

Image Processing for a Morphological Study of the Knee

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Abstract: In this paper, we are interested in the methodological and technological aspects concerning the various phases of the process for the improvement in understanding anatomy of the knee. First the elaboration of the acquisition protocol of the 2D pictures of a dissected femur must allow one to preserve the whole information of the real 3D anatomy. Next the automatic process on the pictures must allow one to extract measures and characteristics which avoid the variations resulting from the manual processing. It is a question of quantifying the outline obtained. In the end, the data analysis allows one to extract some new interpretable knowledge on knee anatomy. The whole process has to be thought through great strictness taking into account the limited number of the available subjects and medical processes preliminary to the image acquisition, if we want to obtain significant and reliable interpretation. Concerning the genu-valgum, two thesis are in conflict [Whiteside 95] and [Castaing 79] about the condyle size. Our study allows us to establish that the lateral condyle is not hypotrophic. This conclusion is important for putting knee prosthesis in place, which aims to restore an ideal anatomy.

Key Words: Medical Picture Analysis, Edge Extraction, Segmentation, Image Acquisition, Optimization, Pattern Recognition, Data Analysis, Condyle, Femur, Genu-valgum.

Introduction

Surgeons often turn to computer scientists in order to carry on their research and increase their efficiency. Theory in this article is many concerned with knee morphology, in particular the deformations called genu-valgum.

The problem to solve needs first a data acquisition, which mean to measure different elements which are at stake (femur - tibia), includes a photo shot phase and then an im

portant processing phase on the obtained pictures and finally modelling. Our study is organized in accordance with these different points.

1. Data acquisition

Schematic representation of the problem (Figure 1) allows one to compare the respective positions of the femur and tibia in the genu-valgum and in the genu-varum.

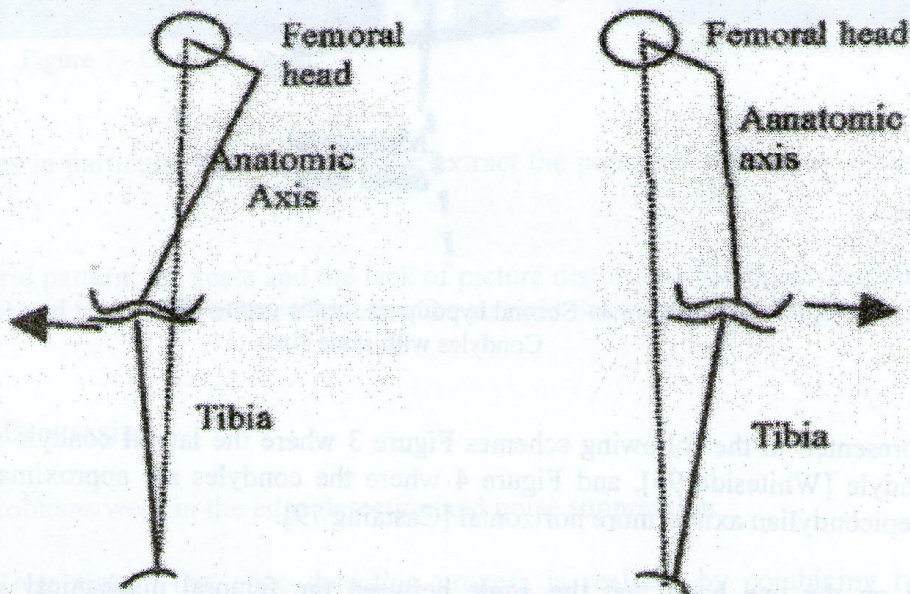


Figure 1 - genu-varum and genu-valgum appearance - Figure 2 - Ideal femur-tibia system sketch

Figure 2 allows one to see the model of an ideal femur-tibia system. Two opposing hypotheses attempt to explain the genu-valgum morphology.

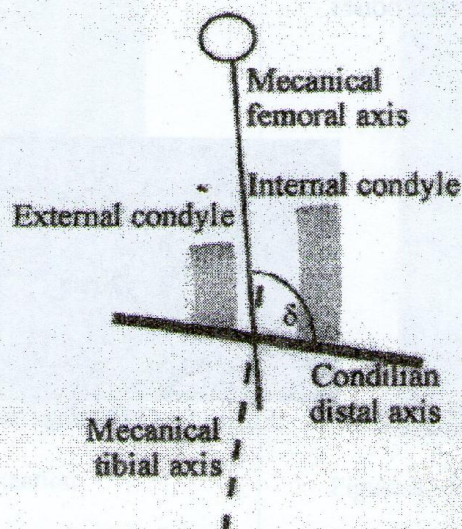


Figure 3 - First hypothesis for the genu-valgum - Condyles with different size

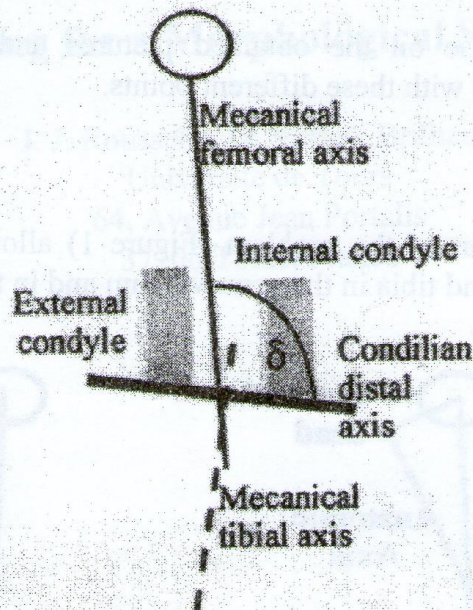


Figure 4 - Second hypothesis for the genu-valgum -
Condyles with same size

They are presented in the following schemes Figure 3 where the lateral condyle is smaller than the medial condyle [Whiteside 95], and Figure 4 where the condyles are approximately the same and where the epicondylar axis is more horizontal [Castaing 79].

We notice on the one hand that the angle between the femoral mechanical axis and the tibial mechanical axis is greater in the case of genu-valgum than in the ideal case and the result is that the distal condylar axis inclines.

On the other hand two theses are in opposition about the reason of this modification of the slope. The difference of point of view is about the size of each condyle. That shows the importance, which must be given to the femoral condyle observation. We don't have to stress here the measuring devices of the different parts of the femur and the tibia, nor the material in use. Let us however note, that the radiographic shots were dismissed, as the outline is difficult to define. It has been decided to use only photographic shots of dissected bones.

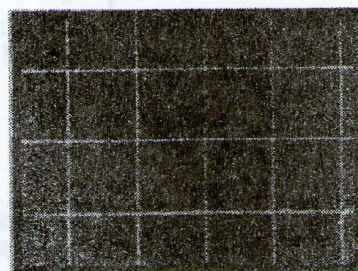


Figure 5 - Grid tuing

To allow reliable comparisons several photos were taken in the same way and under different angles on about forty femurs.

Height pictures were taken on each femur. They were scanned at 600 dpi and a criss-cross pattern was established to verify the measures (Figure 5).



Figure 7 - Complete femur



Figure 6 - External condyle

Two pictures in particular have been used to extract the parameters. They are shown in Figure 7 and Figure 6.

Using the grid pattern, the scale and the lack of picture distortions had been verified. The measures on this test card had been done after extracting the straight lines using the Hough transform.

2. Picture Processing

The main problems were in the edge detection and noise suppression.

2.1. Edge Detecting: The edge detecting process is realized by combining two morphological operations: at first a smoothing operation, then erosion, with a dilation. A 3x3 window is used. The smoothing gives sharpness to the edges. The erosion and dilation shift the gray value edges in opposite directions, so a combination of both images allows one to obtain the edges. Moreover, the smoothing operation produces noise suppression [Haralick 87].

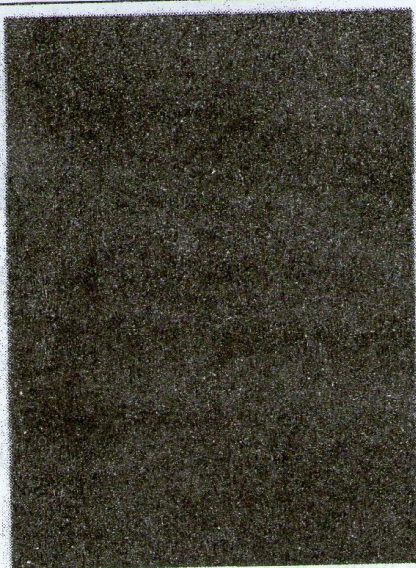


Figure 9 - Edge detection



Figure 8 - Binarisation and noise suppressing

This process is realized in one pass, that needs a 5x5 window due to the 3x3-window convolution by itself.

More precisely we consider a 5x5 analyzed window centered on each pixel. We assign a gray level to this pixel depending on the mean distribution on the nine 3x3 windows contained in the analysed window [Zamperoni 96].

The effect of these operators can be seen in the Figure 9. The residual noise after this operation is slightly less than with the Sobel operator [Coquerez 95].

An additional filtering is executed by a convolution of the picture with the following operator kernel

$$H = \frac{1}{10} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

After that, the picture is binarized and the noise is suppressed. (Figure 8). The method consists in a picture scanning process using a fixed-size square window. If all the edge pixels of the square window have the same color, the window is cleared [Basseville 79].



Figure: 10 - Complete bone outline

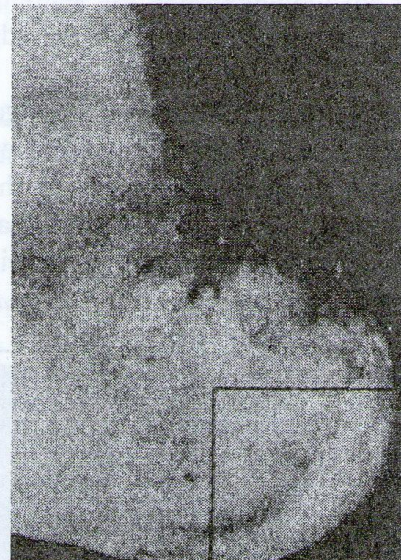


Figure 11 - High and depth measures

Then the femur outline can be extracted using four phases, the rows and the columns of the image are scanned from the external parts of the image to the interior part. The first white pixel met is considered to belong to the femur edge and is included in a chained list.

The same process can be used for several views of the femur, as shown in Figure 10.

2.2. Extraction of the measures

After this global processing, the study is concentrated on the extremities of the bone. The height and depth of the lateral condyle can be determined from the picture resulting from the process just described. We have to find the point of contact with the horizontal and vertical axes. If several near pixels are tangential, we have to select the median pixel (Figure 11).

2.3. Curvature Characterization

A first characterization was realized using the cross four-bar model [Rousselle 98]. This model, very functional, needs seven parameters to be optimized. The reduced number of elements of the data set does not allow us to conclude in a reliable way, with seven parameters.

From the chained list of the outline, an approximation using a Bézier curve was chosen, viewing the regularity of the curve.

On the condyle on which we want to characterize the curve, the zone to be analysed is delimited by two tangents defined while the height and depth measurement. This particularity will allow us to use only four control points for Bézier curve. The intermediate points are used and only two independent weights are introduced (attractors) a and b reels as $a, \leq b \leq 1$ (Figure 12).

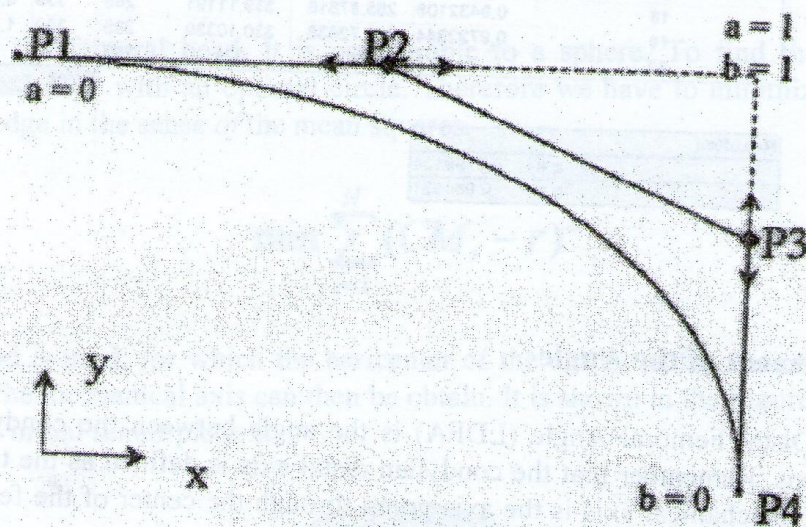


Figure 12 - Bézier curve with four control points

These weights allow us to change the shape of the curvature according to X or Y. The points p_1, p_2 are "floating" respectively on the abscissa and the ordinate axes. The equations could be written:

$$\overline{OM}(t) \begin{cases} \bar{x}(t) = B_{0,3}(t)x_0 + a \cdot B_{1,3}(t)x_1 + B_{2,3}(t)x_2 + B_{3,3}(t)x_3 \\ \bar{y}(t) = B_{0,3}(t)y_0 + B_{1,3}(t)y_1 + b \cdot B_{2,3}(t)y_2 + B_{3,3}(t)y_3 \end{cases}$$

where the $B_{i,n}$ (for i an integer as $0 \leq i \leq n$) are the Bernstein polynomials defined by:

$$B_{i,n} = C_n^i t^i (1-t)^{n-i}$$

The outline was sampled with twenty points chosen at regular spaces on the curve. The optimization of the attractors a and b of the Bézier model is realized by minimizing the quadratic error between a point of Bézier curve and the corresponding outline point. For this optimization we have used the solver of Excel®.

Calculation of the coefficients a and b for the sampled list of the outline points

Nb sampled points	Parameters t	x(t)	y(t)	x real	y real	Distance
1	0	169	440	169	440	0
2	0,1780702	177,96679	438,79556	178	439	0,2071238
3	0,2549394	187,00855	437,0333	187	437	0,0397305
4	0,3171725	195,94388	434,79954	195	435	0,2081684
5	0,3737453	205	432	205	432	3,027E-06
6	0,4257473	213,8736	428,88983	214	429	0,3349379
7	0,4787719	223,24404	424,49911	223	424	0,5555798
8	0,5322247	232,79978	419,35225	232	418	1,5710625
9	0,5748954	240,35794	414,51861	240	414	0,6301401
10	0,6278499	249,46716	407,55081	249	407	0,7220898
11	0,6787560	257,75293	399,76348	258	400	0,3420319
12	0,7273201	265,04733	391,26767	266	392	1,2016179
13	0,7721087	271,09982	382,44912	272	383	1,0553632
14	0,8114184	275,77139	373,88879	276	374	0,2542192
15	0,8493745	279,62668	364,86003	280	365	0,3987156
16	0,8798089	282,18812	357,05672	282	357	0,2060758
17	0,912552	284,39703	348,08054	284	348	0,4051209
18	0,9432108	285,87816	339,11191	285	339	0,8852655
19	0,9722344	286,72638	330,10339	285	330	1,7294692
20	1	287	321	287	321	0
Error						10,748715

Results :	
a =	0,5799134
b =	0,984521

2.4. Measurement of the Angle

The Lateral Distal Femoral Angle (LDFA) is the angle between the condylar distal axis and the mechanical axis. Remember that the condylar distal axis is defined as the tangential axis to the two condyles. The mechanical axis is the axis going through the center of the femoral head to the sulcus (Figure 12).

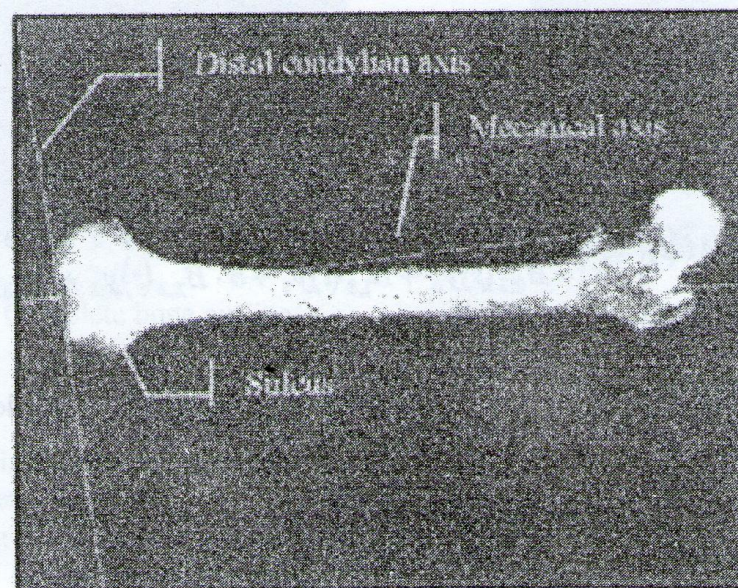


Figure 12 - Axis allowing the LDFA measure.

The sulcus is obtained by the analysis of the part situated at the left of the vertical line, which has the greatest intersection with the bone, that is the inter-epicondyle axis. In that part, the sulcus is obtained using the outline signature.

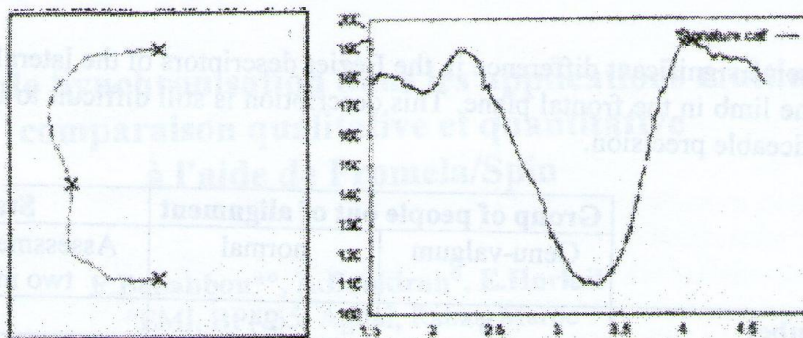


Figure 13 - Sulcus determination - signature method

This signature is obtained by using the (r, t) couple, i.e. the distance and the angle of the outline in relation to the middle of the segment joining the ends of the outline. The sulcus corresponds to a minimum in the signature graph, obvious in the Figure 13.

Now we come to the femoral head. It is comparable to a sphere. To find the sphere center, we approximate the real edge with an optimal circle. Therefore we have to minimize the error between the circle and the edge in the sense of the mean squares.

$$\min \sum_{i=1}^N (CM_i - r)^2$$

An iterative method is used, for which the baricenter of the outline is taken as the starting point for the optimization. The mechanical axis can then be obtained. It is shown in the Figure 12, which has been processed from the initial femur picture.

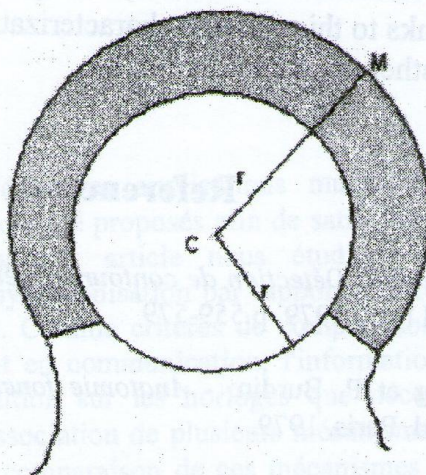


Figure 14 - Optimisation of the femoral head center

3. Result Analysis

The result analysis on 42 adult lower limbs has shown that the size of the condyle does not interfere with the genu-valgum. The first hypothesis is therefore not statistically confirmed. So the second hypothesis is plausible.

A significant variation of the lateral condyle depth is noticed, depending on the offset of the member alignment in the frontal plane. These results prompt us to think that the lower limb valgus offset comes not from the condyle size but from its position on the femur.

There is also some significant difference in the Bézier descriptors of the lateral condyle, depending on the offset of the limb in the frontal plane. This description is still difficult to interpret but, could give this model noticeable precision.

	Group of people out of alignment		Statistic Analysis
	Genu-valgum	normal	Assessment of the difference of two means NF X 06-058
Number	18	24	
Lateral condyle depth (normalised value without dimension)	0.320	0.304	Difference of the superior measure 0.006 with a trust of 99%
Bézier curve descriptors (normalised value without dimension)	58.5	64.9	Difference of the superior measure 3.6 with a trust of 99%

Conclusion

This multidisciplinary work comes from collaboration between surgeons, computer scientist and statisticians. From femur bones of dissected corpses, images had been treated to produce angle measures, heights and a curvature characterization.

The originality comes from the work on dissected bones, that introduces, compared to the classical X-ray or RMN solutions, specific problems in picture processing (scalpel marks, residues). It comes also from the curvature characterization (condyle) using some recent optimization methods. This work could only have been carried out thanks to complementary research by others.

We now find a new characterization of the condyle shape of the patients having genu-valgum. The conclusion drawn thanks to this condyle characterization is very important to design and put in place new knee prostheses.

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