Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jor

Original Article

Predictors of early failure in young patients with displaced femoral neck fractures

Stephen Gardner^{a,*}, Michael J. Weaver^b, Seth Jerabek^c,
Edward Rodriguez^d, Mark Vrahas^e, Mitchel Harris^b

^a Kerlan-Jobe Orthopaedic Foundation, Kerlan-Jobe Orthopaedic Clinic, Los Angeles, CA, USA

^b Department of Orthopedic Surgery, Brigham and Women's Hospital, Boston, MA, USA

^c Department of Orthopedics, Hospital for Special Surgery, New York, NY, USA

^d Department of Orthopedics, Beth Israel Deaconess Hospital, Boston, MA, USA

^e Department of Orthopaedics, Massachusetts General Hospital, Boston, MA, USA

ARTICLE INFO

Article history:

Received 13 November 2013

Accepted 5 January 2014

Available online 7 February 2014

Keywords:

Femoral neck fracture

Complications

Predictors of failure

Young patients

ABSTRACT

Introduction: This study compares early failure rates of sliding hip screw (SHS) and cannulated screw (CS) constructs in young patients.

Methods: Patients <60 years of age, with displaced femoral neck fractures treated with CS or SHS fixation were included. Primary outcome was failure within 6 months.

Results: One patient (3%) with SHS fixation and 6 patients (21%) with CS fixation failed within 6 months ($P = 0.04$). Regression analysis demonstrated type of fixation ($P = 0.005$) and reduction quality ($P = 0.04$) are independent predictors of early failure.

Conclusions: SHS constructs demonstrate a significantly lower short-term failure rate than CS constructs.

Copyright © 2014, Professor P K Surendran Memorial Education Foundation. Publishing Services by Reed Elsevier India Pvt. Ltd. All rights reserved.

1. Introduction

Displaced femoral neck fractures in the young and active population are a relatively rare but potentially devastating injury. Treatment typically involves open or closed reduction and internal fixation with either cannulated screws (CS) or a fixed-angle sliding hip screw (SHS). Reconstruction with total hip arthroplasty is increasingly advocated as the definitive primary treatment in the elderly who sustain displaced femoral neck fractures but is far less desirable and often contra-indicated in a young active patient due to the

significant demands of this population and concerns for implant longevity. The published results of fixation of displaced femoral neck fractures in the “younger population” (<60 years of age) are mixed.^{1–10} Complication rates including loss of fixation, nonunion, and avascular necrosis (AVN) of the femoral head remain high; ranging from 10 to 45% regardless of fixation method.^{9,11}

Currently, there is no clear difference in the literature with regards to the clinical results of patients treated with CS and SHS fixation for displaced femoral neck fractures.^{9,11–13} Biomechanical analysis has indicated that fixed-angle sliding hip screw constructs are stronger than cannulated

* Corresponding author. Kerlan-Jobe Orthopaedic Clinic, 4801 Park Terrace, Los Angeles, CA 90045, USA. Tel.: +1 310 729 5117.

E-mail address: stevegardner22@gmail.com (S. Gardner).

lag screws, especially in the higher energy, vertically oriented femoral neck fractures.^{14,15} However, there is limited clinical evidence to suggest superiority of either implant in terms of AVN, nonunion or need for revision surgery. Furthermore, few series have reported on early (prior to 6 months) loss of fixation in young patients with displaced femoral neck fractures.⁵

The primary aim of this study is to compare the rate of loss of fixation in younger patients with displaced intracapsular femoral neck fractures treated with either SHS or CS constructs. The secondary aim is to identify risk factors associated with either early or late failure of fixation, AVN or nonunion in this patient population.

2. Materials and methods

We performed a retrospective review of a prospectively enrolled trauma database at three American College of Surgeons Level One Trauma Centers from January, 2000 through December, 2010. Institutional review board approval was obtained at all institutions prior to initiating the study. Patients included were skeletally mature, less than 60 years of age, and had sustained a displaced femoral neck fracture (OTA 31.B2/31.B3) and were treated with either CS or SHS fixation.¹⁶ Additionally, only patients with at least 6 months of follow-up were studied. The primary outcome measure was the identification of early failures, defined as the need to return to the OR for revision surgery within 6 months from the time of injury. Additional outcomes included nonunion and avascular necrosis (AVN).

All radiographs were reviewed and classified as displaced intracapsular femoral neck fractures (AO/OTA classification 31.B2 or 31.B3) by a single surgeon (SG). Any patient with a fracture involving either trochanter or extending beyond the intertrochanteric line was excluded. The decision to perform a closed or open reduction, with or without a capsulotomy, was made at the time of surgery by the treating surgeon. All CS fixations were performed with either 6.5 mm or 7.3 mm cannulated partially threaded cancellous screws (Synthes, West Chester, PA) and all SHS constructs utilized the Dynamic Hip Screw System (Synthes, West Chester, PA). CS fixation included three partially threaded cancellous screws, placed in parallel, in an inverted triangle configuration. Screw and thread length was chosen based on fracture characteristics to ensure no threads traversed the fracture. SHS constructs were performed according to the manufacture's technique guide. Our standard surgical practice is to obtain a combined tip-apex distance (TAD) of less than 25 mm.¹⁷

The quality of reduction for all patients and the tip-apex distance (TAD) in the SHS patients were evaluated by a single surgeon (SG). All early failures in the CS group were classified by the Pauwels' classification system.¹⁸ The quality of the final fracture reduction was rated on the basis of maximal residual displacement or angulation on any radiographic view on the first post-operative radiograph as described by Haidukewych et al. Reductions were rated as excellent (<2 mm displacement and/or <5 degrees of angulation), good (2–5 mm displacement and/or 5–10 degrees of angulation), fair (5–10 mm displacement and/or 10–20 degrees of angulation) or poor (>10 mm displacement and/or >20 degrees of

angulation).⁷ TAD was calculated as the sum of the distance from the tip of the lag screw to the apex of the femoral head on the AP and lateral radiographs as described by Baumgaertner et al.¹⁷

The primary outcome measure, early failure, was defined as loss of reduction requiring a return to the operating room within 6 months of the index procedure. Secondary outcomes included nonunion; defined clinically by pain and radiographically by the lack of bony healing at the fracture site, and symptomatic AVN of the femoral head requiring intervention. Baseline patient demographics were collected including age, gender, mechanism of injury and comorbidities (Table 1). The patient population in this series was relatively healthy given the young age and there were few comorbidities documented in the cohort. We identified and searched for specific comorbidities based on their presumed negative influence on bone healing; end-stage renal disease (ESRD), diabetes mellitus (DM), steroid use, alcohol abuse and smoking. Mechanisms of injury were broadly classified as fall, motor vehicle crash (MVC), sports related, and other [seizure (SZ), gunshot (GSW)].

Two-tailed Fisher Exact test was used to compare independent outcome variables. Pearson's Chi-square test was used to compare means of groups. Multivariate logistic regression analysis was performed to control for possible confounding covariates. Kaplan–Meier curve was constructed

Table 1 – Demographics data for fixation types for treating displaced femoral neck fractures.

Variable	Total (N = 69)	SHS (N = 40)	CS (N = 29)	P value
Age, years, mean ± SD	42.9 ± 12.5	42.4 ± 11.8	43.7 ± 13.5	0.68
Gender				
Male	38 (55%)	21 (53%)	17 (59%)	0.63
Female	31 (45%)	19 (47%)	12 (41%)	
Diabetes	2 (3%)	1 (3%)	1 (3%)	1.00
Alcohol Abuse	4 (6%)	2 (5%)	2 (7%)	1.00
Smoking	9 (13%)	3 (8%)	6 (21%)	0.15
ESRD	2 (3%)	2 (5%)	0 (0%)	0.51
Steroids	4 (6%)	3 (8%)	1 (3%)	0.63
Initial post-op reduction ^a				
Excellent	20 (32%)	12 (34%)	8 (29%)	0.60
Good	34 (54%)	17 (49%)	17 (61%)	
Fair	9 (14%)	6 (17%)	3 (11%)	
Mechanism of injury				
MVC	9 (13%)	5 (13%)	4 (13%)	0.65
Fall	42 (61%)	23 (58%)	19 (66%)	
Sports related	12 (17%)	9 (23%)	3 (10%)	
Other (GSW, SZ)	6 (9%)	3 (8%)	3 (10%)	
Follow-up, mos, median (IQR)	18 (11–30)	15 (11–32)	25 (11–35)	0.45
Capsulotomy	13 (19%)	6 (15%)	7 (24%)	0.37
Tip-apex distance, cm, median (IQR) ^a	–	21.4 (17–24.25)	–	–

ESRD, end-stage renal disease; DHS, dynamic hip screw; CS, cannulated screw; MVC, motor vehicle collision; GSW, gunshot wound; SZ, seizure; IQR, interquartile range; AVN, avascular necrosis.

^a Missing information from X-rays (n = 6).

Fig. 1 – Flow chart showing inclusion/exclusion of subjects in this study.

for early fixation failures. SPSS Version 17.0 (SPSS Inc., Chicago, Illinois) was used for the statistical analysis. *P* value was set at 0.05 to indicate statistical significance.

3. Results

One hundred and thirty-three fractures in 132 consecutive patients were identified at the three institutions. Of these, 91 patients were treated with either CS or SHS fixation. 17 of these patients did not have adequate follow-up. Three patients were excluded as their fracture was deemed pathologic and 3 were excluded as their femoral neck fracture was associated with either a femoral head fracture or an acetabular fracture. This yielded the final study cohort of 69 displaced femoral neck fractures in 68 patients (Fig. 1). The median follow-up for those patients that did not fail prior to 6 months was 18 months.

There were sixty-nine displaced femoral neck fractures in sixty-eight patients included in the final analysis (SHS 40, CS 29). Baseline demographic data for the groups is presented in Table 1. There was no statistical difference found between the SHS and CS group in terms of age ($P = 0.68$), gender ($P = 0.63$), mechanism ($P = 0.65$), comorbidities ($P > 0.05$), length of follow-up ($P = 0.45$) or quality of reduction ($P = 0.6$). One patient (1/40; 3%) in the SHS fixation group and 6 patients (6/29; 21%) in the CS group required a return to the operating room for loss of reduction within 6 months of their index procedure. Univariate comparisons suggest that CS fixation is associated with a significantly higher early fixation failure rate compared to SHS (21% vs. 3%, $P = 0.04$) (Fig. 2). There was no difference

between the two groups in terms of the secondary outcomes; nonunion (SHS 4/40, 10% vs. CS 1/29, 3%; $P = 0.39$) and symptomatic AVN (SHS 5/40, 12% vs. CS 2/29, 7%; $P = 0.69$). The overall complication rate in the two groups was similar as well (SHS 10/40, 25% vs. CS 9/29, 31%; $P = 0.60$) (Table 2). Six of the seven early fixation failures were converted to total hip arthroplasty. One patient in the CS group with an early failure related to broken hardware was treated with revision fixation at 5 months. All early failures in the CS group were of intermediate verticality and were classified as Pauwels' Type-2 (median 46°; range 43–50). The only SHS that failed early

Fig. 2 – Kaplan–Meier curves for early fixation failure depicting that patients in the CS group fared worse ($P = 0.014$); the error bars are 95% CIs.

Table 2 – Comparison between fixation types for treating displaced femoral neck fractures.

Variable	Total (N = 69)	SHS (N = 40)	CS (N = 29)	P value
Fixation failure – 6 months	7 (10%)	1 (3%)	6 (21%)	0.04 ^a
Nonunion	5 (7%)	4 (10%)	1 (3%)	0.39
AVN	7 (10%)	5 (12%)	2 (7%)	0.69
Any complication	19 (28%)	10 (25%)	9 (31%)	0.60

^a Statistically significant, Fisher's exact test.

experienced cut-out of the lag screw despite a TAD of 21.8 mm. Eleven of the remaining twelve patients with an identified complication were converted to total hip arthroplasty. One patient underwent core decompression at 26 months. There were no infections in this small cohort.

Smokers showed a significantly higher incidence of early fixation failure than nonsmokers, though the total number of smokers in the cohort was small (3/9, 33% vs. 4/60, 7%; $P = 0.04$). Fixation method, smoking status, and quality of surgical reduction were then included as covariates in a multivariate logistic regression analysis. Results from this analysis confirm that type of fixation (SHS vs. CS, $P = 0.005$) and quality of reduction (fair vs. excellent/good, $P = 0.04$) were independent predictors of early fixation failure and that smoking was not a predictor ($P = 0.13$). Specifically, patients who had a quality of reduction judged as “fair”, were significantly more likely to experience early fixation failure compared to those with good or excellent reductions, independent of fixation method used. Conversely, patients treated with CS fixation were significantly more likely to have fixation failure within 6 months compared to patients treated with SHS constructs, independent of the quality of initial post-op reduction.

Fifty of the 69 fractures (72.5%) had no identifiable complication at their most recent follow-up. In addition to the seven early failures (7/69; 10%; SHS $n = 1$, CS $n = 6$), there were five nonunions (5/62; 8%; SHS $n = 4$, CS $n = 1$), and seven patients who developed symptomatic AVN ultimately requiring surgical intervention (7/57; 12%; SHS $n = 5$, CS $n = 2$). Thus, in our cohort of 69 displaced femoral neck fractures treated with surgical fixation, there were 19 patients with identifiable complications requiring further surgery and 50 with uneventful post-op clinical courses. Comparing the 2 subgroups, those patients with post-op complications to those without complications; the two groups were similar in terms of age ($P = 0.31$), gender ($P = 0.28$), fixation type (SHS vs. CS, $P = 0.60$), and selective comorbidities (ESRD, DM, steroid use, alcohol abuse and/or smoking) ($P > 0.05$) (Table 3). However, univariate comparisons indicate that a higher percentage of patients who experienced post-op complication had radiographic evidence of only a “fair” reduction (6/19, 35%) compared to those not having a complication (3/50, 7%) ($P = 0.006$) (Table 3). Multivariate logistic regression was then performed to determine whether fixation type, age, smoking or quality of reduction had an influence on the likelihood of any complication. Results indicate that only quality of reduction was a significant predictor of any complication ($P = 0.008$), not

Table 3 – Factors associated with any complication.

Variable	Complication (N = 19)	No complication (N = 50)	P value
Age, years, mean $\pm$ SD	45.4 $\pm$ 9.8	42.0 $\pm$ 13.3	0.31
Gender			
Male	8 (42%)	30 (60%)	0.28
Female	11 (58%)	20 (40%)	
Diabetes	1 (5%)	1 (2%)	0.48
Alcohol Abuse	0 (0%)	4 (8%)	0.57
Smoking	5 (26%)	4 (8%)	0.10
ESRD	1 (5%)	1 (2%)	0.48
Steroids	1 (5%)	3 (6%)	1.00
Initial post-op reduction ^b			
Excellent	2 (12%)	18 (39%)	0.006 ^a
Good	9 (53%)	25 (54%)	
Fair	6 (35%)	3 (7%)	
Weight bearing status			
Protected	13 (68%)	27 (54%)	0.41
As tolerated	6 (32%)	23 (46%)	
Fixation			
DHS	10 (53%)	30 (60%)	0.60
CS	9 (47%)	20 (40%)	

ESRD, end-stage renal disease; DHS, dynamic hip screw; CS, cannulated screw.

^a Statistically significant, Pearson chi-square test.

^b Missing information from X-rays ($n = 6$).

smoking ($P = 0.09$), age ($P = 0.17$) nor type of fixation ($P = 0.29$). This implies that any complication (fixation failure, nonunion or AVN) is more likely to occur among patients with reductions judged as “fair” independent of whether SHS or CS fixation is used.

4. Discussion and Conclusions

Currently, there is inconsistent evidence in the literature with regards to optimal fixation technique for displaced femoral neck fractures.^{10–13,19} While femoral neck fractures have been extensively studied, there are few studies that focus on younger patients with displaced intra-articular fractures. Parker and Blundell published a large meta-analysis of 25 randomized trials comparing implant choice for femoral neck fractures and reported no difference between SHS and CS fixation.¹⁹ However, the mean age of the patient cohorts in the studies included in their analysis was significantly greater (>66 years) than in our series. Additionally, there was inconsistency throughout with regards to displaced vs. non-displaced fractures and significant methodological limitations of the studies included in the meta-analysis were reported.

Tooke et al reported on 32 femoral neck fractures in patients fifty years-old or less, and demonstrated no difference in the rate of AVN or nonunion when comparing multiple fixation methods which included fixed-angles SHS and cannulated screw constructs. However, only 18 of these patients had displaced fractures, there was a heterogeneous mix of implants utilized and the study was underpowered.¹⁰ Bhandari et al reviewed 4 randomized controlled trials comparing SHS vs. CS fixation for displaced femoral neck fractures and

reported no difference in outcomes regardless of the implant utilized, although, in his pooled estimates, there was a trend towards reduced risk of revision surgery with SHS constructs.¹¹

Liporace et al reported a series of seventy-six Pauwels' type-3, vertical femoral neck fractures, fifty-eight of which were displaced, with a mean age of 42 years and found a 19% nonunion rate for those patients treated with CS fixation and an 8% nonunion rate in patients treated with SHS fixation.¹ While the difference did not reach statistical significance, this series represents a similar demographic to our patients and a comparable trend towards better outcomes with fixed-angle devices in these fractures.

To the authors knowledge, this series is the first to report a higher early failure rate for displaced femoral neck fractures (OTA 31.B2/31.B3) in young active patients (<60 year of age) treated with CS fixation compared to those treated with SHS constructs. This difference persisted when controlling for quality of reduction and smoking status utilizing a multivariate analysis. Furthermore, the early failures seen in the CS group were all of intermediate verticality (Pauwels' type-2) and therefore fracture morphology likely did not influence the significantly higher early failure rate. There was no difference seen in the rate of symptomatic AVN, nonunion or overall complication among the two devices.

Extensive cadaveric evidence has shown that fixed-angled SHS constructs demonstrate superior biomechanical properties compared to CS constructs.^{11,14,15} Aminian et al compared SHS constructs to CS constructs with cyclic loading to failure and reported decreased stiffness and failure strength with CS.¹⁴ Baitner et al similarly compared SHS and CS fixation techniques in cadaveric models in both incremental and cyclical loading and reported less inferior femoral head displacement, less shearing displacement at the fracture site and greater load to failure for SHS constructs.¹⁵ These biomechanical differences may help explain the greater number of early failures seen in the CS group in our series. Given the overall prevalence of failures between the SHS and CS groups appears to be similar (SHS (25%) vs. CS (31%, $P = 0.60$)), the early failure difference may be explained by the difference in biomechanical strength of the two implants.

The overall union rate of 72.5% and revision rate of 27.5% for displaced femoral neck fractures in young patients seen in this series is consistent with previous literature.^{2,4–8,11,20–22} Furthermore, the nonunion rate of 7% and rate of AVN of 10%, are also consistent with several previously published series.^{1,2,5,7,8} Duckworth et al reported a series of 122 patients less than 60 years of age with displaced femoral neck fractures and demonstrated a 68% union rate, 7.4% nonunion rate and 11.5% rate of AVN. All patients in that series were treated with CS constructs. Interestingly, Duckworth et al reported a 13.1% early failure rate with loss of fixation at a mean time of 3.5 months, slightly lower than that demonstrated in our series (21%, mean time to failure 3.6 months). Risk factors most predictive of failure in their series were alcohol excess, renal disease and respiratory disease.⁵

A well recognized predictor of post-operative complication when treating femoral neck fractures is malreduction.^{20,23–27} Our series supports this finding. In our series, post-operative reductions rated as “fair” did worse in terms of both early

failure and overall complications when compared to those fractures whose reductions were rated as excellent or good ($P = 0.006$). This relationship persisted when controlling for age, smoking status and implant choice. Unique to this study however, was the differential rate of early failure seen between SHS constructs and CS constructs with a significantly higher failure rate seen with CS ($P = 0.005$). Again, this discrepancy persisted when controlling for quality of reduction and may be related to the implant biomechanical differences. Therefore, it appears that implant choice (CS vs. SHS) and quality of reduction (fair vs. good/excellent) were both independent predictors of early implant failure (<6 months) and only quality of reduction was predictive of any complication (early failure, AVN or nonunion) in our cohort.

There are several limitations to the results presented here. The retrospective methodology invites inherent bias and confounding. Variables known or thought to influence outcomes were recorded and comparisons between the SHS and CS groups were performed to help control for confounding. Furthermore, multivariate logistic regression analysis was performed to control for possible confounding covariates.

Another potential weakness of our study is the short length of follow-up for the entire study group (mean 18mo). This short-term follow-up limits the potential for evaluation of longer-term complications, most significantly AVN, which can appear years after injury. This however, should not influence our primary outcome measurement of early failure defined as prior to 6 months. Our cohort is small ($N = 69$), although similar to other published series.^{1,5} There was also a significant cohort lost to follow-up. Seventeen patients (17/91, 18%; SHS 10, CS 7) were excluded due to follow-up less than 6 months. This likely reflects the transient nature of the trauma patient population. However, these patients were noted to be “doing well” at their last clinic visit and thus were unlikely to go on to early failure. However, the ultimate outcome for these patients is undetermined.

There remains controversy with regards to the optimal fixation method for displaced femoral neck fractures in young active patients. Biomechanical and clinical data suggest that SHS constructs are stronger and may lead to reduced incidence of fixation failure and nonunion.^{1,11,14,15} It has been our clinical experience that SHS constructs demonstrate a significantly lower short-term fixation failure rate than CS constructs. Our study's longer-term complications including nonunion and symptomatic AVN are similar to previously published reports and appear to be independent of fixation method. This suggests that biologic, and not mechanical, factors are most important in determining long-term outcomes in these injuries. Furthermore, our series adds to the extensive data pointing towards quality of fracture reduction as an essential predictor of failure in terms of both short and long-term complications. Further prospective studies will be essential in determining the true optimal fixation method for these difficult fractures and elucidate risk factors associated with treatment failure.

Conflicts of interest

All authors have none to declare.

REFERENCES

1. Liporace F. Results of internal fixation of Pauwels type-3 vertical femoral neck fractures. *J Bone Joint Surg Am.* 2008 Aug 1;90:1654.
2. Protzman RR, Burkhalter WE. Femoral-neck fractures in young adults. *J Bone Joint Surg Am.* 1976 Jul;58:689–695.
3. Jain R, Koo M, Kreder HJ, Schemitsch EH, Davey JR, Mahomed NN. Comparison of early and delayed fixation of subcapital hip fractures in patients sixty years of age or less. *J Bone Joint Surg Am.* 2002;84:1605–1612. *The Journal of Bone and Joint Surgery.*
4. Fortina M, Carta S, Crainz E, Urgelli S, Del Vecchio E, Ferrata P. Management of displaced intracapsular femoral neck fracture in young adult: why complications are still so high? Case report of posttraumatic avascular necrosis in a 30-year-old man and a brief review. *J Trauma.* 2009 Nov;67:E163–E166.
5. 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 Joint Surg Br.* 2011 Jun;93:811–816.
6. Swiontkowski MF, Winkquist RA, Hansen Jr ST. Fractures of the femoral neck in patients between the ages of twelve and forty-nine years. *J Bone Joint Surg Am.* 1984;66:837–846.
7. Haidukewych GJ, Rothwell WS, Jacofsky DJ, Torchia ME, Berry DJ. Operative treatment of femoral neck fractures in patients between the ages of fifteen and fifty years. *J Bone Joint Surg Am.* 2004 Aug;86-A:1711–1716.
8. Dedrick DK, Mackenzie JR, Burney RE. Complications of femoral neck fracture in young adults. *J Trauma.* 1986 Oct;26:932–937. *Injury Infection, and Critical Care.*
9. Davidovitch RI, Jordan CJ, Egol KA, Vrahas MS. Challenges in the treatment of femoral neck fractures in the nonelderly adult. *J Trauma.* 2010 Jan;68:236–242. *Injury Infection, and Critical Care.*
10. Tooke SM, Favero KJ. Femoral neck fractures in skeletally mature patients, fifty years old or less. *J Bone Joint Surg Am.* 1985 Oct;67:1255–1260.
11. Bhandari M, Tornetta III P, Hanson B, Swiontkowski MF. Optimal internal fixation for femoral neck fractures: multiple screws or sliding hip screws? *J Orthop Trauma.* 2009;23:403.
12. Kuokkanen H, Korkala O, Antti-Poika I, Tolonen J, Lehtimäki MY, Silvennoinen T. Three cancellous bone screws versus a screw-angle plate in the treatment of Garden I and II fractures of the femoral neck. *Acta Orthop Belg.* 1991;57:53–57.
13. Madsen F, Linde F, Andersen E, Birke H, Hvass I, Poulsen TD. Fixation of displaced femoral neck fractures. A comparison between sliding screw plate and four cancellous bone screws. *Acta Orthop Scand.* 1987 Jun;58:212–216.
14. Aminian A, Gao F, Fedoriw WW, Zhang L-Q, Kalainov DM, Merk BR. Vertically oriented femoral neck fractures: mechanical analysis of four fixation techniques. *J Orthop Trauma.* 2007 Sep;21:544–548.
15. Baitner AC, Maurer SG, Hickey DG, et al. Vertical shear fractures of the femoral neck. A biomechanical study. *Clin Orthop Relat Res.* 1999 Oct;367:300–305.
16. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium – 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma.* 2007 Nov;21:S1–S133.
17. Baumgaertner MR, Curtin SL, Lindskog DM, Keggi JM. The value of the tip-apex distance in predicting failure of fixation of peritrochanteric fractures of the hip. *J Bone Joint Surg Am.* 1995 Jul;77:1058–1064.
18. Bartonicek J. Pauwels' classification of femoral neck fractures: correct interpretation of the original. *J Orthop Trauma.* 2001 Jun;15:358–360.
19. Parker MJ, Blundell C. Choice of implant for internal fixation of femoral neck fractures. Meta-analysis of 25 randomised trials including 4,925 patients. *Acta Orthop Scand.* 1998 Apr;69:138–143.
20. Upadhyay A, Jain P, Mishra P, Maini L, Gautum VK, Dhaon BK. Delayed internal fixation of fractures of the neck of the femur in young adults. A prospective, randomised study comparing closed and open reduction. *J Bone Joint Surg Br.* 2004 Sep;86:1035–1040.
21. Lu-Yao GL, Keller RB, Littenberg B, Wennberg JE. Outcomes after displaced fractures of the femoral neck. A meta-analysis of one hundred and six published reports. *J Bone Joint Surg Am.* 1994 Jan;76:15–25.
22. Kofoed H. Femoral neck fractures in young adults. *Injury.* 1982 Sep;14:146–150.
23. Alberts KA, Jervaeus J. Factors predisposing to healing complications after internal fixation of femoral neck fracture. A stepwise logistic regression analysis. *Clin Orthop Relat Res.* 1990 Aug;257:129–133.
24. Heetveld MJ, Raaymakers E. Rating of internal fixation and clinical outcome in displaced femoral neck fractures: a prospective multicenter study. *Clin Orthop Relat Res.* 2007 Jan;454:207–213.
25. Chua D, Jaglal SB, Schatzker J. Predictors of early failure of fixation in the treatment of displaced subcapital hip fractures. *J Orthop Trauma.* 1998 May;4:230–234.
26. Schep NWL, Heintjes RJ, Martens EP, van Dortmont LMC, van Vugt AB. Retrospective analysis of factors influencing the operative result after percutaneous osteosynthesis of intracapsular femoral neck fractures. *Injury.* 2004 Oct;35:1003–1009.
27. Sochart DH. Poor results following internal fixation of displaced subcapital femoral fractures: complacency in fracture reduction. *Arch Orthop Trauma Surg.* 1998;117:379–382.