Analysis of femoral trochanters morphology based on geometrical model

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This study presents morphological analysis of 20 scans of femur samples from European (Serbian) adults from trochanteric
region based on the customized computer aided reverse modeling procedure. Results indicated that trochanteric region is a separate
morphological unit of proximal femur, named trochanteric wedge or canoe. This new perceiving of trochanteric region seems to
provide a better understanding of trochanteric wedge volume and, therefore, better trochanter fractures treatment, operation
planning, implant and endoprothesis design and selection. Also, it brings a new light to anatomy of proximal femur, its biomechan-
ics and ossification.

Keywords: Proximal Femur (PF), Reverse Modeling (RM), Trochanter, Trochanteric Canoe (Wedge)

Introduction

In orthopaedic surgery, trochanteric region (TR) is important as an entry point, usually lateral side of the
great trochanter, although anterior and posterior approaches have variable interest. Actually, a surgical
approach depends on the type of implant that is going to be used⁰. For implants such as plates and DHS (dynamic
hip screw), lateral approach is standard²: After skin, fat tissue and fascia lata, vastus lateralis muscle is reached
and elevated to approach lateral surface of subtrochanteric area. For implants as intra-medullar nail,
minimally invasive approach is in routine use¹. CAD (computer aided design) modeling of TR of proximal
femur (PF) facilitates the procedure of preoperative planning and reduces the risk of injury of trochanteric
surrounding structures⁴. Despite abundant research of general femoral morphology, especially its specific
morphological parts (femoral head, neck, shaft, and its distal part involved in knee joint), there is a lack of
research on morphology of TR as a separate part of PF. Mainly, TR appears in the researches on PF fractures⁵,
bone mineral density of PF⁶-⁹, bursitis¹⁰,¹¹ and issues related to vascularization¹²-¹⁴ of PF.

Experimental Section

Femoral Samples

Geometry analysis of PF included 20 scans of femur samples. Two dry femur samples (cadaver samples) were
scanned by a laser 3D scanning machine (Atos 2E) in the resolution of 0.02 mm, while other 8 samples were
scanned by computer tomography (CT) in the resolution of 0.5 mm. Samples came from European (Serbian)
adults, as follows: i) 4 women samples, both right and left, age 25, 33, 45, 67; and ii) 6 men samples, both right
and left, age from 22 to 72. It was assumed that this diverse set of samples could present quite a diverse
Reverse Modeling of Trochanteric Region (TR) – Geometry Analysis

Identification of Referential Geometrical Entities of Femur

Geometrical analysis of PF is based on reverse modeling (RM) of scanned samples by CAD software. RM starts with importing the coordinates of points of scanned tissue into appropriate CAD software. For this particular case, CATIA V5 R19 CAD software and its reverse engineering modules were used. In the next five phases, previously developed RM procedure\(^{15}\), customized for femoral geometry is being applied. Most important phase in RM of a human bone’s geometry (and femur) is identification of referential geometrical entities (RGEs). Usually, RGEs include characteristic points, directions, planes and views. All other elements of redesigned bone’s geometry (curves, surfaces and solids) should be referenced to RGEs. Basic subset of RGEs is related to femoral overall geometry\(^{15}\). This subset includes the most prominent points of femur as follows: i) Point of center of the femoral head (P\(_{\text{CFH}}\)); ii) Point of lateral epicondyle (P\(_{\text{LEc}}\)) – the most prominent point on lateral epicondyle; and iii) Point of medial epicondyle (P\(_{\text{MEc}}\)) the most prominent point on medial epicondyle. In RM procedure, P\(_{\text{CFH}}\), P\(_{\text{LEc}}\), and P\(_{\text{MEc}}\) are used as referential points for creation of another crucial RGE of femur: anterior-posterior plane (A-P plane) and the so-called A-P view, mechanical axis of femur (FMA), lateral-medial plane (L-M plane) as well as L-M view, femoral shaft axis (FSA) and femoral neck axis (FNA)\(^{15}\).

Trochanteric Canoe Geometry

A-P View

Besides basic subset, there are other RGEs, which are specific to different parts of femoral geometry. Concerning PF redesign (head, neck and TR), there is a specific subset of points, planes, directions and edges. Initial RGE related to TR is inferior margin of trochanter’s wedge that should be identified in A-P view. It is an imaginary line, in A-P plane, that extends from the lowest point of major trochanter lateral side to the lowest point of minor trochanter (Fig. 2). This line represents projection of trochanteric canoe keel (TCK) in A-P plane. All other characteristic planes and views of TR are designed in relation to inferior margin that is A-P projection of TCK. At the same time, inferior margin of trochanteric wedge represents the longer leg of right-angle triangle, which represents A-P projection of pentahedral wedge (Fig. 3). Hypotenuse of triangle corresponds in a great extent to A-P projection of intertrochanteric crest in upper parts of the major trochanter. Shorter leg of triangle corresponds to the greatest width of major trochanter in A-P projection. Radius of major trochanter lateral side is identified by the circle, which passes through the most inferior point of major trochanter and through the center of femoral head P\(_{\text{CFH}}\).

Geometrical analysis of TR, viewed from A-P, recognizes a few very indicative geometrical (morphometric) proportionalities and constraints as follows (Fig. 3): 1) Axis, which passes through P\(_{\text{CFH}}\) and cuts inferior margin of trochanteric wedge under the right angle, divides it on two parts, of which upper
part (L_TCK1) takes values between 41-65% while lower part (L_TCK2) takes values between 35-59%; 2) Value of more acute-angle of triangle (projection of pentahedral wedge, A_TPW) is between 30-42°; 3) Ratio between the value of diameter of femoral head D_FH and value of diameter of circumference, which coincides with radius of trochanter major lateral side D_TM1, is between 0.53-0.74; 4) Value of the angle between TCK and FMA in A-P view (A_TCKMA) is between 51-63°; 5) Value of the angle between TCK and FSA in A-P view (A_TCKSA) is between 46-56°; and 6) Value of neck-shaft angle in A-P view (A_NS) is between 115-131°.

**TCK View**

There is a plane, which passes through inferior margin of trochanteric wedge and is perpendicular to A-P plane, contains TCK and hence named TCK-plane (Fig. 4). It is used to define a specific kind of top-down view on PF, the so-called TCK view. Projection of TC on TCK plane can be geometrically represented by contour designed from arcs of two circumferences, the greater and smaller one, which are connected by tangent lines (Fig. 5). Greater circumference coincides with contour of TCK projection of major trochanter lateral side. Smaller circumference coincides with contour of TCK projection of minor trochanter outer margin. Tangent line, which connects arcs of greater and smaller circumferences on posterior side of TC, completely corresponds with TCK projection of inter trochanteric crest. On the anterior side, tangent line, which connects arcs of greater and lesser circumferences, corresponds with inter trochanteric line only on its upper part (Fig. 5b).

In this projection (Fig. 5), TCK appears as a symmetry axis of TC contour determined by the centers of greater and smaller circumferences. Geometrical analysis in TCK projection identifies some specific geometrical proportionalities and constraints as follows: 1) Value of TC angle in TCK view (A_TC) is between 31-43°; 2) Angle between TCK and FMA in TCK view (A_TCKMA) is between 7-19° and is very important for identification of spatial location of trochanteric wedge (canoe) in relation to the basic set of femoral RGEs; 3) Angle between TCK and FSA in TCK view (A_TCKSA) is between 21-42° (Fig. 5) and is very important for identification of spatial location of trochanteric wedge (canoe) in relation to femoral shaft and vice versa. This angle indicates the range of backward turning of trochanteric wedge in regard to FSA; and 4) Diameter of greater circumference (D_TMJ, which coincides with contour of TCK projection of the major trochanter lateral side) is almost equal to femoral head diameter D_FH. The plane that is perpendicular to TCK plane and passes through TCK is named TC symmetry plane – TCS plane (Fig. 4).
Third characteristic view of TR is determined by the plane that is perpendicular to TCK (Fig. 6) and named as OKeel-plane (Fig. 4). Lateral side of the major trochanter (stern of TC) is projected into irregular trapezoidal contour, whose bottom edge leans on TCK-plane (Fig. 6a). In the opposite side (looking at the bow of TC), minor trochanter is projected into a circle (Fig. 6b). TKeel view is similar to L-M view, but it gives a more precise insight into spatial location between TC and femoral neck, and TC and femoral shaft (consequently, between femoral shaft and neck). Geometrical proportionalities in TKeel view are as follows: A_TCSMA (angle between projections of TCS plane and FMA), 4-12; A_TCSSA (angle between projections of TCS plane and FSA), 17-30; and A_NASA (angle between projections of FNA and FSA), 139-156°.
Remodeling of Trochanteric Canoe (TC)

TKeel plane is used in RM procedure of TR as a reference for creating series of transversal cross sections (Fig. 7). Curves that are created by the series of cross sections (parallel to TKeel plane of TC on its posterior side), represent half of the ribs of TC hull (Fig. 7). Ribs are then used for efficient redesign of TC hull. Mirror copying of posterior TC hull redesigns the anterior half of TC hull (Fig. 8). Reference plane for mirror copying is TCS plane, which is invisible on anterior side of PF, because it is incorporated in bone tissue at the junction of femoral neck and shaft.

Results and Discussion

One of the most important results obtained from RM of TC geometry could be a new perceiving of TR morphology.

Trochanter Fractures Treatment

New morphological insight into TR and PF could greatly affect orthopaedics. Considering that trochanteric fractures are a very common problem in orthopaedic practice and that treatment of these fractures requires occupation of 30% of orthopaedic beds worldwide, it is easy to understand how important the better perceiving of this morphological bone unit could be. A conventional implant for the treatment of trochanteric or femoral neck fractures comprises several different types of fixing components. Understanding the volume of trochanteric wedge is very important for an adequate placement of fixing components during surgery in different cases of trochanteric fractures. Shape of an implant component that should pass through TR can be designed in respect to the bone mass distribution in order to obtain better bone support. Such a new implant design can decrease...
the rate of mechanical complications such as cut-out
complications, varisation, femur shortening, and can,
therefore, decrease fracture treatment failure in
general.

Operation Planning and Implant Selection, Tumor and
Endoprothesis
RM procedure customized for PF and TR enables
efficient operation planning including method and implant
selection. In the case of tumor surgery of PF, RM of
trochanteric wedge is an unavoidable part of the
development of custom-made endoprothesis.

Anatomy Aspects & Bio-Mechanics Aspect
This kind of TR perceiving brings a new light to the
anatomy of PF including understanding of ossification
of PF in neonatal period. Trochanteric wedge has a very
important role in femur bio-mechanics. Deformities
in regards to its shape and spatial location as well as the
consequential bio-mechanical deficiencies become an
interesting new field of research.

Artificial Femur – Education in Orthopaedics
Another important advantage of RM of femur
(including femoral trochanteric area) as well as the free-
form fabrication of artificial bone models is the possibility
to use them for biomechanical investigations and for
exercising operative techniques.

Conclusions
Morphological analysis of TR based on RM using
modern CAD systems brought out a thesis that TR is a
separate morphological unit of PF. According to this
thesis, geometry of trochanteric wedge or canoe was
remodeled. By detailed geometrical analysis, important
morphometric parameters of TC were identified.
Consequences of such a perceiving of TR could be very
important to trochanter fractures treatment, operation
planning and implant and endoprothesis design and
selection. In addition, thesis on TC could appear as very
usable concerning the additional biomechanical analysis
of femur as well as in regard to additional elucidation of
PF ossification.

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References
1 Andew H & Crenshaw Jr, Surgical techniques and approaches, in
Campbell’s Operative Orthopaedics, edited by S Terry Canale &
James H Beaty (Mosby Company, Philadelphia, USA) 2007,
60-79.
2 Alexa O & Georgescu N, Compression hip screw in trochanteric
fractures. Conclusions based on 128 cases, Rev Med Chir Soc
3 Russell T A, Mir H R, Stoneback J, Cohen J & Downs B, Avoid-
ance of malreduction of proximal femoral shaft fractures with the
use of a minimally invasive nail insertion technique (MINIT), J
4 Grechenig W, Pichler W, Clement H, Tesch N P & Grechenig S,
Anatomy of the greater femoral trochanter: clinical importance
for intramedullary femoral nailing: Anatomic study of 100 ca-
5 Brammar T, Kendrew J, Khan R & Parker M, Reverse obliquity
and transverse fractures of the trochanteric region of the femur; a


