New insights in the treatment of femoral neck fractures

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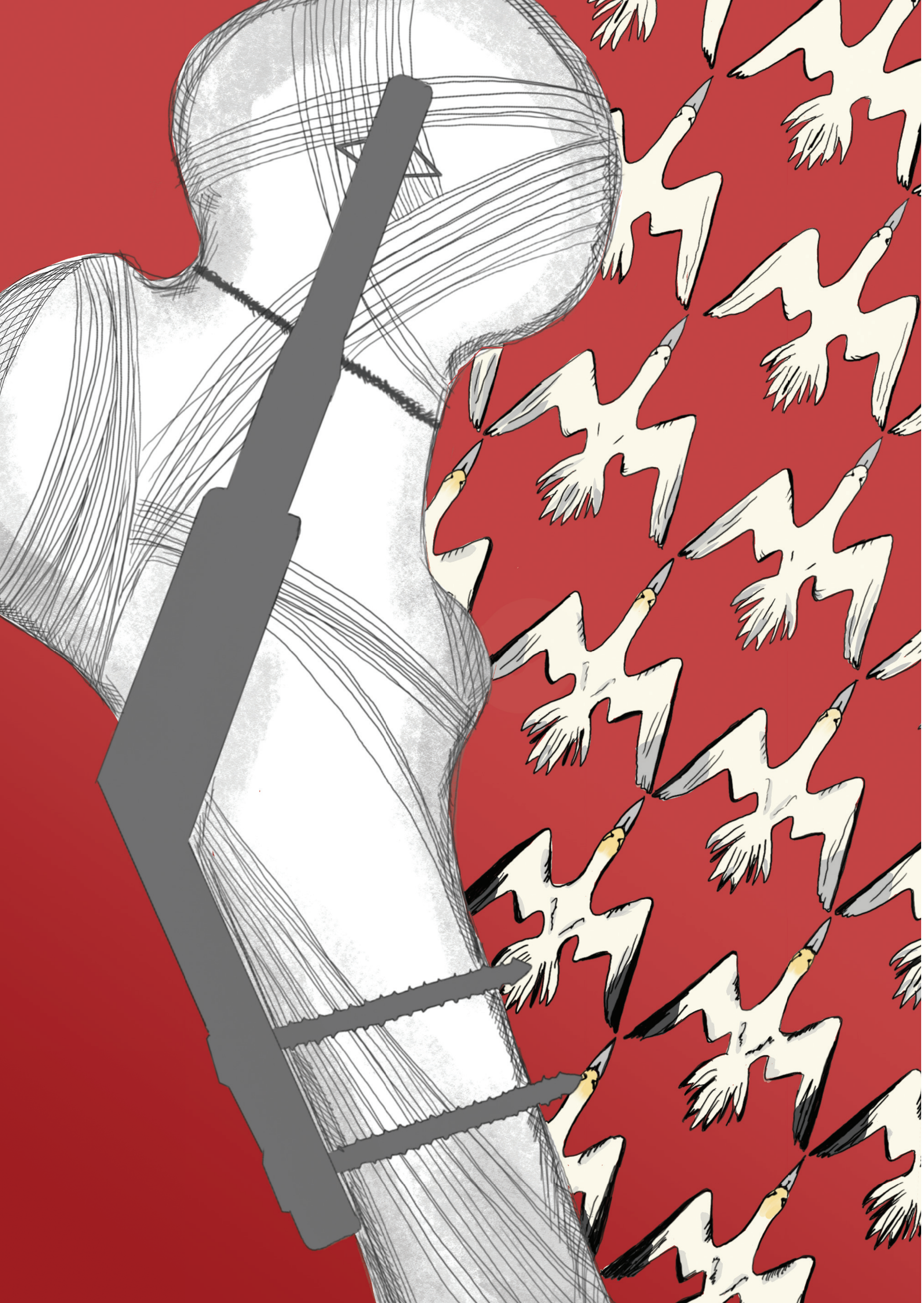

Chapter 8

Discussion, clinical implications, and future perspectives

This thesis does not provide a simple answer on how to treat patients with Femoral Neck Fractures (FNFs). Treatment of a patient with an FNF requires a proper assessment of, and a good conversation with the patient. Successful fracture treatment depends on various factors. Some factors are related to the patient characteristics, others depend on the type of fracture, and again other factors are controlled by the treating surgeon and the treatment of choice. We have to know and recognize these factors, weigh them properly and discuss the treatment options with the patient for the optimal individualised care for each of the FNF patients.

FRACTURE RELATED FACTORS

Almost a century ago, Gathorne Girdlestone stated: '*For a bone is a plant, with its roots in the soft tissues and, when its vascular connections are damaged, it often requires not the technique of a cabinet-maker, but the patient care of a gardener.*'[1] This is particularly applicable to the intracapsular FNF, due to its unique biological features. Displacement of the femoral head is the most crucial factor affecting treatment outcome.[2,3] As described in the introduction of this thesis the healing of the FNF depends on primary bone healing. Primary bone healing requires anatomical alignment of the femoral neck to ensure direct osteonal reconstruction in absence of callus formation. In undisplaced FNF (uFNF) this anatomical alignment and the vascular supply is not significantly disturbed.[4] Undisplaced, stable FNFs are defined as Garden classification type 1 and 2 fractures on the anteriorposterior radiograph.

In **Chapters 3 and 4**, based on the results of the studies, we propose posterior tilt to be included in the assessment of displacement of the FNF (Figure 1). Posterior tilt of ≥20° increases the risk of reoperation fourfold. This significant posterior tilt of the femoral head renders the FNF an unstable fracture. Due to the small number of patients with failed treatment, our conclusion on posterior tilt in **Chapter 3** could not yet been tested in a multivariate regression analysis, which limits the generalisability of the conclusion. But it is supported by the results of a recently published systematic review and meta-analysis.[5] They state that the reoperation rate of uFNFs with a posterior tilt of ≥20° increases from 10.3% to 24.5% (overall risk ratio of 0.11 (95% confidence interval; 0.04–0.18)) compared to uFNF with a posterior tilt of <20°. In that perspective it is interesting that the current Dutch guideline for proximal femur fractures states the Garden type I and II are uFNFs based on the AP view, without considering the lateral radiograph and thus the posterior tilt as an indicator for displacement.[6]

Following our results and conclusions of **Chapters 3 and 4** we recommend, also for the future Dutch guideline, to use the 'Modified Garden Classification' to determine the stability of a FNF (Figure 2).[7] This classification adds posterior tilt to the original Garden classification. The posterior tilt should be measured using the Posterior Tilt Measurement (PTM) according to Palm[8] (Figure 3), because in **Chapter 4** we showed that the PTM is more reliable than the Lateral Garden Angle[9], or any morphological measurement. Displacement in posterior direction influences anatomical alignment and vascular blood supply, just like varus angulation in the coronal plane, but posterior tilt is also often accompanied by posterior comminution (Figure 1). In **Chapter 2,** one of the included studies for our systematic review identified posterior comminution as a predictor for reoperation.[10] It may influence the postoperative stability of the fracture because a gap in the posterior cortex could remain after reduction of the fracture. However, the lack of a good definition of posterior comminution, and solid scientific evidence on the predictive value of posterior wall comminution, prevents a substantiated answer on the question if posterior wall comminution influences the revision rate of FNFs treated with internal fixation (IF).[10-13]

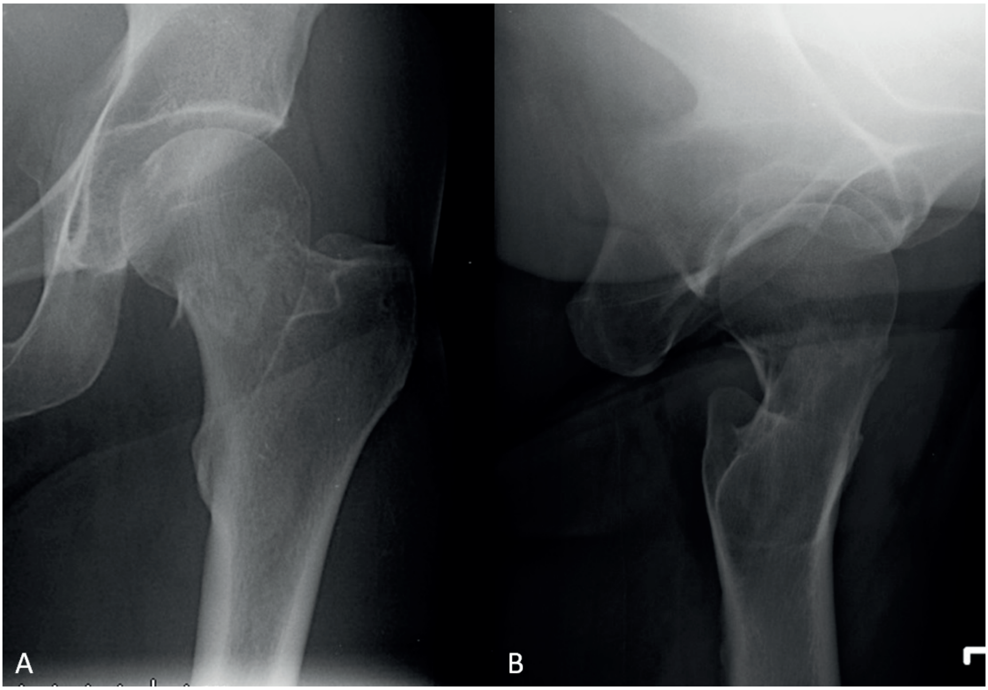

Figure 1. A: Anteriorposterior radiograph of a 'non-displaced' FNF. **B:** Lateral radiograph of a FNF with posterior tilt of the femoral head and comminution of the posterior cortex.
FNF: Femoral Neck Fracture

PATIENT RELATED FACTORS

The phrase: *'There is a fracture. I need to fix it!'* is well-known within the orthopaedic trauma community. Although the discussion in this cartoon about administering anaesthesia to a deceased 97-year-old with a femur fracture is an exaggeration, it holds valuable lessons.[14] With over three-quarters of the proximal femur fractures occurring in patients older than 75 years of age, the comorbidity in most patients with a FNF is high.[15] Undoubtedly, the surgeon must assess the patient thoroughly before he or she chooses if and how to fix the fracture. It is still debated which of the many patient characteristics influence the healing of FNF and to what extent. The Dutch guideline for treatment of patients with proximal femur fractures only identifies renal failure (CKD eGFR <60 ml/min/1.73 m^2) as a strong predictor for reoperation in patients with a FNF.[6] However, their recommendation is based on the review of only four studies.[16-19] This limited overview of literature made us conduct a systematic review and meta-analysis in **Chapter 2** in a search for factors that might be of influence on failure of FNF healing. We screened 2348 studies and identified female gender, age above 50, smoking, inadequate fracture reduction and treatment with cannulated screws as predictors for revision surgery in displaced FNFs (dFNFs), treated with IF. Notably, renal failure was not found to be a predictor for revision surgery. Moreover, we did not even include the two studies mentioned in the Dutch guideline. This was because the primary endpoint in our analysis was revision surgery, and Duckworth et al. also included patients in their analysis that sustained non-union or avascular necrosis of the femoral head (AVN) without revision surgery. Kuo et al. included both non-displaced and displaced FNFs in their analysis and our review focussed solely on dFNFs. We specifically defined our endpoint the way we did as revision surgery due to non-union, cut-out or AVN is a clearly defined and objective endpoint. Other outcome parameters, like the diagnosis non-union, cut-out or AVN are often subjective and debatable. For example, there is no consensus on a uniform definition of non-union.[20] Furthermore, the diagnosis of AVN is mainly based on plain radiographs and can easily be missed at early stages.[21] The explicit outcome 'revision surgery', however, may have one drawback, since it might have led to the exclusion of papers describing potential predictors for failure of FNF healing, defined by other endpoints. Nevertheless, in our analysis 24 factors potentially influencing the risk of revision surgery were identified, from which several patient characteristics were quantified as strong predictors for revision surgery. Therefore, when deciding on the treatment strategy and planning for IF or arthroplasty for a patient with a dFNF, it is important to consider factors such as female gender, age above 50, and smoking.

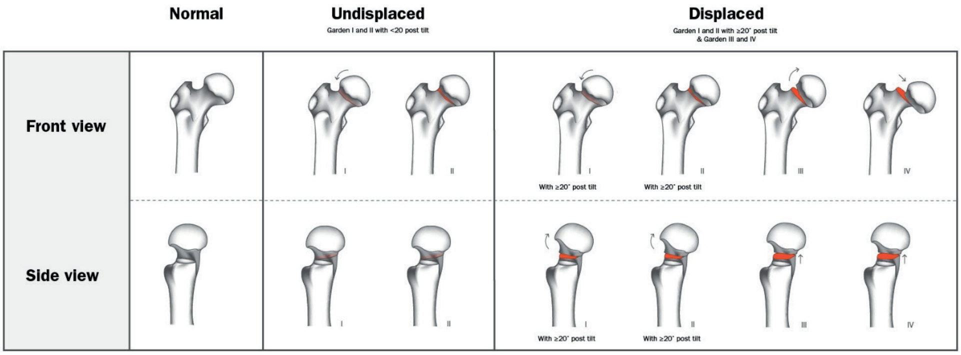

Figure 2. Modified Garden Classification including posterior tilt of the femoral head.[7]

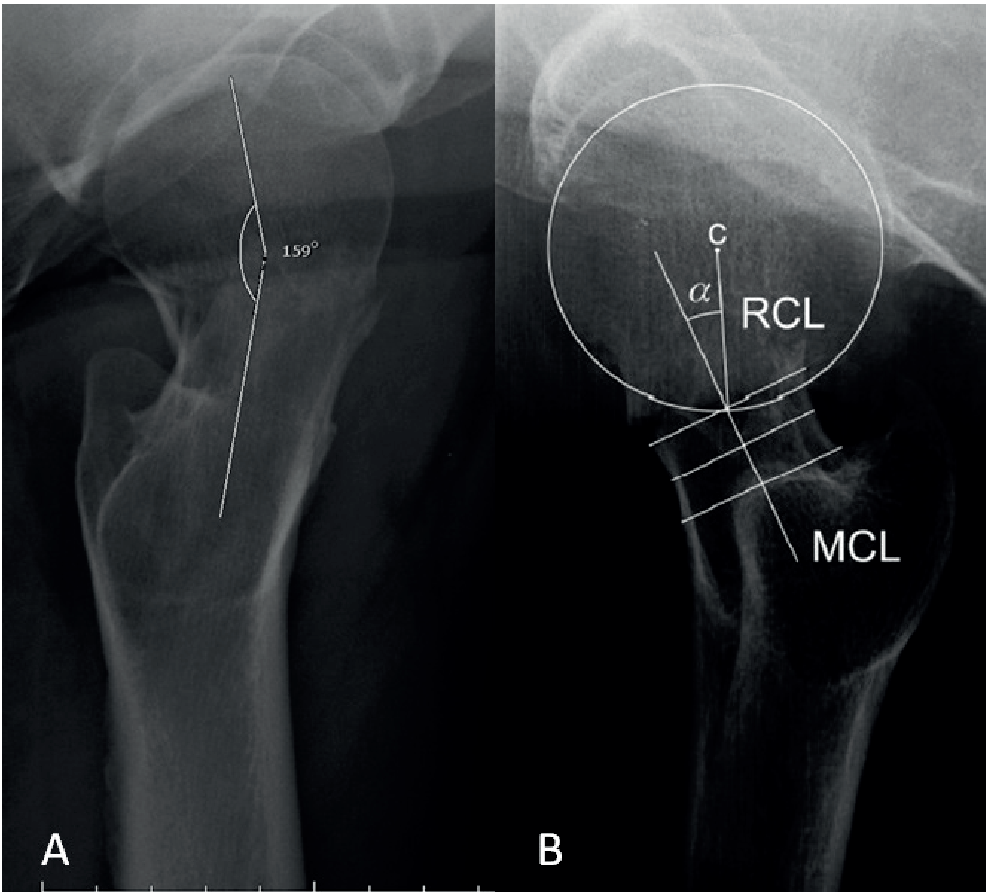

Figure 3. A: Lateral Garden Angle according to Keller.[9] B: Posterior Tilt Measurement according to Palm.[8]

OPERATION RELATED FACTORS

'We are not only justified but warranted in asserting that the only cause for nonunion in the case of intracapsular fractures is to be found in our inability to maintain perfect coaptation and immobilization of the fragments during the time required for bony union to take place – Senn, 1883' [22] Nicholas Senn already told us: the operation procedure is essential in the successful treatment of the FNF. As we described in previous chapters, reduction is the most important step of the procedure. Dislocation of the fracture may not only disrupt the retinacular vessels, the vessels may also become kinked or entrapped.[23] Therefore, early anatomic reduction allows vascularisation to restore. We showed in **Chapter 2** that inadequate reduction may double the risk of revision surgery (odds ratio (OR) 2.28, 95% CI 1.62–3.22) and may increase the risk of AVN in patients treated with the dynamic locking blade plate (DLBP) by almost three times (hazard ratio (HR) 2.90, 95% CI 1.20–7.01) as presented in **Chapter 6**. We did not find any evidence that argues for open reduction of the fracture, it is even associated with a greater risk of reoperation.[24] If adequate reduction (i.e. an acceptable range of 160–180° on AP and no more than 10° posterior tilt on the lateral X-ray) cannot be achieved during the operation the surgeon should consider converting to a prothesis. This may present logistical obstacles, as not all surgeons who perform IF are able to perform total hip arthroplasty. However, it may prevent the need for secondary surgery in the future.

After a good reduction a suitable devise has to be implanted for fixation of the fracture. Cannulated screws (CS) and the Dynamic Hip Screw (DHS), also known as the sliding hip screw, are globally the most used devises for internal fixation of FNFs.[25] In the Netherlands, the DHS is used more frequently than CS to fixate hip fractures, with rates of 13.1% and 5.3%, respectively.[26] In 2017, the FAITH trial, a large international randomized controlled trial (RCT), showed a slight advantage of the DHS over CS in dFNFs.[3] Additionally, as shown in **Chapter 2**, fixed-angle devices are superior to CS in terms of revision surgery (OR 2.16, 95% CI 1.03–4.54). This can be well explained, as fixed-angle devices have been shown to provide better angular and rotational stability, as discussed in **Chapter 5**. The argument that CS are less invasive might be true for the skin incisions, three/four stab incisions versus a small 5 cm incision for the fixed-angle device, but the total implant load is at least as invasive in the femoral neck and head as the DHS, as is described in **Chapter 5**. Taking this into account, a fixed-angle device is preferred over CS for fixation of FNFs.[27] Yet, are we satisfied with the results of the fixed-angle devices, like the DHS, that we have been using for decades? And is (biomechanical) implant improvement a necessary and realistic option?

THE DYNAMIC LOCKING BLADE PLATE

The Gannet, a seabird with streamlined wings that can reach up to two meters in length. The name 'Gannet' is derived from Old English 'ganot' meaning strong. This applies perfectly to the Gannet implant, also called the Dynamic Locking Blade Plate (DLBP) (Figure 4, 5). The idea of the Gannet originated twenty years ago from the lack of a strong and stable fixation for the FNF. Earlier biomechanical studies provided evidence that the DLBP offers a three times better rotational stability compared to the DHS.[28] This is achieved by a smaller implant volume compared to the DHS and CS, which have volumes of 2700 mm^3 and 2520 mm^3 respectively. The DLBP has a volume of only 1800 mm^3, making it a less invasive option.[29] Moreover, the frontal area of the DHS is 133 mm^2 and 31 mm^2 for the DLBP which has a lower impact on the small femoral neck, yet a higher load bearing surface of respectively 221 mm^2 versus 338 mm^2.[28] The operation technique of the DLBP is simple and straightforward and it does not require anti-rotation screws or k-wires during or after implantation.[30] Because the DLBP has to be tapped in and not screwed in like the DHS, the femoral head will not rotate during insertion which can be devastating for the remaining vascular supply. Although the biomechanical rationale and tests were favourable for the DLBP, it was unknown if this would actually result in less revision surgery in the clinical situation. The first large multicentre study of the DLBP showed promising results with a 4% revision rate in 149 uFNF in patients (mean age 69 years, range 35–101 years) compared to 8–14% described in literature.[31-33]

Figure 4. The Dynamic Locking Blade Plate, also know as the Gannet.

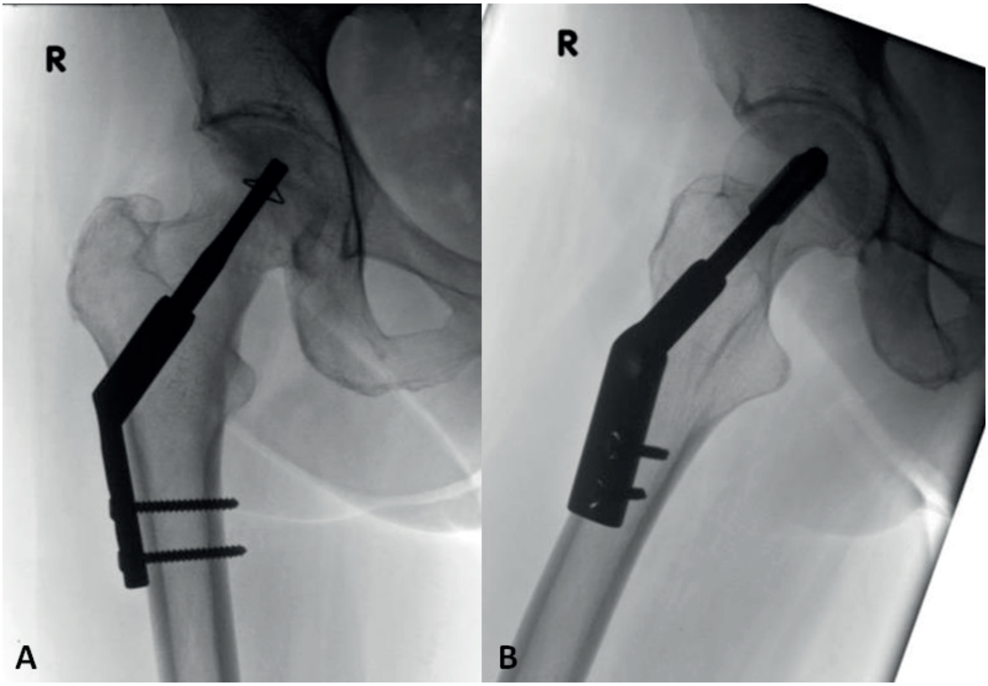

Figure 5. Intraoperative radiograph of the Dynamic Locking Blade Plate fixating a Femoral Neck Fracture.

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In **Chapter 5** we present the results of the second large cohort of 106 young patients with dFNFs treated with a DLBP. They showed a failure rate of 13.2% compared to 32–44% in literature for the DHS and other IF devices.[3,34] We do emphasize that prevention of revision surgery is one aspect of a successful treatment. Functional outcome, patient experience and patient satisfaction are other clinical outcome parameters that are at least as important as successful fracture healing. In **Chapter 5** we assessed functional outcome based on the need for walking aids.[29,31] This simple assessment is not sufficient for representation of the clinical situation as it does not consider factors such as pain or discomfort or assessment of activities of daily living. For example, femoral neck shortening (FNS) is a less familiar complication that may occur after IF of FNFs. FNS can significantly impair gait velocity, gait symmetry, physical function and quality of life.[35,36] The mean FNS after dFNFs treated with the DLBP was 7.1 mm, compared to 9.3–11.0 mm in literature.[35,37] The increased stability of the DLBP may reduce FNS and improve functional outcomes after FNF treatment. The lack of these functional outcome parameters poses a considerable limitation to the aforementioned two large prospective cohorts.

Literature states that most complications and reoperations will occur within two years, yet large cohorts with long-term follow-up of FNFs treated with IF are scarce.[38,39] To provide long-term follow-up insights for the DLBP we retrospectively analysed our first cohorts seven years after treatment of the first patient. In **Chapter 6** we present that revision rates of patients treated with the DLBP doubled within the seven years following their initial one-year follow-up. Revision surgery after two years was mainly because of posttraumatic osteoarthritis (PTOA), defined as having symptoms of osteoarthritis including pain, stiffness of the joint with or without radiologic findings of osteoarthritis in absence of AVN, non-union or cut-out of the implant. It is important to note that a proportion of the 389 patients in our study would also have had a hip replacement for osteoarthritis had they not fractured their hip. The 5-year incidence rate of total hip replacement for osteoarthritis in patients aged 69 years and younger is 1.9–5.6%.[40] The revision rate due to PTOA in our study was 6.2% (24 out of 389 patients). It is debatable whether it is always a failure of treatment if patients treated with the DLBP are revised after a longer period, after union of the fracture and due to PTOA.

Chapter 6 also demonstrated female gender and a Tip-Apex-Distance (TAD) of more than 25 mm as significant indicators for revision surgery of dFNFs treated with the DLBP. This higher revision rate in female patients is consistent with the findings in our meta-analysis presented in **Chapter 2**. TAD >25 mm did not emerge as a significant predictor in our review, as almost all studies on TAD and failure of fracture healing are described in patients with extracapsular and not intracapsular femoral fractures. The results of the DLBP are good compared to current literature. Revision rates are lower after treatment with de DLBP compared to cannulated screws or pins, 10.0% versus 10.7–19% in uFNF and 28.8% versus 31.3–45.6% in dFNF.[41-45] We have not been able to find any large, long-term studies of FNFs treated with a DHS. The DEFENDD trial in **Chapter 7** was designed to answer the question if the DLBP is superior to the DHS in treatment of dFNFs in all aspects of clinical practice. A population with dFNFs was chosen because, as described in the introduction of this thesis, displacement of the femoral head leads to instability of the fracture and high failure rates. Therefore, there is more to gain with a biomechanically stable implant in dFNFs than in uFNFs. Revision operation due to non-union, AVN or cut-out is the primary outcome parameter in this trial. Patients-reported outcome measures (PROMs) are also being acquired. Pre- and postoperative function and health-related quality of life questionnaires will be filled out by the patients up to one year postoperative. The DHS has been used globally for multiple decades and is provided by a wide range of commercial producers, making it a more cost-effective option compared to the DLBP. However, if the DBLP proves superior in terms of revision surgery and operation time, it may ultimately result in lower treatment costs. A cost-effectiveness analysis will provide these results.

Overlooking the evidence that is produced regarding the DLBP, we can state that the implant has improved the results of FNF treatment in terms of revision surgery. Level 1 evidence and PROMs are still to be provided by the DEFENDD trial.

CLINICAL IMPLICATIONS OF THIS THESIS

'Everything should be made as simple as possible, but not simpler' – Albert Einstein. Over the past decade, we strived to develop a treatment algorithm for FNFs, incorporating the DLBP, based on our own data and the most recent literature. However, this endeavour has proven to be more challenging than anticipated. Treatment of the FNF does not lend itself for a simple algorithm. As again shown in this thesis, the determination of the optimal treatment for FNFs depends on many factors and, most importantly, is a shared decision.

Despite the absence of a new treatment algorithm for the FNF, as a result of this thesis, the studies in this thesis still contribute to current knowledge on the topic in several ways:

- The original Garden classification requires modification as the lateral or axial radiograph should be incorporated in the Garden classification.
- If posterior tilt of the femoral head exceeds 20°, the related FNF should be considered a displaced and instable fracture, and should be treated accordingly.
- Posterior tilt should be measured using the Posterior Tilt Measurement according to Palm.[8]
- Patients with a dFNF should be treated with a fixed-angle device, preferably the DLBP and not with cannulated screws or pins.
- Patients with uFNFs of all ages can be treated with the DLBP. Female patients with a dFNF, age over 50 years and/or smoke, have a higher risk of revision surgery and therefore may be better treated with arthroplasty.
- If the surgeon is unable to achieve adequate reduction of the FNF they should consider converting to (hemi)arthroplasty.

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This knowledge can assist surgeons in their daily practice, and it can complement future guidelines for the treatment of FNF.

FUTURE PERSPECTIVES

'*As for the future, your task is not to foresee it, but to enable it*.' – *Antoine de Saint Exupery*. Since 2023, the term "artificial intelligence" (AI) has emerged as the single most important concept in relation to future perspectives. The use of AI in FNF treatment may also be a potential avenue for future research. As previously discussed in **Chapters 2, 4 and 6**, the failure rate may double or triple if the fracture is inadequately reduced. However, the surgeon's decision regarding the adequacy of reduction is based on visual assessment alone, which resulted in almost 13% of inadequately reduced fractures. By employing artificial intelligence and machine learning, an intraoperative assistant can be developed to provide real-time, accurate assessments of femoral neck fracture reductions, that might significantly improve quality of reduction and treatment outcome.

Although a universal algorithm for the treatment of FNFs could not be produced, several treatment algorithms have been developed in the past.[46-48] These algorithms are based on the healing of the fracture and take patient and fracture-related factors like age, displacement of the fracture, comorbidity, cognitive impairment, limitations in ambulation or delay, into account. Yet none of these algorithms include patients' preferences or have conservative therapy as a treatment option. To successfully treat FNFs, it is important to identify the primary outcome parameter(s) based on the patients' preferences. This could be reluctance towards a prothesis, achieving full functional recovery or only attaining independence in activities of daily living, absence of any pain or the need for a minimal invasive procedure or one definitive operation. Even conservative treatment is a viable treatment option for frail patients with limited life expectancy.[49] Future research should compare PROMs for different therapies and determine the factors that influence these outcomes, such as FNS, rather than focusing on creating a comprehensive treatment algorithm for FNFs. Functional outcome and patient experiences after treatment with the DLBP should be compared to treatment with DHS or total hip replacement in a randomized controlled trial.

Additionally, it is necessary to aid both junior and senior physicians in discussing treatment options and outcomes with the patients. Especially in vital patients under the age of 70 with a dFNF, since the treatment strategy for these patient group is not definite. The development of a patient decision aid could be beneficial for doctors and patients. After all, a successful treatment is determined not only by union of the bone, but foremost by patient satisfaction.

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