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USER DEFINED GEOMETRIC FEATURE FOR THE CREATION OF THE FEMORAL NECK ENVELOPING SURFACE

Miloš Stojković[1], Milan Trifunović[1], Jelena Milovanović[1], Stojanka Arsić[2]

[1]University of Nis, Faculty of Mechanical Engineering, Nis, Serbia
[2]University of Niš, Faculty of Medicine, Nis, Serbia

Abstract. *There is a growing demand for application of personalized bone implants (endoprostheses or macro-scaffolds, and fixators) which conform to the anatomy of the patient. Hence the need for a CAD procedure that enables fast and sufficiently accurate digital reconstruction of the traumatized bone geometry. Research presented in this paper addresses digital reconstruction of the femoral neck fracture. The results point out that the User-Defined (geometric) Feature (UDF) concept is the most convenient to use in digital reconstruction of numerous variants of the same topology, such as in this kind of bone region. UDF, named FemoNeck, is developed to demonstrate capability of the chosen concept. Its geometry, controlled by a dozen of parameters, can be easily shaped according to the femoral neck region anatomy of a particular patient. That kind of the CAD procedure should use a minimally required set of geometric (anatomical) parameters, which can be easily captured from X-ray or Computed Tomography (CT) images. For the statistical analysis of geometry and UDF development we used CT scans of proximal femur of 24 Caucasian female and male adults. The validation of the proposed method was done by applying it for remodeling of four femoral necks of four different proximal femurs and by comparing the geometrical congruency between the raw polygonal models gained directly from CT scan and reconstructed models.*

Key Words: *Femoral Neck, Proximal Femur, Femur, Bio-Shape, User-Defined Feature, CAD*

1. INTRODUCTION

The personalized medicine (PM) market encompasses tailor-made medical products segmented into PM diagnostics, PM therapeutics, PM care, and nutrition & wellness. Considering a remarkable growth as well as volume increasing trends, two market research studies [1, 2] indicate the global personalized medicine market as the greatest single business opportunity of our lifetime. These two market observations, and a series of similar ones, highlight "personalized medical care" as the keyword that will be unavoidable in the terminology of health care in near future. In the relevant market niche of bone implants (endoprostheses and macro-scaffolds) and fixators, personalization becomes an undoubtable trend, too. Parthasarathy [3] observes that personalized implants for reconstruction of the bone defects (craniomaxillofacial) show better performance over their generic counterparts. Due to precise adaptation to the region of implantation, personalized bone implants enable faster and fuller reinnervation and revascularization of the traumatized region [4] and, consequently, better and more efficient recovery of the bone and neighboring tissue. In addition, application of the personalized implants usually requires less invasive surgical intervention and less time [3]. New manufacturing technologies (especially additive ones) eliminate most of the constraints regarding shape, material, size and internal structure design of the implants [3], allowing the designers to optimize them in accordance with the required mechanical and physiological properties of the region of implantation. Hence, it is obvious that personalized implants and fixators aimed for bone tissue recovery are already in a queue for extensively developing forthcoming products [5].

However, even though it may seem that all prerequisites for easy production of personalized implants are met, there is still a long way ahead to achieve a commercially efficient, standardized production procedure.

1.1. Approaches in the Personalized Implants Design

Despite the common opinion that the design method is the smallest challenge in this case, in real life a great difficulty arises right from the lack of an optimal design procedure for personalized implants or fixators. The ideal scenario would be if an orthopedic surgeon is able to redesign the personalized implant during the analysis of the radiologic images of the patient's traumatized region, that is, without external help of the CAD designer (Fig. 1). There are two general approaches that can be applied for this kind of automatic CAD procedure. The first one is to use cloud of points generated from radiographic images (Computed Tomography (CT) scans) as anchor points for facet tessellation of outer or even internal surfaces (e.g. trabecular structure). However, to the design corresponding personalized implant, that is, endoprosthesis and scaffold, the creation of a bone geometric model native to the geometric kernel of a CAD program is almost unavoidable. Any further changes in design, i.e. in geometry, are much easier for the cases where the CAD program manipulates with native geometric model.
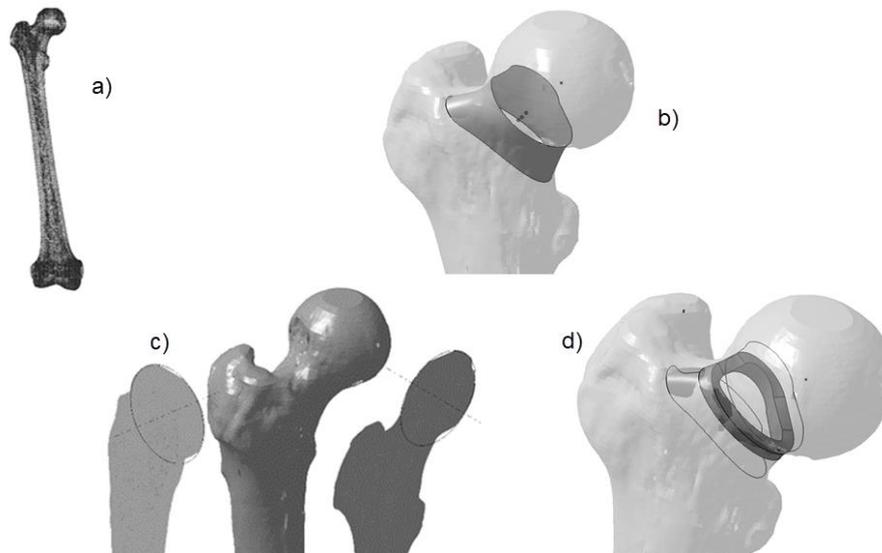
Fig. 1 Workflow diagram explaining the approach: a) Acquiring and healing radiographic image (X-ray, CT scans), b) Digital reconstruction of the bone region geometry, b) Capturing anatomic parameters, d) Modeling the implant – complementary geometry

Another, and probably better, variant of this approach is to use cloud of points acquired from radiographic images (CT scans) as referential points, not for facet tessellation, but for initial shape modeling based on subdivision surfaces: SubD or T-splines [6, 7] (Fig. 2). The geometry created in this way would be native to the geometric modeling kernel of a CAD program and could also be parametrically controlled [8]. Having in mind that these controlling parameters correspond to specific anatomical and morphometric measurements captured from X-ray images or CT scans by the orthopedic surgeon, there is a need for a skeleton model of the SubD model.
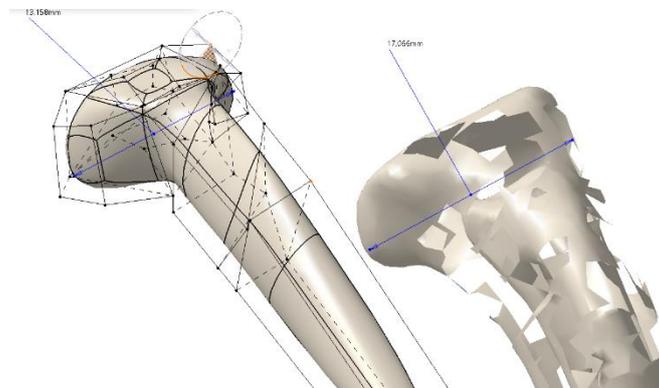
Fig. 2 Developing SubD model within the polyhedron of control points

The second approach involves the use of User-Defined (geometric) Features (UDF) – a compound of basic geometric features of the CAD program, but mutually harnessed and controlled by a set of geometric (anatomical) parameters. In brief, this approach uses a kind of previously prepared generic shape that fits into the region of the bio-shape of interest (e.g. femoral neck or trochanteric region [9], knee [10], or sternum [4]). The generic shape is constructed by means of standard geometric features. Their mutual geometric relations, which keep these features in a consistent topology, are driven by the imposed geometric constraints (e.g. tangency, perpendicularity, etc.), logical (e.g. if-then rules) and mathematical relations. At the top of the design structure there are several parameters, which are the driving variables for all these relations, directly or indirectly. When these constraints directly correlate to the distinctive morphometric measurements that can be captured from radiologic images, the generic shape can be easily created and personalized by the surgeon. Yet, the main advantage that comes out from using UDFs in digital reconstruction of bio-shapes is a built-in association between the digital model of reconstructed bio-shape (part of the bone) and the corresponding and complementary model of the implant or fixator.

In this approach a collection (set or base) of models and corresponding UDFs must be prepared for every single bone region of interest, in advance. Though it may seem as a rather extensive task, it is limited in scope, and the existence of this collection can bring remarkable benefits to the patients' health care.

1.2. Femoral Neck Fracture Case

One of the most frequent cases of bone fracture is a femoral neck fracture. There are several approaches in classification of femoral neck fractures (lat. *fracturaecollifemoris*), as shown in [11]. These fractures are highly complex, and their treatment is a challenging clinical problem, especially in the situations where fixation elements should be customized for the specific patient. Therefore, the existence of an appropriate and accurate CAD model of the femoral neck could bring significant improvement to the surgical (orthopedic) treatment of the femoral neck fracture. The goal of the research reported in this paper was to explore the femoral neck geometry, looking for the most efficient CAD procedure for digital reconstruction of the femoral neck volume enveloping surface. The decision was to use UDFs that consist of regular CAD features for modeling the generic solid shape or surface that matches the femoral neck region with maximal possible geometric congruency with the real one.

2. RELATED WORK

In [12, 13] the authors present the approach which is based on reshaping (scaling) the standard sample of the human bone 3D generic model to match X-ray image of a particular patient bone. The model created with this approach does not have precisely defined geometric entities (points, planes, spline curves). It can be very hard to control the accuracy of the 3D model, without precisely defined geometry.

In [14] the authors propose the process of creating contour curves based on cross-sections of bone obtained from CT slices. This method may not give satisfactory results since there is no information on cross-sections other than from CT slices. The approach presented in [15] uses the curves obtained from different cross-sections for creating femur 3D model.

Some methods for digital reconstruction of patient-specific surface models are based on deformation of 3D model relative to the measurements or geometry captured from X-ray images. Non-Stereo Corresponding Contours (NSCC) method [16] uses 2D contours identified semi-automatically on bi-planar patient-specific radiographs. The NSCC algorithm [17] is used to perform first a rigid matching, and then a non-linear deformation of the generic object, by kriging, as a method of interpolation, in order to minimize the distance between its 3D retro-projected contours and the corresponding region contours identified on both radiographs. The main limitation of this method is reliance on one generic surface object of the considered anatomy, i.e. not taking into consideration shape variations. The method presented by Galibarov et al. [18] uses a library of generic proximal femur models instead. The contour extracted from the radiograph is used for selection of a closest matching 3D model from a library. The selected generic model is then warped to improve correlation with the extracted contour. Problems can occur for the femur shapes which are not covered by an assumed size distribution. According to the authors, error values doubled when there was not a relatively close match in the library of generic models. One general limitation is the fact that planar pelvic radiographs do not capture very well three-dimensional morphology of the regions with complex geometry (e.g. greater trochanter region). Another method that uses a set of whole femur sample models was presented by Wu et al. [19]. The authors claim that, in the situations when major adjustment is needed in some local region, the model must be overall deformed to maintain the correlation between parameters. A well-processed femur model was selected as a template for guiding other sample models to achieve quick compatible segmentation. Based on mesh segmentation, complete morphological parameters of all femur sample models were calculated. Then, according to partially known parameters, the best matching sample and (group) average model was selected to perform global interpolation resulting in a rough femur model. The rough model regions are then further deformed locally. Only longitudinal parameters were well controlled during the deformation process, while some complicated parameters, such as shaft curvature radius, needed to be more delicately controlled.

A statistical shape analysis provides an important and increasingly popular means for generating patient-specific surface models. Statistical shape models (SSM) aim at describing the natural variability of a shape, e.g. the morphological variation of the same bone from different subjects [20]. The general idea behind SSM is to perform a linear decomposition of the shape variability from a set of training data by defining a mean shape and modes of deformations under some mathematical criteria. The power of this approach depends on the variations contained in the given training database, which is one of its disadvantages [21]. The reconstruction technique presented by Zheng and Schumann [21] uses the Point Distribution Model (PDM) constructed from a training database consisting of 30 CT scans of patient hips without pathology. It requires two X-ray radiographs (AP and AX view) as the input. The user needs to interactively define one outer contour from the AP view of the proximal femur and one to two contours from the AX view. Three anatomical landmarks (the center of the femoral head, a point on the axis of the femoral neck, and the apex of the greater trochanter) are used for PDM initialization. The locations of these landmarks on the mean model of the PDM are extracted before the reconstruction while their locations in the reference coordinate system of the input radiographs are defined interactively from the input radiographs. The initial scale and the initial rigid transformation are obtained by performing a paired point scaled rigid registration.

Subdivision surfaces allow the design of efficient, hierarchical, local, and adaptive algorithms for modeling, rendering, and manipulating free-form objects of arbitrary topology.

The basic idea of subdivision is to define a smooth surface as the limit surface of a subdivision process in which an initial control mesh is repeatedly refined with newly inserted vertices [22]. The subdivision based modeling can be dated back to Chaikin's corner cutting algorithm for defining free-form curves starting from an initial control polygon through recursive refinement. The scheme was later extended by Doo and Sabin and Catmull and Clark for defining free-form surfaces starting from an initial control mesh of arbitrary topology. The most important advantage of subdivision surfaces is the ability to handle control meshes of arbitrary topology. Another advantage is that the continuity conditions along all patch boundaries are automatically maintained with subdivision surfaces. Application of subdivision surfaces for a piece of human femur bone is presented in [23]. General surface representation that combines B-spline and Catmull-Clark subdivision surfaces for modeling objects with arbitrary topology and that provides an algorithm for simultaneously fitting smoothly connected multiple surfaces from unorganized measured data was proposed.

3. METHODS

3.1. Creation of the User Defined Geometric Feature: *FemoNeck*

If one adopts the concept of trochanteric wedge as a specific wedge-shaped morphological bony structure between the femoral head and the body (shaft) [9], consideration of femoral neck as a transition structure that connects the femoral head and the trochanteric wedge is imposed. Multi-sections surface appears as the most appropriate basic CAD feature to be used for UDF creation, considering the main shape of the femoral neck region (Fig. 3). Besides the main shape, geometry of the femoral neck UDF should include smooth transition surfaces to both ends of the femoral neck, that is, to the femoral head and the trochanteric wedge.
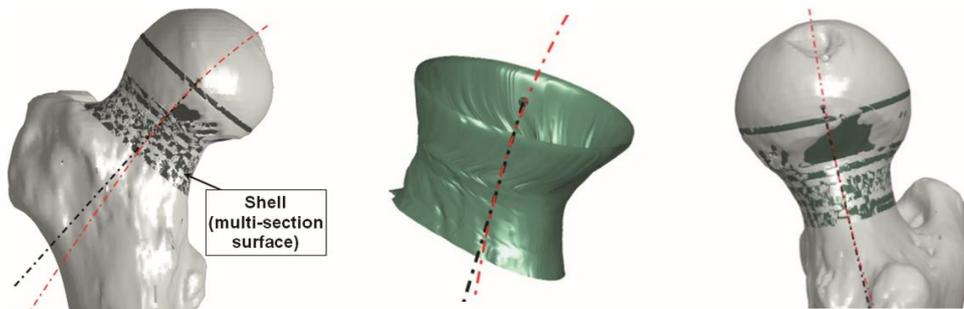
Fig. 3 Femoral neck defined as a smooth transition structure between the femoral head and the body. Concept of using shell for reconstruction of the human femur neck

The most challenging task is to define the guiding line, or a curve, after which the sections should be lined up, as well as to identify how the complex sections should be designed. The following activities were carried out to develop the proper UDF:

1. Collecting the raw material (CT scans) for analysis of femoral neck geometry
2. Identifying Referential Geometric Entities (RGE) for digital reconstruction:
   a. Including definition of the femoral neck guiding line, or a curve, for the multi-sections surface

3. Analysis of the geometry of cross sections:
   a. Identifying the minimally sufficient set of cross-sections
   b. Identifying the simplest, but sufficiently geometrically congruent, basic 2D sections that fit chosen cross-sections
   c. Identifying the most robust dimension schema which can drive the designed 2D sections, and correspondent 2D section parameters
   d. Identifying additional parameters
   e. Identifying the parameter's tree and their relations
4. Identifying referential entities for UDF placement

3.2. Material

Research included both geometric and anatomical analyses conducted over twenty CT scans of femur proximal part, made by 64-slice CT (MSCT, Aquillion 64, Toshiba) with the resolution of 0.5 mm. All 24 samples came from Caucasian adults, of different gender and age:

- 6 x 2 (both left and right femur) female samples, aged between 25 and 67
- 6 x 2 (both left and right femur) male samples, aged between 22 and 72

CT data were transformed from clouds of points to initial polygonal models, as presented in [4, 9, 24, 25].

3.3. Identifying Referential Geometric Entities

The next step in the reverse modeling process, following the generation of initial polygonal model, is recognition and definition of RGEs [9,24]. For this task, and further geometry creation activities, we used CAD software CATIA V5. In the case of the proximal femur region, the geometric entities that we identify as referential are:

- Point of center of the femoral head – P_CFH (lat. *caput femoris*)(Fig. 4)
- Inferior margin of the trochanter wedge – IMTW(Fig. 4)
- TKeel plane, normal to the bottom line of the trochanter wedge (Fig. 4)
- Femoral neck axis – FNA(Fig. 5)
- Angle between FNA and femur body(Fig. 5)
- Femoral neck curve – FNC(Fig. 5)

Creation of FNC starts with construction of FNA. According to the procedure for definition of proximal femur RGEs [24, 25], the femoral neck axis starts from P_CHF and ends perpendicularly to the inferior margin of trochanteric wedge (in anterior-posterior plane and view).
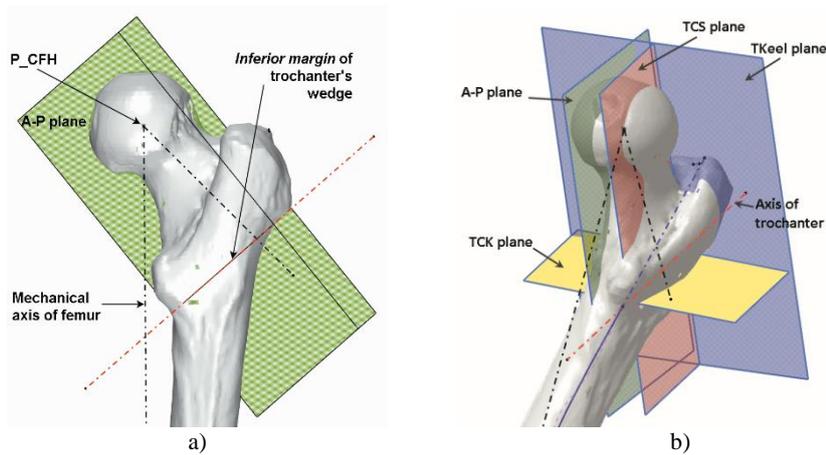
Fig. 4 Proximal femur RGEs [9]

Lateral-medial aspect of the axis is needed for determination of FNA spatial location. In this view, the projection of a small trochanter boundary is used as a reference which FNA touches tangentially (Fig. 5). Following the FNA direction, a series of cross sections of the femoral neck volume is being created. The centers of gravity of these cross sections are used as control points for spline generation, i.e. FNC approximation (the main reference is P_CFH, through which FNC passes).
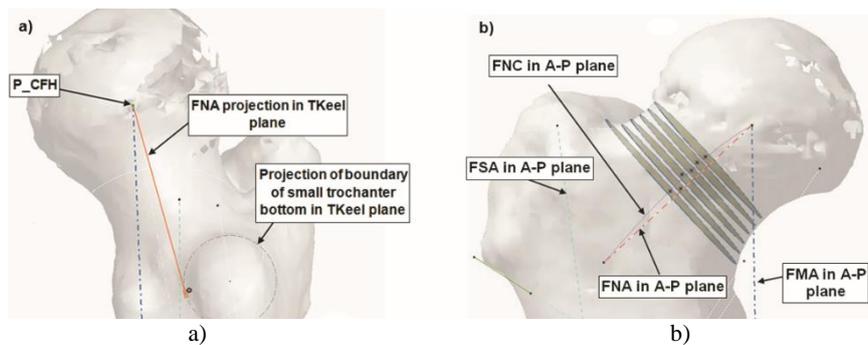
Fig. 5 FNA spatial location; a) FNA in TKeel projection, medial aspect; and b) FNC and FNA in A-P (Anterior-Posterior) projection

3.4. Analyzing the Geometry of Femoral Neck Contour Curves

Once FNC is defined, it becomes a guiding curve for a series of the planes normal to the FNC, which cut the polygonal model in the femoral neck region creating a series of cross-sections of the femoral neck enveloping surface (Fig. 6). These intersection contour curves are being used to analyze the femoral neck geometry, trying to identify the minimal set of the regular geometric features that could combine in a robust UDF which will enable an easy and accurate remodeling of the particular femoral neck geometry.
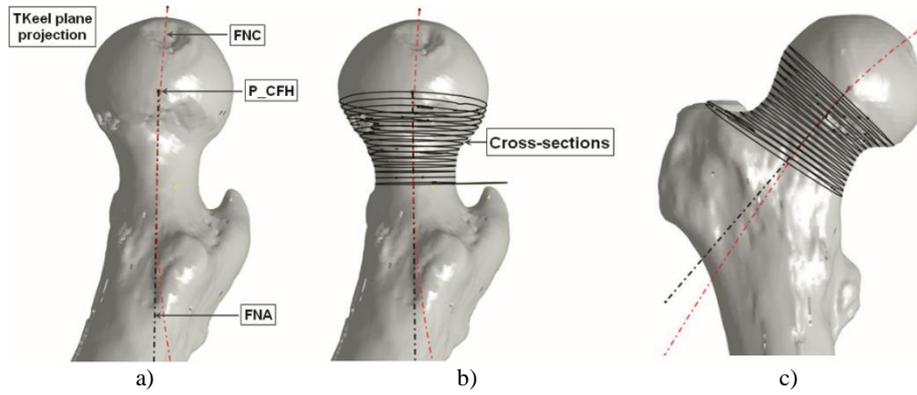
Fig. 6 Femoral Neck Curve creation and corresponding sections
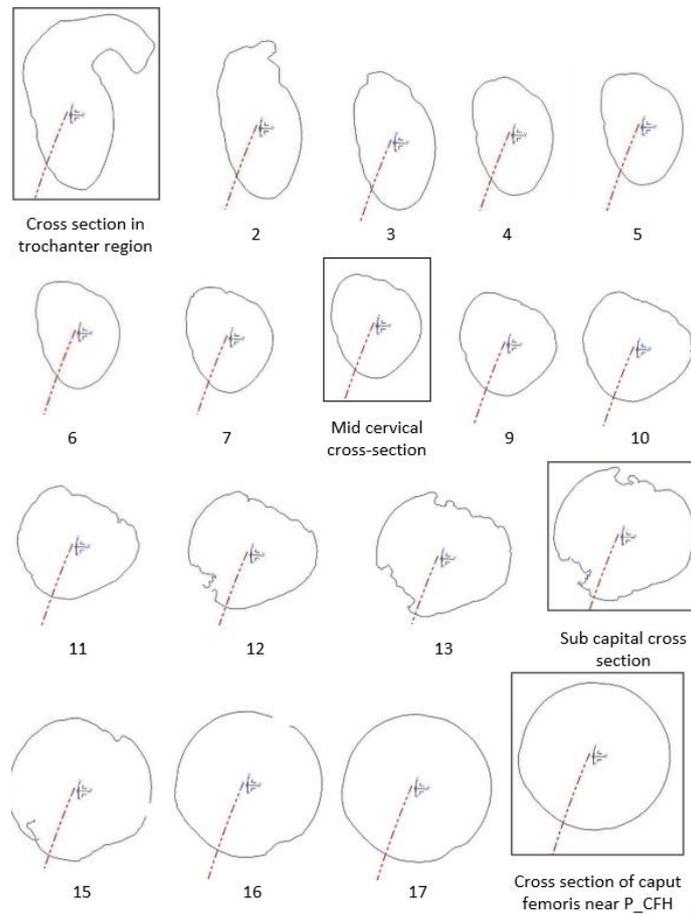
Fig. 7 Series of cross sections representing contour curves of the femoral enveloping surface

A series of cross-section curves (Fig. 7) are used as a set of underlying 2D patterns to sketch approximate contour curves. Approximation should be done by combining minimal number of basic geometric elements which can accurately describe contour curves and be applicable to all contour curves. Therefore, the analysis is being focused just on structurally similar cross-sections which are above the trochanteric region and below the femoral head (sub-capital cross-sections). After all, only these cross-sections are real representatives of the enveloping surface of the femoral neck geometry. The most representative cross-section is the mid-cervical one.

The analysis shows that each cross-section can be approximated with sufficient accuracy by the sketch made of two partial ellipses connected with tangent lines. It turns out that each 2D sketch, i.e. contour curve of the femoral neck enveloping surface, can be designed by combining four basic geometric elements: two ellipses and two lines. Additionally, each contour curve can be surrounded by a trapezoid, made of auxiliary constructional lines, whose function is to control position and shape of basic geometric elements of the contour curve (Fig. 8).

a)   b)
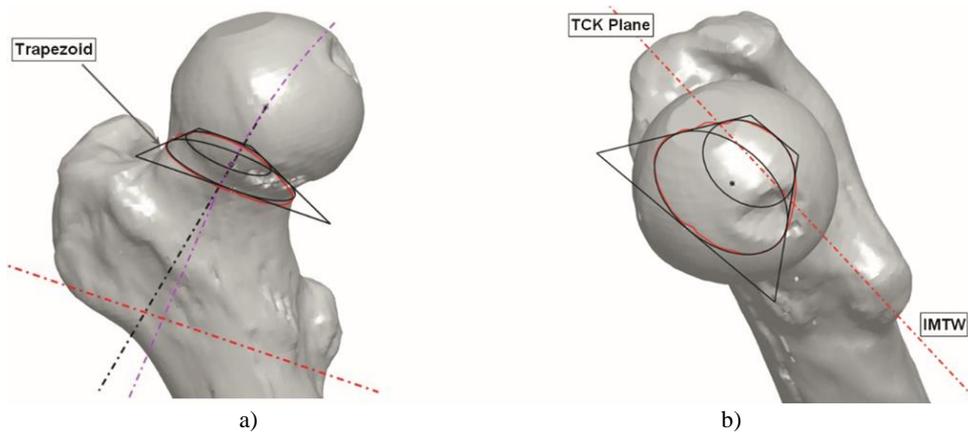
Fig. 8 Intersection approximated with 2D basic geometric elements

3.5. Identifying the Parameters of FemoNeck UDF

The shape of a femoral neck contour curve reconstructed by the user-defined 2D sketch that consists of two ellipses and two straight lines inscribed in the control trapezoid can be managed easily (Fig. 9) by changing four parameters of ellipses (major axis and minor axis lengths: CAL, CPL, CAS, CPS), and three variables of trapezoid (height: H, and base angles: AL, AM).

The position and orientation (rotation) of the trapezoid and the inscribed contour curve are controlled by additional three parameters: two offsets of the midsegment mid-point from P_CFH projection (LM_Shift, AP_Shift), and Torsion angle (TACS) (the angle between trapezoid base and projection of trochanteric wedge axis: IMTW) (Fig. 10).

The rotation angle of the trapezoid base corresponds to the femoral neck cross-sections torsion angle related to the trochanter region cross-section and is directly related to the parameter of specific contour curve identification (ID_CS) [9].

a)   b)
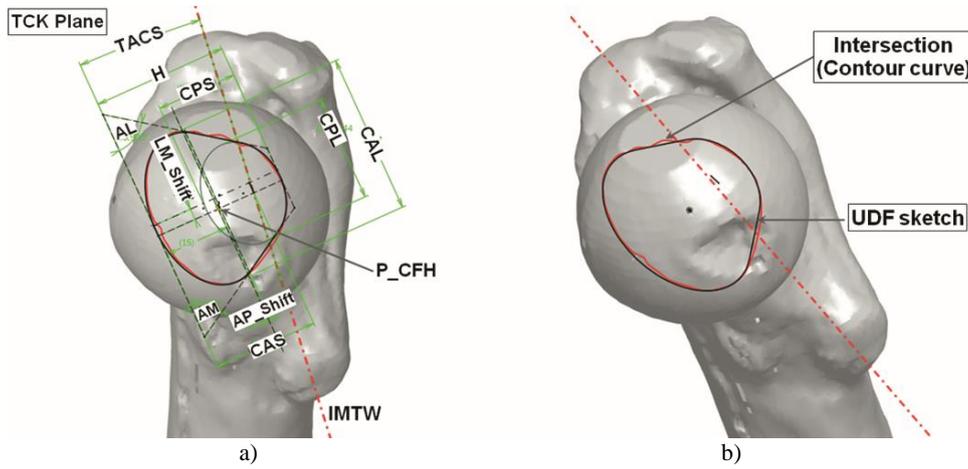
Fig. 9 Approximate reconstructing of a contour curve by UDF- 2D sketch – black compound curve (parameters shown in the figure can be read in Table 1)
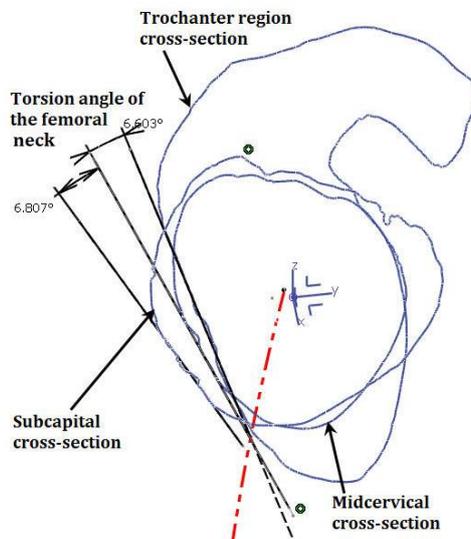
Fig. 10 Angular orientation of trapezoid surrounding 2D sketch

As explained herein before, each contour curve corresponds to the specific cross-section of the femoral neck enveloping surface, and each cross-section corresponds to the specific plane which is normal to the femoral neck curve (FNC) at the specific point located in a specific distance from P_CFH. The length of FNC arc from the point that identifies specific cross-section plane to the P_CFH is the last parameter (cross-section distance – CSD) that is directly related to the specific contour curve (ID_CS). Hence, the femoral neck contour curve defined in this way, driven by this set of parameters, composes 2D geometric UDF that is named FemoNeck_section (Fig. 11).
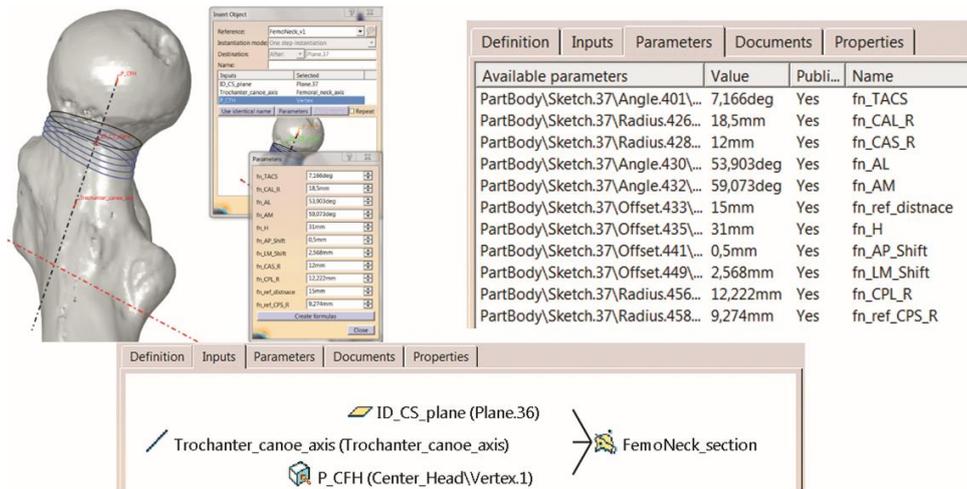
Fig. 11 Controlling the shape of FemoNeck_section UDF instances

By changing the variable parameters of the FemoNeck_section (most of numerical parameters), the contour curve is being shaped to match the corresponding bone contour (Table 1, and Fig. 11).

Table 1 Parameters of FemoNeck UDF

Parameter	Parameter description	Relation	Format	Unit
NSD	Number of cross section distance	Variable	Integer	
CSD	Cross section distance	Variable	Real (Length)	(mm)
ID_CS	ID of the cross section	ID_CS = F(CSD)	Integer	
TACS	Torsion angle of the cross section	TACS = F(CSD)	Real (Angle)	(deg)
H	Height of trapozoid	Variable	Real (Length)	(mm)
AL	Trapezoid angle on lateral side	Variable	Real (Angle)	(deg)
AM	Trapezoid angle on medial side	Variable	Real (Angle)	(deg)
CAS	Short chord of ellipse on anterior side	Variable	Real (Length)	(mm)
CAL	Long chord of ellipse on anterior side	Variable	Real (Length)	(mm)
CPS	Short chord of ellipse on posterior side	Constrained	Real (Length)	(mm)
CPL	Long chord of ellipse on posterior side	Variable	Real (Length)	(mm)
LM_Shift	Trapezoid shift from P_CHF projection in LM dir	Variable	Real (Length)	(mm)
AP_Shift	Trapezoid shift from P_CHF projection in AP dir	Variable	Real (Length)	(mm)

The user defined feature used for remodeling of the femoral neck geometry (we named it *FemoNeck*) includes one multi-sections surface element and two variable-radius fillet elements (oval transition surfaces) towards the femoral head and the trochanteric wedge. Considering that the main shape of the femoral neck will be formed by using basic geometric feature type of

multi-sections surface, the contour curves (*FemoNeck_sections*) will take the role of the main components which shape the enveloping surface (Fig. 12).

In this way, *FemoNeck_section* UDF becomes a part of supreme *FemoNeck* UDF enabling an easy and fine adjustment of the enveloping surface shape in order to achieve maximal geometric congruency with the real bone surface (Fig. 13). Moreover, by employing statistical analysis of parameters [26, 27], it is possible to fully automate an adjustment procedure, i.e. searching for optimal values of the variable parameters.
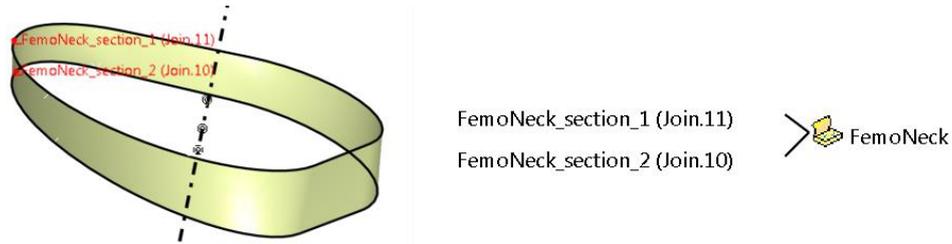
Fig. 12 User defined CAD feature*: FemoNeck*

a)   b)
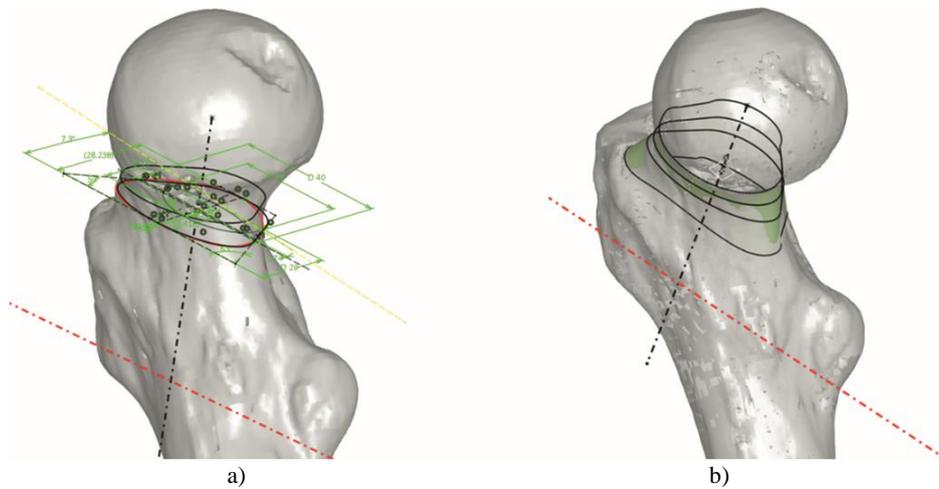
Fig. 13 *FemoNeck* UDF in use: Reconstruction of human femur neck outer surface

3.6. Referential Entities for UDF Placement

The user should identify the center of femoral head (P_CFH) and the femoral neck axis (FNA) as positioning references for FemoNeck UDF placement. They can both be defined by the surgeon while analyzing X-ray digital images (AP and LM projections). All necessary input elements for P_CFH and FNA reconstruction are generated by sketching the circles around the femoral head and small trochanter contours in AP and LM projections, as well as underlining the inferior margin of the trochanteric wedge in AP view. Finally, the user should define distance between cross-sections to control the smoothness of multi-sections surface and fineness of its details.

4. RESULTS

The application of FemoNeck UDF was tested in the femoral neck reconstruction of four new cases (different from the learning base of 24 models). Two input models are made from the CT scans of proximal femurs of two women, and the other two models from the CT scans of proximal femurs of two men. For each geometry input, we applied the FemoNeck UDF to reconstruct the geometry of each femoral neck. Afterwards, the comparison between the geometry of raw polygonal model and the reconstructed model was done. The threshold for acceptable deviation in congruency between cross-sections and reconstructed contour curves is set to 0.5 mm. Each femoral neck was sliced by 13 planes at distance of 1.5 – 2.2 mm depending on size of the bone. For the presentation of the results, five representative cross-sections and corresponding FemoNeck_section instances were chosen: 1st – close to trochanteric wedge, 4th – between trochanteric and mid-cervical cross-section, 7th – mid-cervical, 9th – between mid-cervical and sub-capital, and 13th – sub-capital.
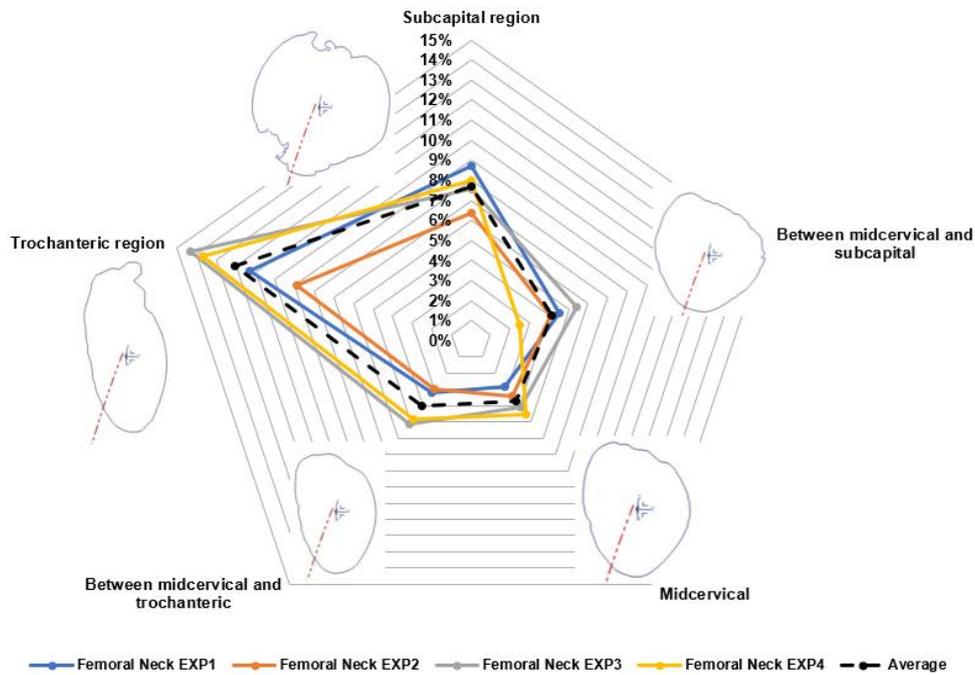
Fig. 14 Percent of the reconstructed contour curve length: FemoNeck_section instance
that deviates more than 0.5 mm from corresponding cross-section curve

After semi-automatic adjustment (without using statistical analysis) the average value of the portion of FemoNeck_sections that deviated from their corresponding cross-sections of femoral neck for more than 0.5 mm was 6.35 % of their length. The results, presented in Fig. 16, indicate that the greatest deviation was encountered near the trochanteric region, which is expected due to a very irregular transition between the neck and the trochanteric wedge. In the sub-capital region, again, an abrupt change of shape around the femoral head rim has led

to a slight increase in deviation. Considering the achieved accuracy in the context of orthopedic interventions, FemoNeck has been showed as a usable and sufficiently accurate solution for digital reconstruction of the femoral neck geometry and its geometrically complementary parts – implants.

4. Discussion

Before the beginning of the discussion, it should be emphasized that digital reconstruction of the bone surfaces is not an aim by itself, but just a first step in a process of modeling personalized bone implant geometry and its manufacturing process.

The efficiency and accuracy of digital reconstruction of the bone geometry by UDF substantially depend on the way its structure is prepared. Selection of basic geometric features that constitute an UDF, as well as definition of their mutual relations, which includes topologic and dimensional interdependences, makes a difference between robust and applicable UDFs and those who are not. The main shortcoming of UDF application for the cases like specific bone region geometry reconstruction comes from necessity to invest a considerable effort in UDF structure preparation. However, once well structured, it becomes a powerful CAD tool for creation of "families" of shapes that are topologically congruent, like endless variations of the femoral neck shape from one patient to another.

The most common current alternative in remodeling complex bio-shapes, like bone surfaces, is tessellation of elementary facets over the cloud of points. Despite its capacity to remodel complex surfaces very precisely and quickly, the greatest issue with this approach is geometric inertness for further modification.

Application of subdivision surfaces seems an even more attractive CAD approach due to fascinating easiness of shaping the digital geometry of any complexity. Another great advantage of this approach is that the geometry is native to the geometric kernel of CAD software. The shortcoming is that it requires not just a very skillful, but also talented CAD expert for digital sculpturing to efficiently and accurately shape a very complex geometry of the bone, and later corresponding implant. Regarding personalized implants design procedure, this approach seems as more convenient than manipulation with tessellated models; yet it still shows very similar limitations – each subsequent modification of the same bone topology (e.g. femoral neck) requires no small intervention of the CAD designer on geometry free forming.

The best solution for designing personalized bone implants and fixators could be to create a collection of specific UDFs that are made by combining SubD surface features (and corresponding volumes) and regular geometric features. The biggest challenge regarding this kind of UDFs is managing the topology of SubD model within the UDF. It should be controlled by the parameters that directly correlate to distinctive morphometric measurements. One solution that may enable this kind of direct control could be usage of user-defined polyhedron [28], whose vertices are coupled with control points of SubD surfaces by specific topologic and dimensional relations and constraints. The user defined SubD model for digital reconstruction of a particular bone region, as femoral neck, can take a role of a base model geometry for creating a set of corresponding geometric complements – implants and fixators.

5. CONCLUSIONS

The paper presents research regarding CAD methodology that should be employed for digital reconstruction of complex topologies, like human bone enveloping surfaces. The focus of the research was on geometric remodeling of the femoral neck region (lat. *collumfemoris*). Even though the femoral neck is not characterized by very complex topology, like some other human bone regions, it was chosen as the most appropriate to easily present the research results. Moreover, in real life, this part of thigh bone is very often being fractured and, consequently, there are many diverse demands for implant solutions regarding this region. The results point out that the UDF concept is the most convenient to use in digital reconstruction of numerous variants of the same topology, even the very complex one. Specific UDF – FemoNeck, was created to test validity of that finding. Testing the application of FemoNeck has shown that it is very robust and sufficiently accurate in digital reconstruction of femoral neck geometry.

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