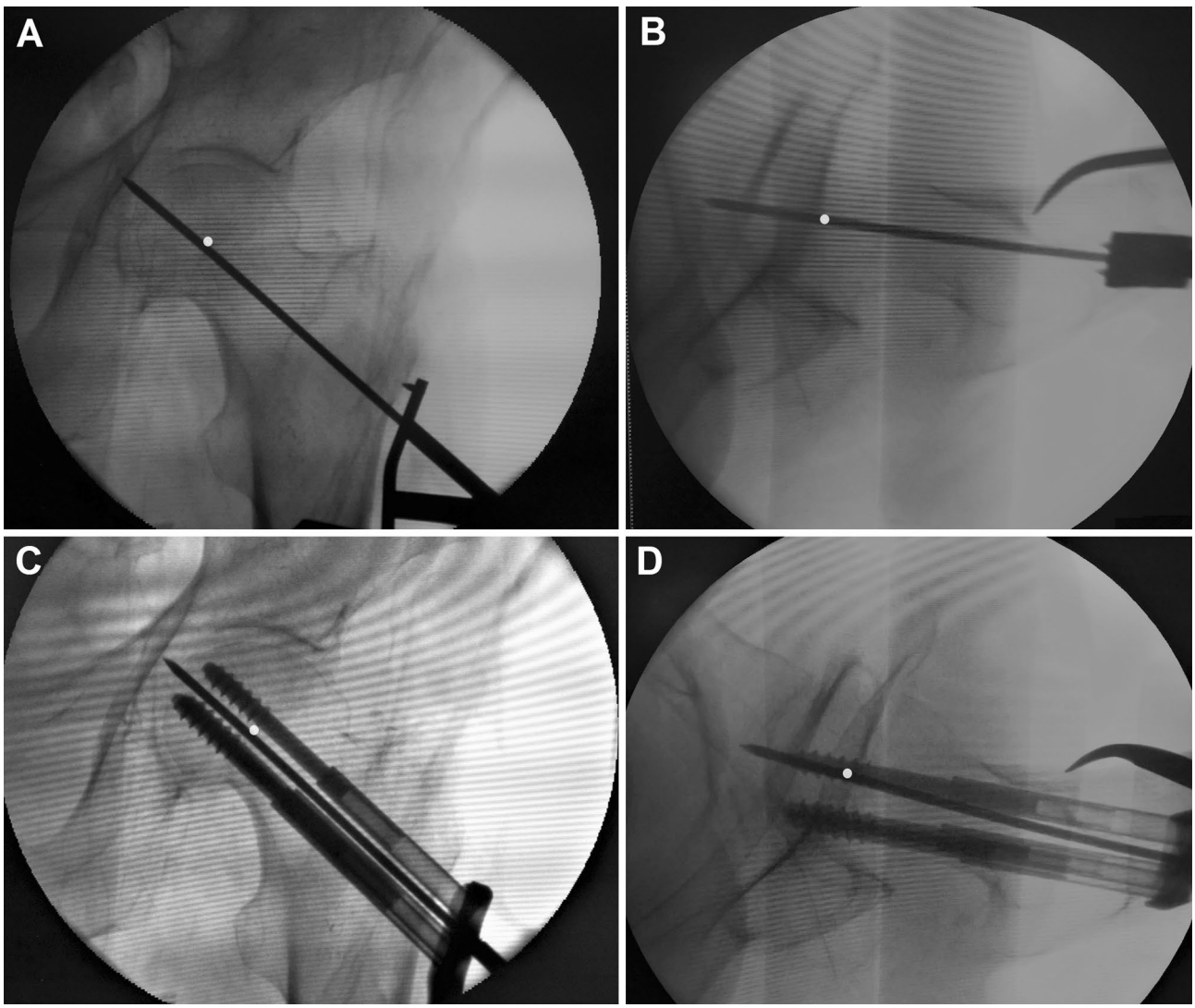

Fig. 5 Central guide wire bending. After drilling through the aiming guide the central guide wire runs through the centre of the femoral head in anteroposterior (**a**) and lateral (**b**) views and seems straight. The guide wire is located between superior and inferior telescoping screws, and is parallel to them in anteroposterior view (**c**). In lateral view, wire is placed between anterior and posterior telescoping screws laterally, but, toward femoral head centre, it converges to the treaded part of anterior telescoping screw (**d**). In comparison to straight telescoping screws, the guide wire is curved (**d**). White dot indicates femoral head centre

view, because the screws were not always aligned in a row due to the degree of leg rotation.

Conclusion

In our group of patients treated with dynamic locking plate, we found 41% failure rate. This high failure rate was associated with poor fracture reduction, not subchondrally and centrally placed telescoping screws and the complete collapse on at least one of the telescoping screws.

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