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Anchorage strategies in geriatric hip fracture management

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Abstract: There is an enormous humanitarian and socio-economic need to improve the quality and effectiveness of care for patients with hip fracture. To reduce mechanical complications in the osteosynthesis of proximal femoral fractures, improved fixation techniques have been developed including blade or screw-anchor devices, locked minimally invasive or cement augmentation strategies. However, despite numerous innovations and advances regarding implant design and surgical techniques, systemic and mechanical complication rates remain high. Treatment success depends on secure implant fixation in often-osteoporotic bone as well as on patient-specific factors (fracture stability, bone quality, comorbidity, and gender) and surgeon-related factors (experience, correct reduction, and optimal screw placement in the head/neck fragment). For fracture fixation, the anchorage of the lag screw within the femoral head plays a crucial role depending on the implant's design. Meta-analyses and randomized controlled studies demonstrate that there is a strong trend towards arthroplasty treating geriatric femoral neck fractures. However, for young adults as well as older patients with less compromised bone quality, or in undisplaced fractures, head-preserving therapy is preferred as it is less invasive and associated with good functional results. This review summarizes the evidence for the internal fixation of femoral neck fractures and trochanteric femoral fractures in elderly patients. In addition, biomechanical considerations regarding implant anchorage in the femoral head including rotation, migration, and femoral neck shortening are made. Finally, cement augmentation strategies for hip fracture implants are evaluated critically.

Keywords: cement augmentation; cut-out; femoral neck fracture; helical blade; rotationally stable screw-anchor; sliding hip screw; trochanteric femoral fracture.

Introduction

In Germany, the elderly population (> 65 years) will grow from 26% of the total population in 2013 to 40% in 2040 [1]. The recently published EuroHOPE patient database oversees 59,605 hip fracture patients across seven European countries. The hip fracture prevalence of patients older than 50 years ranged from 307/100,000 in Finland to 1269/100,000 in Italy. The 30-day and 1-year mortality rate peaked with 11.7% and 34.8% in Hungary and was lowest in Italy with 4.0% and 19.7%, respectively [2]. The 2012 annual number of hip fractures in the United Kingdom was reported to be 77,000 [3] and is projected to rise to 101,000 by 2020 [4]. Extrapolated to German's population, the 2013 incidence of hip fracture was 126 per 100,000 residents per year [4, 5]. The Institut für Qualitätssicherung und Transparenz im Gesundheitswesen (IQTIG) published recently its 2015 Hip Fracture Report covering 59,948 medical records of hip fracture patients who received internal fixation from 1215 German hospitals. The IQTIG report revealed an in-hospital mortality rate of 4.9% and a total reported complication rate of 16.3% [6]. In total, the 1-month mortality rate after hip fracture ranges from 4% to 12% and reaches up to 35% after 1 year [2, 6, 7]. The hip fracture patient frequently presents with complex comorbidities, including but not limited to impaired hepatic and renal function, diabetes mellitus, dementia, delirium, coronary artery disease, heart failure, and patient polypharmacy. These are all individually linked to an increase on postoperative complications and mortality [5].

The average hip fracture patient in Germany spends a mean time of 13 days in the hospital (median of 11 days) [6]. Among patients who survive to 12 months, 40% of those who could walk independently before fracture require human assistance to walk 10 feet [8]. Hip fractures create substantial needs for informal caregiving [9] and postacute and long-term care that carry major costs to

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society [10]. Moreover, the disability caused by hip fractures matter to older adults. Elderly women stated that they would rather die than experience the loss of independence associated with hip fracture [11].

Femoral neck fractures

Osteoporotic fractures of the femoral neck pose an ever-expanding existential problem both for the individual and for society. Despite numerous innovations and advances regarding implant design, systemic and mechanical complication rates remain high. Because mortality and morbidity are high, hip fractures have a direct impact on public health [12] and are one of the main reasons for disability [13].

Surgical treatment should be straightforward and less invasive, allow immediate weight-bearing, and should be associated with a low complication rate. Various factors such as patient age, comorbidities, activity level, age of the fracture or preinjury arthrosis, and experience of the surgeon influence the decision-making for fixation versus arthroplasty in displaced femoral neck fractures. Yet, the optimal treatment is still a subject of debate [14, 15]. Meta-analyses and randomized controlled studies demonstrate that there is a strong trend towards arthroplasty [15–17]. The main reason being that internal fixation is associated with a considerably higher reoperation rate in comparison to arthroplasty [16, 17]. Even long-term investigations of arthroplasties of up to 17 years show a significantly lower rate of revision surgery (internal fixation 39%, arthroplasty 9%) [17]. Despite lower initial treatment costs for internal fixation, the total burden on the health-care system is higher than with the use of arthroplasty due to the high reoperation rate [16]. However, for young adults as well as older patients with less compromised bone quality, or in undisplaced fractures, head-preserving therapy is preferred as it is less invasive and associated with good functional results [18]. Commonly accepted fixation constructs are a three-screw technique or the sliding hip screw (SHS) composed of a lag screw implanted in direction of the femoral neck axis and a plate mounted at the lateral side of the femur [14]. Whereas the screws offer advantages in terms of torsional stability, the preservation of blood supply to the femoral head, and a less invasive approach, the SHS provides higher biomechanical stability, especially in osteoporotic bone [15]. Under loading conditions, the lag screw can slide within a barrel in an axial direction, allowing for a controlled collapse of the fracture side. However, despite various improvements in implant design, insufficient fracture fixation with failure

rates of up to 37% within 2 years remains a common complication in the treatment of femoral neck fractures [16]. The main biomechanical complication in young adults is leg shortening caused by subsidence (e.g. excessive sintering and shortening or varus collapse) [18]. Patients with osteoporosis often show femoro-acetabular penetration or cut-out following a rotational movement of the femoral head fragment [18]. For fracture fixation, the anchorage of the lag screw within the femoral head plays a crucial role depending on the implant's design [19]. One approach for the improvement of implant anchorage is the development of a blade as a load carrier instead of the traditional lag screw [20, 21]. A recent approach is the combination of a blade and a screw in one single implant, which is placed on the market as “rotationally stable screw-anchor (RoSA)” [22, 23]. In a first clinical setting, the fixation of unstable trochanteric femur fractures using the RoSA in combination with a trochanteric stabilizing plate (TSP) led to a great primary stability, with significant advantages with regard to limited femoral neck shortening [24]. However, a clinical evaluation of this innovative implant in femoral neck fractures is still missing.

Trochanteric femoral fractures

Although each year sees various modifications and improvements in operating techniques treating trochanteric fractures, these fractures are still associated with a mechanical complication rate of 0%–20% [25–29]. A1 fractures are considered stable and the SHS with its straightforward surgical technique that protects the trochanteric tendon insertion and its low cost is the implant of choice [26, 30–32]. The surgical technique comprises the closed reduction of the fracture on a fracture table. Open reduction is rarely necessary. Extramedullary stabilization of the fracture is performed via a lateral approach. The underlying biomechanical principle is a gliding of the screw in a metal sleeve allowing for postoperative impaction and dynamic compression of the fracture with weight-bearing. The plate is fixed to the femoral shaft with two to four screws. The use of the two-hole version is associated with less blood loss and a shorter procedure time [33]. A2 and A3 fractures are considered unstable and the degree of instability of the A2 subtypes as well as the choice of implant are subject to debate [32, 34–36]. Despite numerous surgical innovations in the past few years, the literature regarding treatment recommendations, especially in the presence of instability, is still inconsistent and a high mechanical complication rate remains [25, 26, 28, 29, 36]. There is no sufficient evidence from randomized

trials that primary arthroplasty is advantageous compared to intramedullary implants with head component or extramedullary implants with a sliding screw and side plate [37, 38]. In contrast, a known disadvantage is the higher transfusion rate associated with arthroplasty [38]. Fixation of the prosthesis is difficult in the presence of a fracture of the greater trochanter, fracture of the lateral wall, and severe comminution of the medial buttress [30]. Due to the higher complication rate associated with arthroplasty, unstable fractures should be treated with internal fixation and arthroplasty should only be performed when the fracture has healed [30].

The SHS is associated with a high complication rate when used in unstable trochanteric fractures (up to 25%) [27]. Cephalomedullary devices have been commonly used in the last few years due to their biomechanical superiority and less invasive technique [26, 28, 39]. Several meta-analyses have not been able to confirm the clinical superiority of extramedullary or intramedullary implants [32, 40, 41]. Parker and Handoll [32], in a Cochrane Review, concluded additional studies are needed particularly for the more recently developed designs of intramedullary nails that have potentially fewer complications in comparison to those with previous nails. Evidence-based treatment recommendations for unstable trochanteric fractures classified as AO/OTA-A2 are still lacking and there is a need for comparative studies including newly developed devices of the third generation [e.g. proximal femoral nail antirotation (PFNA; Synthes) and Gamma-3-nail (Stryker)] [32]. They are associated with a lower complication rate compared to the second generation [39] and are currently widely used [36]. The PFNA possesses a helical blade instead of a screw for fixation in the head/neck fragment. With bone compaction around the PFNA blade and consecutive rotational stability and cut-out resistance, lower reoperation rates (3%–7%) for unstable fractures have been described [28, 29, 39]. The angular stable, less invasive percutaneous compression plate (PCCP) has similar reoperation rates (Orthofix, McKinney, TX, USA) [25, 36, 42]. Decision-making between intramedullary and extramedullary fixation for A1 and A2 fractures is multifactorial and also based on surgeon expertise. However, an intramedullary fixation with a sliding screw achieves high primary stability and seems to be advantageous in reversed fractures (31A3) [43, 44].

Biomechanical considerations

Biomechanical studies have shown that the pertinent benefit of the helical blade lies in its rotational stability

[45, 46]. However, its resistance to pull-out forces is rather low [46], restricting the possibility of intraoperative compression. Besides, the migration along the blade axis can cause complications such as cut-through or reverse migration [47]. Based on these findings, the RoSA was developed [22, 23]. The benefits of the blade (loading and rotational stability) are combined with those of the screw (pull-out resistance and compression capability) in a single-load carrier. In previous biomechanical studies in trochanteric femoral fractures, the RoSA implant showed benefits with regard to stiffness, failure load, and rotational stability [22, 23]. In an unpublished study in unstable femoral neck fractures using biomechanical composite sawbones, RoSA fixation turned out to provide the highest stiffness and rotational stability and the least fragment displacement, head migration, and femoral neck shortening in comparison to SHS-screw and SHS-blade systems. High implant stiffness, along with a reduced cranial-caudal displacement of the head-neck fragment (equivalent to fracture displacement), is important for controlled fracture healing *in vivo*. Controlled fracture impaction occurs when the fixation device contributes to axial and torsional stability in addition to sliding capability. In contrast, fracture collapse occurs when reduction is not maintained or when additional fracturing occurs [48]. The typical mode of failure for SHS constructs with posterior rotation and retroverted varus deviation of the femoral head has been described earlier [49]. In this light, Kunapuli et al. reported three modes of failure of SHS systems: varus, torsion, and shear displacement [50]. Previous studies, on the contrary, showed that the failure mode associated with the SHS was screw bending rather than cut-out [22, 51]. However, the main reasons for fracture collapse in the SHS systems seem to be the low resistance to tendencies for rotation, migration, and sliding.

Rotation, migration, and femoral neck shortening

The main biomechanical complication in young adults is leg shortening caused by construction subsidence, such as excessive femoral neck shortening or fracture collapse [18]. Patients with osteoporosis often show excessive migration or cut-out following a rotational movement of the femoral head fragment [18]. Former studies described the role of rotational moments and migration tendencies as precursors to cut-out [45, 46, 52]. However, our own studies show that femoral neck shortening, when excessive, leads to fracture collapse before cut-out occurs and

plays a key role in early failure. Therefore, rotation and migration tendencies are precursors to femoral neck shortening with consecutive fracture collapse rather than cut-out. One possible reason for the improved anchorage of blade systems is bone compaction around the implant's surface during insertion, leading to enhanced implant fixation by biological and mechanical mechanisms as proposed by Kold et al. [53]. Yet, this theory seems controversial, as another study could not confirm the potential benefit of bone compaction at least with regard to axial stiffness and cycles to failure [54]. Apparently, the benefit of bone compaction by helical blades for implant anchorage is especially relevant in osteoporotic bone with reduced bone density [55]. However, the clinical relevance of the helical blade and its ability to increase bone density and therefore primary stability remains controversial, and clinical proof is still pending [56].

Cement augmentation strategies

Treatment success depends on secure implant fixation in often osteoporotic bone as well as on patient-specific factors (fracture stability, bone quality, comorbidity, and gender) and surgeon-related factors (experience, correct reduction, and optimal screw placement in the head/neck fragment) [44, 57, 58]. Varus collapse or the cut-out of the femoral neck screw (3%–7%) are still the main reasons for failure [39], especially with eccentric placement [44] and inadequate reduction [25, 57]. Fracture reduction and implant positioning are directly related, with correct reduction being the prerequisite to correct implant placement. However, in recent years, cement augmentation strategies came to the fore and were discussed to an increasing degree. The first clinical results of cement augmentation of the PFNA are promising with a complication rate of 3% [59]. The authors of this multicenter trial reported no head necrosis or blade migration. Especially, patients with poor bone quality seemed to profit and less amount of cement was used in these cases to avoid complications [60]. After an assessment of bone quality [61], cement augmentation of osteoporotic fractures or compound osteosynthesis is recommended in individual cases [60]. However, in a recent survey, only 7%–17% of respondents fully agreed with the benefit of using cement augmentation techniques for hip fracture implants [36]. Several biomechanical studies could show some advantages of cement usage, especially in cases of eccentric implant position or low bone density [62]. In specimens with intertrochanteric fracture using an augmented SHS,

an enhanced cut-out resistance by 42% was shown [63]. However, Hofmann-Fliri et al. showed no biomechanical advantage with respect to secondary displacement following augmentation of three cannulated screws in a non-displaced femoral neck fracture [64]. In the past, clinical studies with only short-term results and with only small numbers of patients were published [59, 65–67]. In addition, results with relation to fracture stability or other prefracture criteria are missing. In a systematic review including seven studies (280 patients with augmentation vs. 175 patients without augmentation), a better stability was seen [68]. In this review, radiographic parameters (mean lag screw sliding distance and varus deformity) were better in the augmentation group. However, a more stringent research methodology is necessary to determine the extent of the benefit of cement augmentation strategies [68].

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Author Contributions

Mathias Knobe: writing of the manuscript. Hans-Christoph Pape: approval of the manuscript.

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Reviewer Assessment

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Reviewers' Comments to Original Submission

Reviewer 1: Kajetan Klos

Nov 16, 2016

Reviewer Recommendation Term:	Accept
Overall Reviewer Manuscript Rating:	95
Custom Review Questions	Response
Is the subject area appropriate for you?	4
Does the title clearly reflect the paper's content?	5 - High/Yes
Does the abstract clearly reflect the paper's content?	5 - High/Yes
Do the keywords clearly reflect the paper's content?	5 - High/Yes
Does the introduction present the problem clearly?	5 - High/Yes
Are the results/conclusions justified?	5 - High/Yes
How comprehensive and up-to-date is the subject matter presented?	5 - High/Yes
How adequate is the data presentation?	N/A
Are units and terminology used correctly?	5 - High/Yes
Is the number of cases adequate?	N/A
Are the experimental methods/clinical studies adequate?	N/A
Is the length appropriate in relation to the content?	5 - High/Yes
Does the reader get new insights from the article?	5 - High/Yes
Please rate the practical significance.	5 - High/Yes
Please rate the accuracy of methods.	N/A
Please rate the statistical evaluation and quality control.	N/A
Please rate the appropriateness of the figures and tables.	N/A
Please rate the appropriateness of the references.	5 - High/Yes
Please evaluate the writing style and use of language.	5 - High/Yes
Please judge the overall scientific quality of the manuscript.	5 - High/Yes
Are you willing to review the revision of this manuscript?	Yes
Comments to Author:	
The topic of this paper is very interesting and deals with a current and common injury. The paper is well written. All current methods are discussed in detail. The informations are directly related to everyday clinical practice.	

Reviewer 2: Benjamin Bücking

Nov 28, 2016

Reviewer Recommendation Term:	Accept with Minor Revision
Overall Reviewer Manuscript Rating:	N/A
Custom Review Questions	Response
Is the subject area appropriate for you?	4
Does the title clearly reflect the paper's content?	5 - High/Yes
Does the abstract clearly reflect the paper's content?	4
Do the keywords clearly reflect the paper's content?	5 - High/Yes
Does the introduction present the problem clearly?	4
Are the results/conclusions justified?	4
How comprehensive and up-to-date is the subject matter presented?	5 - High/Yes
How adequate is the data presentation?	5 - High/Yes
Are units and terminology used correctly?	5 - High/Yes
Is the number of cases adequate?	N/A
Are the experimental methods/clinical studies adequate?	N/A
Is the length appropriate in relation to the content?	3
Does the reader get new insights from the article?	4
Please rate the practical significance.	4
Please rate the accuracy of methods.	N/A
Please rate the statistical evaluation and quality control.	N/A
Please rate the appropriateness of the figures and tables.	N/A
Please rate the appropriateness of the references.	5 - High/Yes
Please evaluate the writing style and use of language.	3
Please judge the overall scientific quality of the manuscript.	4
Are you willing to review the revision of this manuscript?	Yes
Comments to Authors:	
<p>Thank you very much for the opportunity to review the manuscript „Anchorage strategies in geriatric hip fracture management“.</p> <p>In general the manuscript gives an excellent overview about different fixation strategies in the osteoporotic bone of hip fracture patients.</p> <p>Remarks:</p> <ul style="list-style-type: none"> - Abstract: It should be added as a limitation for the importance of the described anchorage strategies (as described later in the text) that in most of the geriatric displaced femoral neck fractures joint replacement is preferred. - L37ff: 59,948 were only the patients who received internal fixation. The number including joint replacements was much higher - please correct - L 97f: the manufacturer should be added. - L150: As previous mentioned the DHS is the implant of choice for A1 fracture - therefore „A1“ should be deleted. - L 204-211: This is redundant to previous sentences in this manuscript - please delete or shorten. 	

Reviewers' Comments to Revision

Reviewer 2: Benjamin Bücking

Dec 02, 2016

Reviewer Recommendation Term:	Accept
Overall Reviewer Manuscript Rating:	N/A
Custom Review Questions	Response
Is the subject area appropriate for you?	4
Does the title clearly reflect the paper's content?	5 - High/Yes
Does the abstract clearly reflect the paper's content?	5 - High/Yes
Do the keywords clearly reflect the paper's content?	5 - High/Yes
Does the introduction present the problem clearly?	4
Are the results/conclusions justified?	4
How comprehensive and up-to-date is the subject matter presented?	5 - High/Yes
How adequate is the data presentation?	4
Are units and terminology used correctly?	4
Is the number of cases adequate?	N/A
Are the experimental methods/clinical studies adequate?	N/A
Is the length appropriate in relation to the content?	4
Does the reader get new insights from the article?	4
Please rate the practical significance.	4
Please rate the accuracy of methods.	N/A
Please rate the statistical evaluation and quality control.	N/A
Please rate the appropriateness of the figures and tables.	N/A
Please rate the appropriateness of the references.	4
Please evaluate the writing style and use of language.	4
Please judge the overall scientific quality of the manuscript.	4
Are you willing to review the revision of this manuscript?	Yes
Comments to Authors:	
My concerns are adressed	