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TRAUMATOLOGY AND ORTHOPEDICS CLINIC

THE PROXIMAL LATERAL FEMUR LOCKING COMPRESSION PLATE DESIGN AND FEMUR PROXIMAL PART MORPHOMETRIC INTERFACES RESEARCHES

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SUMMARY

Introduction

Proximal femur fractures continue to be one of the most common orthopaedic injuries, with considerable challenge to orthopedic surgeons and with significant cost to the individual and society. The locking compression plate for the proximal femur (PF-LCP) is an innovative and represents a feasible alternative for the treatment of these complex proximal femur fractures.

Aim

To investigate interfaces among the proximal lateral femur locking compression plate design and morphometric features of the femur proximal part using 3D reconstructions and virtual preparation methods.

Methods

A meta-analysis of the worldwide scientific medical literature related to the use of proximal lateral femur locking compression plate in the treatment of femur proximal part fractures was performed. A comparative study of the proximal lateral femur locking compression plate designs contained in the world market was performed. A prospective cross-sectional, population-based study of 44 normal subjects was conducted under computer tomography scanning for optimization capabilities of the proximal lateral femur locking compression plate design using 3D reconstructions and virtual preparation methods.

Results

The 86 scientific medical articles were analyzed to establish the complications frequency associated with lateral plating of the proximal femur comminuted fractures with anatomically precontoured locking compression plates. The main construction aspects and design considerations of five locking compression plates anatomically precontoured to the proximal metaphyseal region of the femur were examined and compared. The degree of PF-LCP proper implantation is associated with the width of the patient femoral neck and neck-shaft angle. The same PF-LCP design may be inappropriate for different genders and various populations.

Conclusions

Up to 37.5 percent of patients surgically treated for proximal femur fractures at the follow up period occur complications associated with mechanical damages of proximal femur locking plates. The key design features of the proximal femur locking compression plate (PF-LCP) are anatomical adaptation to the femur proximal metaphyseal region, varied angles of multiple screws prevents rotational instability in the head neck area and the Kickstand screws maintain neck shaft angle. A distinct plate design may be necessary to accommodate differences between the genders and various populations. The width of the femoral neck and neck-shaft angle can be used for the anatomical shape design of femoral plates for osteosynthesis of fractures in the trochanteric regions.
CONFLICTS OF INTEREST

The author reports no conflicts of interest.
ABREVIATIONS AND TERMS

DHS - sliding hip screw device;
DCS - dynamic condylar screw;
IM - intramedullary nail;
LCP – locking compression plate;
PF-LCP - proximal femur locking compression plate;
AP – anterior-posterior view;
CT - computed tomography;
DICOM - Digital Imaging and Communications in Medicine format;
Comminuted fractures - a bone injury that results in more than 2 separate bone components is known as a comminuted fracture. Some comminuted fractures have specific names such as 'butterfly fragment' or 'segmental fracture';
Osteosynthesis - is the reduction and internal fixation of a bone fracture with implantable devices that are usually made of metal. It is a surgical procedure with an open or percutaneous approach to the fractured bone. Osteosynthesis aims to bring the fractured bone ends together and immobilize the fracture site while healing takes place;
3D reconstruction - is a process of extracting accurate 3D anatomic models from patients CT images.
INTRODUCTION

Proximal femur fractures continue to be one of the most common orthopaedic injuries, with considerable challenge to orthopedic surgeons and with significant cost to the individual and society [1,2,3]. The treatment objectives are clear it is to achieve anatomic reduction with a stable fracture fixation and to allow early functional rehabilitation but complication rates after hip fracture treatment are high. Within the first postoperative year, mortality is 20%–30%, and depending on fracture and operation types, 10%–20% patients are reoperated [1,2]. In the World scientific literature we can find some developed an evidence-based treatment algorithms for hip fractures, covering the femoral neck and trochanteric area up to 5 cm distal for the minor trochanter [3,4]. However, the best means of treating extracapsular proximal femur fractures has been the subject of debate for a considerable time [5]. These extracapsular proximal femoral fractures or trochanteric fractures are most commonly treated with an extramedullary sliding hip screw device (DHS) or dynamic condylar screw (DCS) and an intramedullary (IM) nail. [3,4,5]. Traditional open plating is associated with higher rates of delayed and non-union and an elevated infection rate perhaps due to damages of the periosteal blood supply and severe soft tissue detachment [5]. Intramedullary (IM) nails have been advocated for the fixation of trochanteric fractures, because of their percutaneous insertion, load-sharing ability and short moment arm providing both biological as well as biomechanical advantages. However, when a fracture extends to the piriformis fossa or greater trochanter and posteromedial cortex near the lesser trochanter, intramedullary nails are unsuitable because it is difficult to achieve stable fixation of the proximal bony fragment [5]. All these types of implants are associated with reduction-fixation-related complications also [5]. Extramedullary implants such as dynamic condylar screw (DCS) or Angle blade plate, when used in extracapsular proximal femur fractures are associated with secondary varus collapse, cut-out, implant failure and limb shortening on weight bearing due to medialisation of the distal fragment [5]. The improper fit of the implant to the proximal part of the femur do not allows restoration of normal neck shaft angle relationship [5]. The ideal implant for stabilisation of extracapsular proximal femur fractures with a medial comminution near the lesser trochanter is debatable. The locking compression plate for the proximal femur (PF-LCP) is an innovative and represents a feasible alternative for the treatment of these complex proximal femur fractures [6]. The precontoured nature and the perfect fit of the implant to the proximal part of the femur avoids different types of malreductions [6]. The PF-LCP is an angular-stable plate and acts as an internal fixator, does not require contact with underlying bone and splints the fracture, which allows some amount of elasticity across the fracture site [6]. Future various types of studies are required to evaluate the validity of the proximal femur locking compression plate for the treatment of these challenging injuries.
AIMS AND OBJECTIVES OF THESIS

Aim:

To investigate interfaces among the proximal lateral femur locking compression plate design and morphometric features of the femur proximal part using 3D reconstructions and virtual preparation methods.

Objectives:

1. To perform a meta-analysis of the worldwide scientific medical literature related to the use of proximal lateral femur locking compression plate in the treatment of femur proximal part fractures.
2. To perform a comparative study of the proximal lateral femur locking compression plate designs contained in the world market
3. To investigate optimization capabilities of the proximal lateral femur locking compression plate design using 3D reconstructions and virtual preparation methods.
LITERATURE REVIEW

Anatomical features:

The greater trochanter of the femur is a bony prominence provides insertion for the gluteus medius and minimums and allows abduction of the hip. The lesser trochanter is a smaller prominence which allows flexion of the hip and where iliopsoas muscle is inserted (Fig. 1).

In case of extracapsular fractures, where usually blood supply is not compromised, intertrochanteric fractures (between greater and lesser trochanter) and subtrochanteric fractures (below the lesser trochanter) are distinguish [7].

![Fig.1 Normal Hip joint X-ray (A) Acetabulum; (B)Greater trochanter; (C) Femoral neck; (D) Lesser trochanter (Nicholas Joseph Jr. R.T. Film Critique of the Lower extremity -Part 1 CE Essentials)](image)

The angle of inclination (angle between femoral neck and the medial side of the femoral shaft in frontal plane view) is about 125-135 degrees. Increasing or decreasing those angulation, leads to malalignment and are known as coxa vara or coxa valga respectively [7]. (Behrang Amini, www.physio-pedia.com/Femur) (Fig. 2).

![Fig. 2 Angle of inclination normal femur (www.paleyinstitute.org)](image)

The microstructure and biomechanics of femur allows to understand the mechanism of injury and helps during the treatment.
The trabeculations arise on the lines of force to which the bone is exposed. In the femoral neck and in the intertrochanteric region, trabeculation presents a transition from the bony cortex to the metaphysis. (Fig. 3).

**Fig. 3.** AP radiograph of right hip of a 30y old subject. 1a x-ray in positive; 1b schematic representation of the trabecular groups of tension and compression; 1c x-ray in negative (W trine of ward, C trace)

Subchondral bone plate is a later of dense bone that is below the articular cartilage of synovial joints. It forms the main supporting structure for cartilage and transmits the charges from the cartilage to the underlying spongy bone.

Cancellous bone of the femoral head is characterized by plaques or plates instead of canes, found in the lumbar spine. It has been found a relationship between the elasticity of trabecular bone and the presence of plates instead of canes [8]. (Fig. 4).

**Fig. 4.** Bone structures typical of the spongy bone of the lumbar spine (canes) and the femoral neck (plates)

According to AO classification, extracapsular femoral fractures are classified as described in Fig. 5.
Locking compression plate for proximal femur fracture

Implant design features:

Stable trochanteric fractures can be treated successfully with conventional implants such as sliding hip screws (Fig. 6), cephalomedullary nails (Fig. 7) and angular blade plates (Fig. 8). However, comminute and unstable inter- or subtrochanteric fractures, fractures with extension into the piriformis fossa and combined intracapsular and extracapsular fractures are well treated using LCP [6]. Locking compression plate as an extramedullary, anatomically precontoured and angular-stable fixation device. The convergent angle design (95°, 120°, 135°) and the locking interface of the proximal cannulated locking screws improve proximal femur stability even in osteoporotic bones. LCP provides angular stability and axial compression [9].

LCP enables the use of the standard plate technique, the internal fixator approach and the combination of both methods. (Fig. 9)

In the metaphyseal-diaphyseal area, the intramedullary canal is too wide to provide stability with an intramedullary device and the cortical bone is thinning out, providing insufficient bone for stable cortical fixation and compression plating. Periarticular region is also a natural area for application of locked plating due to the need to provide angular stability to a joint surface so as to allow for early joint motion [7].

Fig. 5 AO/OTA Trauma Foundation. Long bones fracture classification
LCP allows:
- Angular stable support of fragments regardless of bone quality.
- Reduces the risk of primary and secondary loss of reduction even under high dynamic loading.
- Reduced impairment of periosteal blood supply due to limited plate-periosteum contact
- Favourable hold also in osteoporotic bone and in multiple fracture fractures.
Because the screws are tightly locked in the plate there is no tension on the bone; compression is eliminated between bone and plate and the periosteum is undamaged and circulation retained [10].

The LCP is anatomically precontoured to the metaphyseal zone of the proximal femur. The two proximal round holes are made for cannulated 7.3 mm locking head screws inserted at predetermined angles of 95° and 120° in relation to the shaft of the femur. The third hole holds a cannulated 5.0 mm locking head screws inserted at the level of the calcar at a 135° angle. The remaining screw holes (from 4 to 16 holes) allow the placement of either a conventional or a locking head screw at the level of the shaft [6].

Fig. 9. (Image from U.G., J.J. S.S., B.L; Malaysian Orthopaedic Journal (2014))

Summarizing, according to AO foundation, the new combination hole including in locking compression plate has two parts:

1. One part has the design of the standard LC-DCP compression hole (Dynamic compression unit), which accepts a conventional screw allowing axial compression.
2. The other part is threaded and conical, to accept a locking head screw, for angular stability.

Surgical method:

1. Preoperative: All patients underwent routine laboratory tests and organ function assessment after admission. Arterial blood gas analysis for patients who were extremely weak or had heart or pulmonary diseases. During perioperative period, fluid infusion was supplied according to physiological need and daily amount lost. All patients underwent surgery as soon as the preoperative preparation was finished (mean of 3 days).
2. Closed fracture reduction was performed before surgery under fluoroscopic view in the anteroposterior and lateral views and then secured in traction. In highly comminuted and
unstable fractures that could not be reduced by traction on a fracture table, we preferred free draping of the lower extremity in the supine position on a radiolucent operating table [6].

3. Surgical technique: Patient usually is placed in supine position over surgical table and lateral approach is typically performed. Then, a small incision from the major trochanter is made distally (approximately 6 cm length). After a longitudinal incision of the iliotibial band, the fascia of the lateral vastus is incised in an L shape at its proximal insertion and the muscle is flipped anteriorly to visualize the lateral aspect of the proximal femur. Vascularization should be preserved and comminuted place avoided. (Fig.10)

a. Closed reduction fractures: Less invasive plate technique is used and the plate is then slid distally in the submuscular plane by the use of a distal counterincision at the level of the tip of the plate. The most distal hole of the plate can be used to attach a suture that is pulled through the distal counter incision to facilitate the correct distal alignment of the plate to the bone, which must be visualized under fluoroscopy.

b. If complex or comminuted fracture which cannot be reduced prior the surgery, the plate can be used as a reduction tool. In this case, the proximal fragment is first fixed to the plate and the plate is then reduced to the femoral shaft. This facilitate the reduction; a strong K-wire pin can be temporarily fixed to the greater trochanter to reduce the proximal segment.

Then, a drill tip guide wire is inserted through a wire sleeve that is threaded to the most proximal hole at a determined 95º angle (Fig. 11-A). A second guide wire is then inserted through the sleeve of the second hole in a 120º angle. Finally, a third guide wire are advanced to the subchondral bone and their correct placement is confirmed by fluoroscopy in AP and lateral views (Fig. 11-B). At this point and before the placement of the proximal locking head screws, is crucial to recheck the perfect alignment of the distal part of the plate to the femoral shaft (Fig. 11-C). Consequently, appropriate screw length is determined by a measuring device over the guide wires.
Fig. 10. Displaced right subtrochanteric fracture (AO type 3.2-B1.1). A - The fracture extends proximally to the piriformis fossa; B - Closed reduction was performed under fluoroscopic view in AP and axial; C - Views and the fracture subsequently was secured in traction.

The plate fixed to the proximal segment may now be used for anatomic reduction to the shaft in cases where initial closed reduction was unsuccessful. Correct placement and screw length is ensured under fluoroscopy in two planes and the guide wires are removed. The convergence of the three locking head screws in the AP plane and the divergence in the lateral plane allows an angular stable buttress that increases the stability of fracture fixation. The plate is then distally fixed with an additional 2 to 3 bicortical locking head screws.

In metaphyseal comminution, at least 3 to 4 holes of the plate should be left empty at the level of the fracture. This allows a larger area of stress distribution on the plate and reduces the strain at the fracture. Filling all screws holes may lead to stress concentration and high risk of strain [6].

Fig. 11. Surgical technique of the LCP of the same patient. A - First guide wire inserted through a wire sleeve that is threaded to the most proximal hole at a predetermined 95º angle. B - The three guide wires are advanced to the subchondral bone and their correct placement is confirmed by fluoroscopy in AP/axial views. C - Recheck before the placement of the proximal locking head screws.

4. Postoperative management: The drain was removed after 48h. Patients were mobilised on the second postoperative day allowing only toe touch weight bearing. Partial weight bearing was allowed at 6 weeks and was gradually increased as tolerated. Patients were followed up at 6 weeks, 3 months, 6 months and then till last follow-up and evaluated with the Harris Hip Score (evaluating pain, function, absence of deformity and range of motion). (Fig. 12)
Fig. 12. Postoperative radiographs demonstrate an anatomic fracture reduction and adequate position of the LCP in AP and lateral planes.
METHODOLOGY AND METHODS

A meta-analysis of the worldwide scientific medical literature related to the use of proximal lateral femur locking compression plate in the treatment of femur proximal part fractures.

The search of scientific literature was performed similarly to systematic reviews regarding the methods paragraph of the PRISMA statement [11].

The analysis of scientific medical articles was performed in three directions:

- determination of complications frequency associated with lateral plating of the proximal femur comminuted fractures with anatomically precontoured locking compression plates.
- determination of the capability to restore destroyed anatomy of proximal femur by connecting of the separated ossium fragments with placement of the anatomically precontoured to the proximal metaphyseal region of this bone locking compression plates.
- determination of implants failure reasons at the follow-up period after osteosynthesis of the proximal femur fractures with anatomically precontoured locking compression plates.

The study was performed by searching medical research articles in the databases:

"SpringerLink"
https://www.springer.com/gp/products/springerlink

„HINARI Research in Health“
http://www.who.int/hinari/en/

„OvidSP (Wolters Kluwer)“
http://www.ovid.com/site/catalog/journals/index.jsp

„Sciencedirect“
http://www.sciencedirect.com/

„Taylor & Francis Group“
http://www.tandfonline.com/action/showPublications?display=byAlphabet&

Scientific medical articles were searched using the keywords "femoral plating“, „proximal femur locking compression plate“, „trochanteric femoral fractures“, „proximal femoral fractures“. 86 scientific medical articles were found according to this methodology.

A comparative study of the proximal lateral femur locking compression plate designs contained in the world market

The investigation of the anatomically precontoured to the proximal metaphyseal region of the femur locking compression plates designs and features of technical solutions was performed by analysis of
data presented on the websites of the leading enterprises in this area, i.e.: Aesculap AG & Co.(Germany), BHH Mikromed (Poland), Smith & Nephew (US), Synthes (US), Zimmer (US) and Kanghui Medical A Medtronic company (China).

http://www.smith-nephew.com/key-products/trauma/
http://www.synthes.com/sites/NA/Products/Trauma/Pages/home.aspx
http://www.kanghui-med.com/

The World orthopedic implants market research has shown that only five locking compression plates anatomically precontoured to the proximal metaphyseal region of femur are manufactured currently. The main aspects of these implants construction and design considerations were examined and compared.

**An optimization capabilities of the proximal lateral femur locking compression plate design using 3D reconstructions and virtual preparation methods**

3D reconstruction is a process of extracting accurate 3D anatomic models from patients CT images. Using special software, it is possible to reconstruct bone, joints, major blood vessels. This software recognizes different tissues by their density and it can be manually corrected by choosing the contour of organ or other anatomic structure.

Totally, 88 femur computed tomography (CT) scans done in 44 selected participants at LHSH. We included subjects of more than 18 years of age with nonpathologic and normal low limb alignment bones and excluded the bones with visible previous procedures or with signals of underwent bone fixation, or those with visible tumors or deformities that might compromise its structure and form.

A prospective cross-sectional, population-based study of 44 normal subjects was conducted under computer tomography scanning. Nineteen women and 25 men were involved with right and left femur analyzed.

CT images of a patient were imported into 3D reconstruction software, e.g. *Mimics Medical* (Materialise, Belgium) which allows to segment different tissues by their density (Hounsfield Units, HU). A complete femur segmentation from proximal to distal ends was acquired and each image was obtained in Digital Imaging and Communications in Medicine (DICOM) format. These
reconstructions were then analyzed through a series of standardized measurements in a 3-dimensional CAD software package Rhinoceros (McNeel North America) (Fig. 13).

![Fig. 13. Proximal femur part 3D reconstruction](image)

The three proximal femoral morphologic dimensions were measured bilaterally by 2 independent observers. The two measurements were obtained in millimeters and the one in degrees, based in the following variables:

1. Cervical-diaphyseal angle - angle between the axis of the neck and the femur body axis.
2. Width of the femoral neck in its middle third. The contour of the narrow end of neck cross-section was fitted with a circle. The diameter of the circle was defined as the width of the femoral neck.
3. Length of the femoral neck - the distance between the head and the intertrochanteric line.

The morphometric parameters were measured using the 3-dimensional CAD software package Rhinoceros (McNeel North America).

The first stage of investigation was determination of the correlation between cervical-diaphyseal angle, width, length of the femoral neck and appropriate implantation of the locking plate.

The features of proper implantation of the locking plate and screws:

1. The adaptation of the implant to the lateral surface of the femur greater trochanter and body is very strict. The gap between the implant and bone less like 5 mm.
2. The Kickstand screw is placed as inferiorly as possible in the femoral head on the anteriorposterior (AP) view. On the axial view this implant should lie centrally. Deviations dorsally aretplerated.
3. The pre-shaped plate fits the anatomy of the femur greater trochanter and allows multiple screw insertions into the femoral head–neck fragment.

The 3D scanning of the Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China) was performed and its virtual prototype was created (Fig. 14).

![Fig. 14. The virtual prototype of the Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China) (A – the front view, B – lateral view).](image)

The virtual application of the Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China) to the lateral aspect of the femur greater trochanter was performed by repeating all the specific proximal femur fracture osteosynthesis steps (Fig. 15).

![Fig. 15. The virtual osteosynthesis of the proximal femur fracture and screws insertions into the femoral head–neck fragment.](image)
The comparison of proximal femur morphologic features and osteosynthesis quality between males and females were done using these virtual models and simulation methods.

The second stage of investigation was comparison of the proximal femur morphology between different populations and determination of the association between these anthropometric data and quality of the locking plate application to the proximal femur part.

The control group for comparing proximal femur morphology between different populations was formed by searching medical research articles in the databases:

"SpringerLink"
https://www.springer.com/gp/products/springerlink

„HINARI Research in Health“
http://www.who.int/hinari/en/

„OvidSP (Wolters Kluwer)“
http://www.ovid.com/site/catalog/journals/index.jsp

„Sciencedirect“
http://www.sciencedirect.com/

„Taylor & Francis Group“
http://www.tandfonline.com/action/showPublications?display=byAlphabet&

Scientific medical articles were searched using the keywords "femoral neck shaft angle“, „femoral neck length“, „femoral neck width“, „femur morphometry“, „femur anatomy“, „femur dimensions“. 11 scientific medical articles were found according to this methodology.

Statistical Analysis. The data were summarized as the mean and standard deviation. Statistical analyses for comparison of morphologic data between previously published studies and our research or proximal femur anatomical features between males and females were done using the Student’s t-test for independent samples, in cases of normality of data, and the Mann-Whitney test, in cases of non-normality. A P value of < 0.05 was indicated as statistically significant. The results were computed and analyzed statistically with SPSS 17.0.
RESULTS AND DISCUSSIONS

A meta-analysis of the worldwide scientific medical literature related to the use of proximal lateral femur locking compression plate in the treatment of femur proximal part fractures.

The proximal lateral femur locking compression plate is a new device for treating selected fractures of the trochanteric region and subtrochanteric fractures with extension into the greater trochanter or reverse oblique intertrochanteric fractures [12].

However up to 36.8 percent of patients surgically treated for proximal femur fractures at the follow up period occur complications associated with mechanical damages of implants [13].

Mechanical failures of the implants are not only associated with the fact that the osseous fragments cannot move properly but to the forces acting on the proximal femur at the place of the fracture also [13]. The implants are vulnerable to mechanical forces at the proximal femur, not only for bone fragment fixation, but due to their specific structure [13].

Usually, proximal femur locking compression plates are thin and are destroyed by the mechanical forces acted on the proximal part of the femur. [12, 14, 15]. In order to avoid the mentioned adverse events, the thickness of the implant was increased [16].

The destruction of these implants manifested by loosening or breakage of screws, that had inserted into the proximal part (head) of this structure, which is anatomically adapted to the lateral surface of the femur greater trochanter [12, 13, 15, 16, 17]. Complications associated with the screws breakage occur in about 14.3 percent of the cases [17]. Approximately 10.5 percent of the patients six months after surgery complain about hip pain and inability to walk because screw of the implant destroyed femoral neck and head [17]. In the proximal femur fracture with comminuted medial cortex, the implant near the fracture site resisted greater loads [17, 18]. The highest concentration of mechanical loads is at the junction of the LCP two areas, i.e. one part which is in contact with lateral surface of the femur graeter trochanter and another which is palaced on the lateral side of this bone body [12]. From 29 to 33 percent in this area of the implant damages occurs [12, 16]. Frequently breaks screws that were at the bicortical fixation of the fracture, which might have been too rigid and consequently did not tolerate the motion at the fracture site [18]. The screws which were too near the zone of the fractures had reduced the swinging part of itself also [18]. 14.3 percent of subjects with 31-A3 proximal part femur fracture after surgical intervention had displaced implants which does not fix the bone fragments completely [17]. Up to 1 percent of the patients with types 31-A2 and 31-A3 of the femur fractures suffered from implants failure during first three months after osteosynthesis [19]. 31.6 percent of patients during the first three to six months after osteosynthesis with extramedulary implants had displaced femur fragments [17]. 21.1 percent of patients suffered from varus collapse of the fracture three to six months after surgery [17] (Table No. 1).
Table No. 1. Clinical studies with locking plates for proximal femoral fractures. Complications in percentage of number (n) at follow-up.

<table>
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<th>Author, Year, Country</th>
<th>Design</th>
<th>Device (manufacturer)</th>
<th>Patients (number)</th>
<th>Adequate anatomy restoration (percent)</th>
<th>Non-unions (percent)</th>
<th>Mechanical Failure (percent)</th>
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<td>0 %</td>
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<td>Ma et al. 2010 Taiwan</td>
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<td>10 %</td>
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<td>Case series</td>
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<td>-</td>
<td>28.6 %</td>
<td>14.3 %</td>
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<td>90.63 %</td>
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<td>37.5 %</td>
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</tbody>
</table>
Up to 44.4 percent of the patients with the proximal femur fracture configuration that involved loss of the posteromedial buttress had secondary loss of reduction during follow-up after osteosynthesis with locking compression plate [17]. Up to 2.7 percent of the patients with 31-A2 and 31-A3 types of the femur fractures had a situation where screws penetrated the anterior cortex of the femur neck and head during operation [19]. In most cases break screws that are screwed into the upper and lower third of the femoral neck and head where the highest biomechanical forces are located [19]. Some patients can complain about the pain around the greater trochanter immediately after the proximal femur fracture fixation with a proximal femur locking compression plate or at the follow up period after prolonged walking [5, 20]. This type of the pain was present in about 40 percent of patients and it was most often in skinny persons [17, 21]. The reason of these patients complains is not correctly fitted proximal femur locking compression plate to the lateral surface of the femur greater trochanter and due to the constant irritation of the soft tissues trochanteric bursitis was developed [22].
A comparative study of the proximal lateral femur locking compression plate designs contained in the world market

The locking compression plate was introduced in the 21st century as a new implant that allows angular stable plating for the treatment of complex comminuted and osteoporotic fractures. The LCP acts as an internal fixator, does not require contact with underlying bone and splints the fracture, which allows some amount of elasticity across the fracture site. More recently, locking plates particularly designed for the proximal femur, PF-LCP have become available especially for the management of complex trochanteric fractures.

Only five locking compression plates anatomically precontoured to the proximal metaphyseal region of femur are manufactured by the largest producers of orthopedic implants currently.

4.5 mm LCP Proximal Femur Plate. (Synthes USA)

![Image of 4.5 mm LCP Proximal Femur Plate.](http://www.synthes.com/sites/NA/Products/Trauma/Pages/home.aspx)

This implant was approved by the AO foundation and allows to use the AO principles:

A) Anatomic reduction: Which facilities restoration of the neck-shaft angle by proper screw placement

B) Stable fixation: Combination of conventional and locking plate offers optimum fixation irrespective of bone density.

C) Preservation of blood supply: A limited-contact design reduces plate to bone contacts and helps to preserve the periosteal blood supply.

Features:

1. Limited-contact stainless steel plate.
2. Anatomically contoured to the lateral aspect of the proximal femur, specifically designed for left or right femurs.
3. Plate length covers the entire diaphysis.
4. Locking screws provides angularly stable construct independent of bone quality.
5. Plated can be tensioned to create a load-sharing construct.
6. Three proximal screw holes are at following angles:
   a. First proximal hole: 95º
   b. Second proximal hole: 120º
   c. Third proximal hole: 135º
7. Screws used:
   a. The two proximal screw holes are designed for 7.3 mm cannulated locking screws to compress the plate to the bone.
   b. The third locking hole is designed for 5.0 mm cannulated locking screws, to create a locked, fixed-angle screw/plate construct
   c. The remaining screw holes are Combi holes, to achieve plate to bone apposition as well as axial compression or angular stability.
   May be used:
   - 4.0 mm Locking screws to create a locked, fixed-angle screw/plate construct
   - 4.5 mm Cortex Screws to compress the plate to the bone or create axial compression
   - 5.0 mm Cannulated Conical Screws to compress the plate to the bone and provide interfragmentary compression.
   - 5.0 mm Locking Screws to create a locked, fixed-angle screw/plate construct
   - 7.3 mm Cannulated Locking Screws to create a locked, fixed-angle screw/plate construct

Indications:
1. Fractures of the proximal end of the femur combined with ipsilateral shaft fractures.
3. Fixation of osteopenic bone and fixation of nonunions or malunions.
4. Fractures of the trochanteric region, trochanteric simple, multifragmentary pertrochanteric, intertrochanteric reversed or transverse or with additional fracture of the medial cortex.
LCP Proximal Femoral Hook Plate (Synth USA)

Fig. 17. LCP PFHP (Synth, USA) (1 - the part of the implant, which is attached to the femur trochanteric region, 2 - implant portion which is attached to the lateral surface of the femur body).

(Figure from http://www.synthes.com/sites/NA/Products/Trauma/Pages/home.aspx).

Features of the implant:

1. The first part of the plate, which is attached to the femoral body lateral surface have holes developed for cortical and locking screws.
2. The proximal part of the plate ends in two hooks that are engaged into the superior tip of the greater trochanter.
3. The most proximal screw hole accepts a 7.3 mm cannulated locking or cannulated conical screw, oriented at 95° to the plate shaft.
4. The second proximal screw hole accepts a 5.0 mm cannulated locking screw oriented at 110° to the plate shaft.

Plate:

a. Anatomically precontoured to approximate the lateral aspect of the proximal femur.

b. The plate is made of 316L Steel alloy.

c. The length from 133 to 385 mm.

d. The combi-holes in the plate shaft accept 5.0 mm locking screws in the threaded portion or 4.5 mm cortex screws in the DCU portion.

e. In the plate part which is attached to the femur body lateral side the apertures for the cortical and locking screws are located in not straight line also.

Screws:

a. The holes in the plate proximal part developed for the 7.3 mm self-tapping, self-drilling and cannulated locking screws with 30-145 mm length.
b. The holes in the plate shaft accept 5.0 mm self-tapping, self-drilling and cannulated locking screws with length from 10 to 100 mm.

c. The holes in the plate shaft accept 4.5 mm diameter cortical screws with length from 10 to 100 mm.

**Proximal Femoral Locking Plate (BHH Mikromed, Poland)**

---

**Fig. 18** PFLP (BHH Mikromed): (1 - the part of the implant, which is attached to the femur trochanteric region, 2 - implant portion which is attached to the lateral surface of the femur body).

(Figure from [http://www.mikromed.pl/ang-2-01-katalogi-do-pobrania.html](http://www.mikromed.pl/ang-2-01-katalogi-do-pobrania.html)).

**Features:**

1. Anatomically contoured to the lateral aspect of the proximal femur.
2. Left and right specific.
3. The design of the implant is resistant to torsional and bending biomechanical forces.

**Plate:**

a. Width 18 mm.

b. Length of 139 to 391 mm.

c. The most proximal three screw hole accepts a 7.3 mm cannulated locking screw.

d. In the plate part which is attached to the femur body lateral side the apertures for the cortical and locking screws are located in not straight line also.

**Screws:**

a. The holes in the plate proximal part developed for the 7.3 mm self-tapping, self-drilling and cannulated locking screws with 30-145 mm length.

b. The holes in the plate shaft accept 5.0 mm self-tapping, self-drilling and cannulated locking screws with length from 10 to 100 mm.
c. The holes in the plate shaft accept 4.5 mm diameter cortical screws with length from 10 to 100 mm.

**Peri-Loc (Smith& Nephew, USA)**

*Fig. 19 Peri-Loc (Smith & Nephew, USA): (1 - the part of the implant, which is attached to the femur trochanteric region, 2 - implant portion which is attached to the lateral surface of the femur body). screw in the femoral neck and head.*

(Figure from [http://www.smith-nephew.com/key-products/trauma/](http://www.smith-nephew.com/key-products/trauma/)).

**Features:**

1. Anatomically contoured to the lateral aspect of the proximal femur.
2. Left and right specific.
3. The design of the implants is resistant to torsional forces and prevents from development of femur proximal part varus deformation.

**Plate:**

a. Six distinct points of fixation in the proximal femur, i.e. six locking screws can be inserted into neck and head of this bone.

b. The length from 99 to 396 mm.

c. Bullet plate tip assists with percutaneous insertion and minimize prominence.

d. Locking or non-locking option in every screw hole.

e. Each screw hole accepts 4.5mm Cortex, 4.5mm Locking, 5.7mm Cannulated Locking, 6.5mm Cancellous, 6.5mm Cannulated Conical and/or 6.5mm Cannulated Locking Screws.

f. 2.0 m anatomic bow beginning at the sixth hole to maximize plate coverage extending down the femoral shaft.

**Screws:**

a. Low profile heads to reduce soft tissue irritation.

b. Self-Tapping 4.5mm Cortex and 4.5mm Locking Screws and 30- 145 mm length.
c. Self-Drilling, Self-Tapping 5.7mm Cannulated Locking, 6.5mm Cannulated Conical and 6.5mm Cannulated Locking Screws and 10 to 100 mm length.

Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China)

![Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China)](http://www.kanghui-med.com/#)

**Fig. 20** Proximal Lateral Femoral Locking Compression Plate 4.5/5.0 (Kanghui Medical, Medtronic Company, China)

(Figure from [http://www.kanghui-med.com/#](http://www.kanghui-med.com/#))

Features:

1. Anatomically contoured to the lateral aspect of the proximal femur.
2. Left and right specific.

Plate:

a. Width 20 mm.
b. Length of 139 to 391 mm.
c. Five distinct points of fixation in the proximal femur, i.e. six locking screws can be inserted into neck and head of this bone.
d. The length from 99 to 396 mm.
e. Trapezoid shape plate tip assists with percutaneous insertion and minimize prominence.

Screws:

a. The holes in the plate proximal part developed for the 5.0 mm self-tapping, self-drilling locking screws with 20-90 mm length.
b. The holes in the plate shaft accept 5.0 mm self-tapping, self-drilling locking screws with length from 10 to 60 mm.
c. The holes in the plate shaft accept 4.5 mm diameter cortical screws with length from 10 to 60 mm.
An optimization capabilities of the proximal lateral femur locking compression plate design using 3D reconstructions and virtual preparation methods

The mean neck-shaft angle, the mean length and the mean narrowest width of the femoral neck of all subjects were 125.8° (SD, 5.5), 26.7 (SD, 4.2) mm, 39 (SD, 4.2) mm respectively. For gender comparison the male group had significantly greater values in width of the femoral neck in its middle third (p<0.05). Oppositely, females demonstrated higher neck-shaft angle on anteroposterior view (p<0.05) (Table No. 2).

**Table No. 2. Subjects demographics and femoral measurements from AP view.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Men (Mean ± SD)</th>
<th>Women (Mean ± SD)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>62.2 ± 14.1 yr.</td>
<td>66 ± 20.6 yr.</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>Neck-shaft angle</td>
<td>124.9 ± 5.2 °</td>
<td>127 ± 5.7 °</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Narrowest neck width</td>
<td>41.8 ± 3.7 mm</td>
<td>35.4 ± 2 mm</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Neck length</td>
<td>28.1 ± 4.3 mm</td>
<td>24.9 ± 3.5 mm</td>
<td>p &lt; 0.05</td>
</tr>
</tbody>
</table>

The degree of PF-LCP proper implantation is associated with the width of the patient femoral neck and neck-shaft angle (Table No. 3).

**Table No. 3. The relations between proximal femur morphology features and PF-LCP implantation quality degree.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Men (N - 25)</th>
<th>Women (N - 19)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proper adaptation of the PF-LCP</td>
<td>20 (80 %)</td>
<td>14 (73.7 %)</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>The screws out of neck-head fragment</td>
<td>0</td>
<td>16 (64 %)</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>limits</td>
<td>1</td>
<td>7 (28 %)</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2 (8 %)</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>The Kickstand screw position in the femoral head</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The statistical examinations revealed that the same PF-LCP design may be inappropriate for different genders and various populations (Table No 4).

According to our calculations the worse results of proper implantation of the proximal femur locking compression plates may be in these populations because the mean femoral neck width was less and the mean neck-shaft angle was higher compared to our analysed subjects morphological features of these anatomical structures.

**Table No. 4. The comparison of the measured parameters from the proximal femur of the different populations.**

<table>
<thead>
<tr>
<th>Author, Year, Country</th>
<th>Number of samples</th>
<th>Description of samples</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Neck-shaft angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atilla et al. 2007, Turkey</td>
<td>114</td>
<td>-</td>
<td>128.4 ± 4.75°</td>
</tr>
<tr>
<td>Mishra et al. 2009, Nepal</td>
<td>50</td>
<td>-</td>
<td>132.3 ± 8.4°</td>
</tr>
<tr>
<td>Umer M et al. 2010, Pakistan</td>
<td>136</td>
<td>M-116</td>
<td>130.3 ± 6.1°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F-20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean-33yr.</td>
<td></td>
</tr>
<tr>
<td>Ito M et al. 2010, Japan</td>
<td>36</td>
<td>F-36</td>
<td>131.2 ± 5.8°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>81.4 ± 5.8yr.</td>
<td></td>
</tr>
<tr>
<td>de Sousa et al. 2010, Brasil</td>
<td>110</td>
<td>-</td>
<td>132.1 ± 7.2°</td>
</tr>
<tr>
<td>Study</td>
<td>Sex</td>
<td>Age</td>
<td>Angle</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------</td>
<td>------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Baharuddin MY et al. 2011</td>
<td>M-30</td>
<td>25 ± 5.2yr.</td>
<td>131.1 ± 3.7°</td>
</tr>
<tr>
<td></td>
<td>F-30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ravichandran et al. 2011</td>
<td>-</td>
<td></td>
<td>126.55 ± 0.2°</td>
</tr>
<tr>
<td>Brassil</td>
<td>578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pires et al. 2012</td>
<td>M</td>
<td>59.2 ± 20yr.</td>
<td>129.2 ± 5.5°</td>
</tr>
<tr>
<td>Brassil</td>
<td>305</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gujar et al. 2013</td>
<td>-</td>
<td></td>
<td>136.3 ± 6°</td>
</tr>
<tr>
<td>India</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lin KJ et al. 2014</td>
<td>M-47</td>
<td>36.5 ± 11.5yr.</td>
<td>129.9 ± 5.8°</td>
</tr>
<tr>
<td>Taiwan</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The present study</td>
<td>M-25</td>
<td>63.8 ± 17.1yr.</td>
<td>125.8 ± 5.5°</td>
</tr>
<tr>
<td>Lithuania</td>
<td>F-19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The present study
CONCLUSIONS

1. Up to 37.5 percent of patients surgically treated for proximal femur fractures at the follow up period occur complications associated with mechanical damages of proximal femur locking plates.

2. The key design features of the proximal femur locking compression plate (PF-LCP) are anatomical adaptation to the femur proximal metaphyseal region, varied angles of multiple screws prevents rotational instability in the head neck area and the Kickstand screws maintain neck shaft angle - prevent varus collapse.

3. The male group demonstrated greater width of the femoral neck in its middle third (p<0.05). Oppositely, females demonstrated higher neck-shaft angle on anteroposterior view (p<0.05). A distinct plate design may be necessary to accommodate differences between the genders and various populations. The width of the femoral neck and neck-shaft angle can be used for the anatomical shape design of femoral plates for osteosynthesis of fractures in the trochanteric regions.
REFERENCES


