

# MORPHOMETRIC STUDY OF THE HUMAN PELVIS

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## ABSTRACT

Finite element model analysis and numerical simulations are more and more used in the field of automobile safety. The models of anthropomorphic dummies are already developed. The following work, which is carried out both by the Laboratory of Biomechanics LBM (ENSAM) and the Laboratory of Accidentology and Biomechanics LAB (Nanterre), consists in a geometrical study of the human pelvis. This analysis, based on the Reynolds' data, is performed to determine significant parameters for each class of pelvis. A statistical study has been performed with Student and Snedecor tests, to analyse the means and the variances of the characters. These parameters, exclusively computed distances, could be used to distort a mesh with an interpolation technique (kriging).

## INTRODUCTION

Finite element model analysis and numerical simulations are more and more used in the field of the automobile safety. The models of anthropomorphic dummies were already developed, but the behaviour of the human being in car accidents needs now a new approach, consisting in the development of a human FE model. The biomechanical aspects were previously studied through cadaver tests, this FE model will increase our biomechanical knowledge, particularly for the evaluation of new safety devices in vehicle environment.

This work, which is carried out both by the Laboratory of Biomechanics LBM (ENSAM) and the Laboratory of Accidentology and Biomechanics LAB (Nanterre), consists first in an anatomical reconstruction of a human being, in a seated position. The next step consists in the validation of each segment, as well as a whole body evaluation. But the multiple human parameters, age, gender or geometry, results in a wide range of responses from cadavers tests used for the validation.

Thus this paper is focused on the pelvic bone and its geometry. A statistical analysis based on Reynolds' data [6], is performed to extract significant parameters, for each class of pelvis.

These parameters could be used to distort an existing mesh of the pelvic bone.

## ANALYSIS OF THE REYNOLDS' DATA

H.M. Reynolds [6] published a morphometric study of the pelvis of the United States' population.

The Classification was done on the factor H.E.S. basis (Health and Examination Survey) resulting from a study made by the U.S. Public Health Service between 1961 and 1964. This factor stipulates that a relationship between the size and the weight of a subject exists.

The assumption made by Reynolds and based on criterion H.E.S., was that the size and the weight of the pelvis vary like the stature.

The pelvis measured by Reynolds result from the "collection" of Hamann-Todd skeletons of the Cleveland Museum of Natural History (3000 pelvis) collected between 1919 and 1939. The weight, the size and the age of each subject have been indexed.

Reynolds defined 3 pelvis sizes for the 2 genders, according to the size and the weight, by adding a corrective factor to the weight considered as too weak (Figure 1).

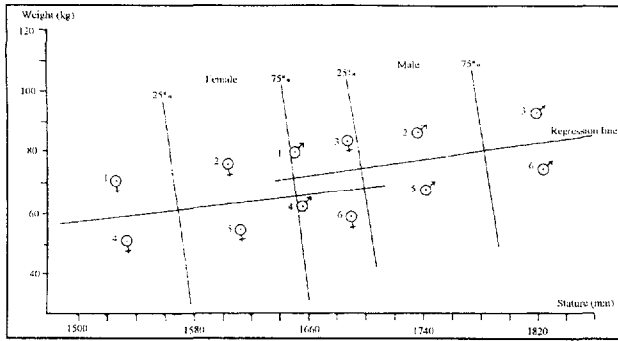


Figure 1 : Distribution of the population (after Reynolds)

He retained for its study only 3 groups :

- Small Female (SF)
- Medium Male (MM)
- Large Male (LM)

The pattern of the measured settlement is thus the following : Small female 24% - Medium male 52% - Large male 24%.

The pelvis population being able to be measured consists of 165 pelvis. Within sight of the 3 groups chosen, only 88 pelvis will be measured, divided into Small female (28), Medium male (34), Large male (26).

The reference axis system of measurement (Figure 2) is an anatomical reference system, which corresponds to the pelvis position of the subject in standing position.

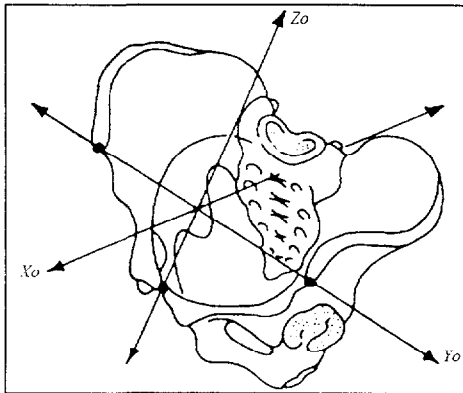


Figure 2 : Reference axis system  $R_0$  of measurement

Reynolds thus measured 105 points per pelvis, by considering a symmetrical pelvis. The measured points (on the right half-pelvis) are represented on the following pictures (Figures 3-4-5-6-7).

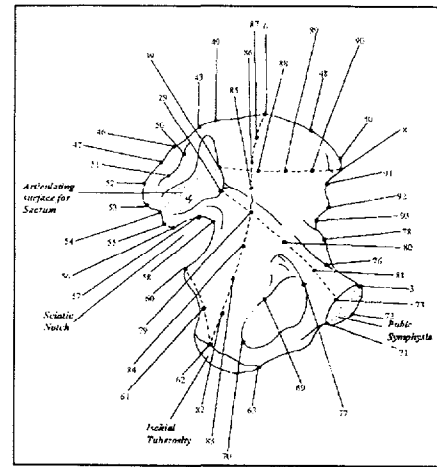


Figure 3 : Data points for the iliac wing (after Reynolds)

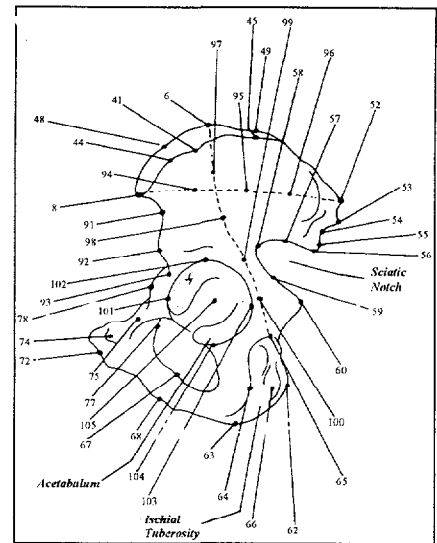


Figure 4 : Data points for the iliac wing (after Reynolds)

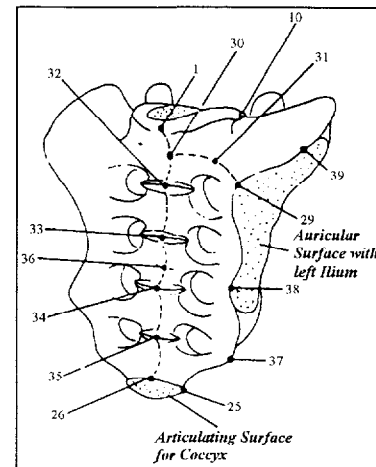


Figure 5 : Data points for the sacrum (after Reynolds)

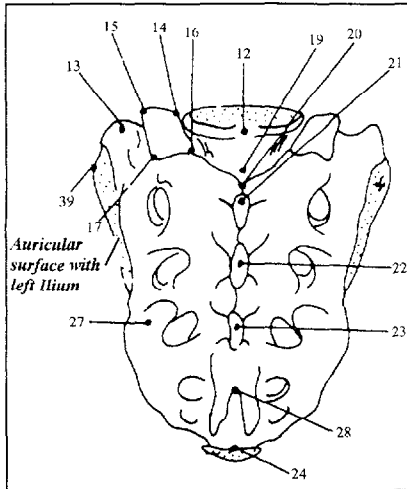


Figure 6 : Data points for the sacrum (after Reynolds)

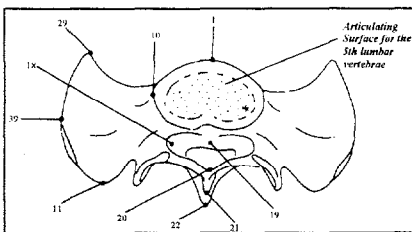


Figure 7 : Data points for the sacrum (after Reynolds)

In Reynolds' publication, the average values, the standard deviation and the number of measurements associated with each coordinate, are given.

The first 9 measured points are used to locate the pelvis skew system.

The number of measurements and the standard deviation are variable according to the measured coordinate. The palpation variation of some points, whose definition is not precise enough, generates a great uncertainty (Points in the medium of the iliac wings, edges of the iliac wings).

Statistical calculations are made on small samples, the number of measurements being at the utmost of 34.

To be able to apply statistical tests, the studied characters must follow a normal law distribution and their variances must be equal. The characters' normality is an assumption made by Reynolds since he carries out calculations of average and standard deviation (Gaussian law). This is the case in biology where the characters result from the addition of multiple independent effects, that follow laws close to the normal one. The differential factor acts much more on the average value than on the variability.

## METHOD

Notations used :

- For the sample :	Number of individuals	n
	Standard deviation	s
	Mean	m
- For the population :	Number of individuals	N
	Standard deviation	$\sigma$
	Mean	$\bar{x}$

For each Reynolds' group and each coordinate, we initially calculate the average of the total population, the standard deviation on the average and the total.

Then we calculate the minima and maxima values of the average, and the minima and maxima values of the character, by considering that the average of the population  $x$  and the sample  $m$  are identical.

These values are calculated by considering only 68% of the population, which corresponds to the calculation of the minima and maxima values with  $\pm ?$ .

Calculation of the standard deviation on the average :

$$v(\bar{x}) = \sqrt{\frac{1}{n-1}} \cdot s$$

Calculation of the total standard deviation :

$$\sigma = \sqrt{\frac{n}{n-1}} \cdot s$$

Comparison statistical tests on the points are carried out to determine characteristic points of the structure.

Since the test of comparison is only possible if the compared characters have identical standard deviations, a statistical test must also be applied to the variances.

## COMPARISON OF THE VARIANCES

To check the variances' equality, those of the two characters are compared.

For sample A and B :

- Number of individuals	$n_A$	$n_B$
- Standard deviation	$\sigma_A$	$\sigma_B$
- Mean	$m_A$	$m_B$
- Estimated variance		

$$S_A = \sqrt{\frac{n_A}{n_A - 1}} \cdot \sigma_A \quad S_B = \sqrt{\frac{n_B}{n_B - 1}} \cdot \sigma_B$$

The test of Snedecor F is applied.

The ratio F is calculated :

$$F = \frac{S_A^2}{S_B^2}$$

from where

$$F = \frac{(n_B - 1) \cdot n_A \cdot \sigma_A^2}{(n_A - 1) \cdot n_B \cdot \sigma_B^2}$$

The value F is compared to the Fs from the table " point 2,5% " [7] at intersection of column (n<sub>A</sub>-1) and line (n<sub>B</sub>-1). If F is lower than Fs, the two variances do not differ significantly (to 5%). This percentage is the one used as reference in medical and biological tests.

### COMPARISON OF THE AVERAGES

The comparison of the averages is based on calculation of the parameter t, and is valid if the variances of the characters are closely related (test of Snedecor F).

We will compare the samples two by two. Three comparisons should be made, between the small female and the medium man, between the small female and the large man and between the medium man and the large man. The comparison will be carried out between small samples (n<30), or between a small sample and a big one (n>30). Calculations will be in any case identical in both cases.

The variable t is calculated :

$$t = \frac{m_A - m_B}{\sqrt{\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}}}$$

For this calculation, s<sup>2</sup> is the common likely variance of the two samples :

$$s = \sqrt{\frac{(n_A - 1) \cdot S_A^2 + (n_B - 1) \cdot S_B^2}{n_A + n_B - 2}}$$

If |t| is lower than t from the table [7] for a degree of freedom equal to (n<sub>A</sub>+n<sub>B</sub>-2) and a risk of 5% (value retained by the biologists), the difference between the two characters tested is not significant. In the contrary case, it is significant.

### COMPARISON OF THE POINTS

The populations are compared two by two, according to the three coordinates by differentiating them X, Y then Z.

In order to have a significant coordinate, the variances should not differ significantly from more than 5% and the t test should be significant for the three comparisons.

Thus all the significant coordinates are deduced from the 105 Reynolds' points.

Moreover, we study the variation of the coordinates to determine its monotony (increase or decrease on three groups SF-MM-LM), and then to deduce the really significant points.

Only 13 coordinates are therefore significant on the 315 raised by Reynolds. We observe an increase of the coordinate values, therefore a total increase in pelvis dimensions is related to the size of the subject (for example, width of the sacrum).

Only few points are significant for this classification, measurements of distances would have been more significant to classify the pelvis.

We then become interested in the distances resulting from the points measured by Reynolds.

### COMPARISON OF THE DISTANCES

**Anatomical Distances** - Distances which, from an anatomical point of view, appear representative of general dimensions and the pelvis morphology, are calculated. 28 distances are thus calculated for each of Reynolds' pelvis. These distances are used in obstetrics before a childbirth.

The calculated distances are for example :

- Diameter of acetabulum
- Width of the pelvic aperture
- Biischial distance (between right and left tuberosities)
- Distance between iliac crests
- Pelvis width
- Distance between the two posterior superior iliac spines
- Height of the pelvis (between the top of the iliac crest and the ischial tuberosity)
- Angle of pubic arch
- Axis of foramen obturator
- Width of the sacrum
- Height of the sacrum
- Distances between the pubic symphysis and the sacral vertebrae (which characterize the curve of the sacrum).

None of them appear significant to differentiate the pelvis. We can notice that some distances are more important for the female than for the male :

- Biischial distance
- Width of the pelvic aperture
- Angle of pubic arch

The pelvis morphology of the male is thus completely different from the female's one, which assures us in our search for significant parameters, to get different finite element models.

To determine significant distances differentiating the pelvis groups, only a calculation of all the distances between all the points of a pelvis (measured and

symmetrical) enables us to extract the most significant one and therefore the parameters.

**Significant Distances** - Afterwards we consider a complete pelvis instead of a half one. The pelvis are always regarded as symmetrical. Each pelvis thus consists of 210 points on the whole, with redundant points. The number of calculated distances for one pelvis is thus higher than 21000, and these distances are associated with their standard deviation and a number of measurements.

**Standard deviation of a point** - To determine the standard deviation relating to a point, the maximum standard deviation on the 3 coordinates is considered. As a matter of fact, the point is included statistically in an ellipsoid of semi-axes ( $\sigma_x$ ;  $\sigma_y$ ;  $\sigma_z$ ) (Figure 8) , by considering 68 % of the population.

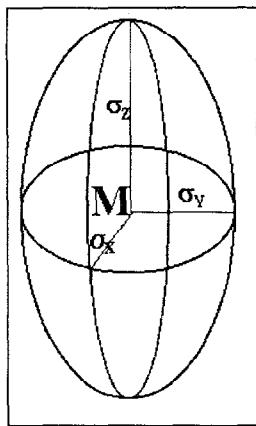


Figure 8 : Standard deviation ellipsoid around a point

By only taking account of the maximum standard deviation on the 3 coordinates, the point is included statistically in a sphere of  $2\sigma_{max}$  diameter (Figure 9). The number of measurements associated with the point is the one which is associated with the maximum standard deviation.

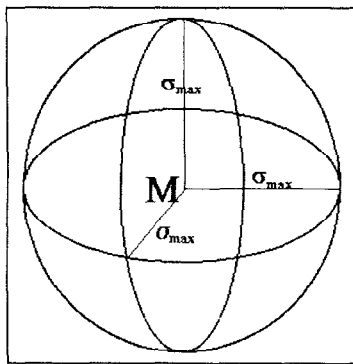


Figure 9 : Standard deviation sphere around a point

**Distance between 2 points** - The calculation of the average distances between the points is easy.

We consider 2 points  $M_1$  and  $M_2$  and the associated variation-types  $?_1$  and  $?_2$ . The average distance between these two points is :  $dist = \|\overline{M_1 M_2}\|$

The standard deviation connected with this distance is :

$$\sigma_{dist} = \sqrt{\sigma_1^2 + \sigma_2^2}$$

The number of associated distances is equal to the lowest number of measurements on the coordinates of the 2 points.

In this way, we obtain all the distances, the standard deviation and the number of distances associated, for the 3 Reynolds' pelvis classes.

Using the same statistical tests as those applied to the points, we deduce from them the characteristic distances for tests with 5% and monotonous variations (Distances Small Female < Distances Medium Male < Distances Large Male).

So we obtain 490 significant distances to differentiate the 3 different pelvis groups.

Among them, some are not reliable. Indeed, some points cannot be taken into account. They are on the symmetry plane of the pelvis, others are already on the right half-pelvis. Others still have high degree of uncertainty of palpation, the localisation of the point is not very reliable taking into account its geometrical definition.

The number of distances is now reduced to 378, then to 264 by removing the redundant distances. These distances must be individually studied to evaluate their relevance and facility of measurement.

The selection criteria for the distances are the following

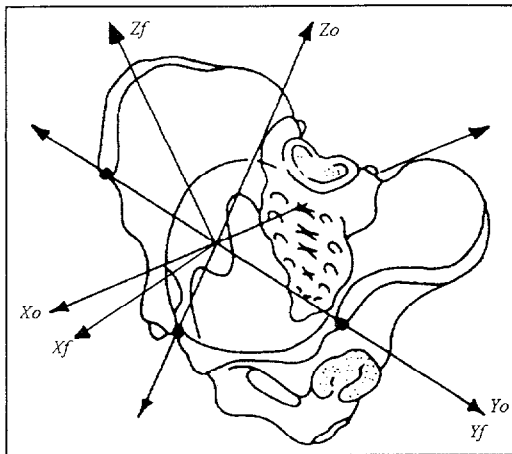
- Palpation facility of the extreme points
- Distances concerning the points of the general reference marks
- Distances concerning the anatomically recognised points
- Distances along the axes, but also omnidirectional to get the complete morphological differences.

So we obtain 138 significantly different distances to classify the pelvis according to the 3 Reynolds' groups.

## PELVIS CLASSIFICATION

**Geometry Acquisition** - The purpose of this geometrical study is to obtain a pelvis data base resulting from French human beings and the classification of the pelvis according to the Reynolds' groups.

The used measurement protocol is based on the palpation of isolated pelvis, resulting from the given body. The measured points are a result of the Reynolds' study and are adapted so as to be compared with his results. The reference system of measurement (Figure 10), related to the assembly of setting and maintenance in position of the pelvis, is not identical to the Reynolds' one but differs only by a rotation around the Y axis and a translation.



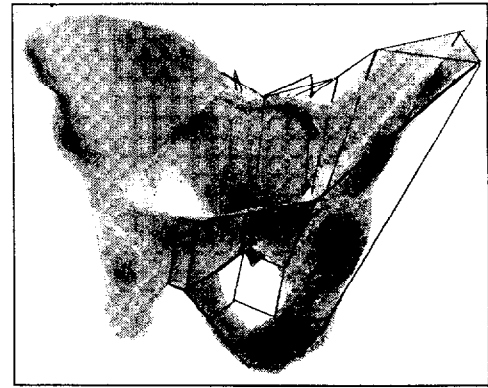
**Figure 10 : Reference axis system of Reynolds  $R_0$  & Guillemot's  $R_f$  measurement**

The Fastrak's measurement device is an electromagnetic system composed of a pen and 3 motionless magnetic reels. The movement of the pen induces a modification of the magnetic field in the reels, which makes it possible to calculate the coordinates of the pen point compared to a reference mark related to the reels. The assembly of measurement consists of Plexiglas and plastic elements to avoid any interference with this magnetic system.

The weight and volume are also measured for each pelvis.

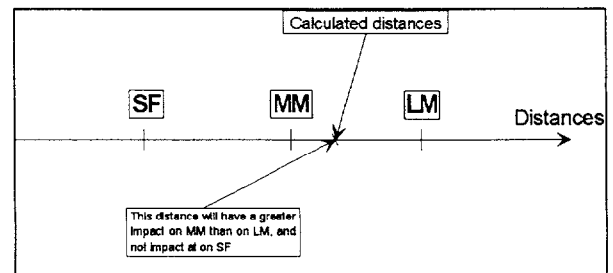
The data base currently consists of 25 pelvis.

**Pelvis Comparison** - We consider the points which take into account the significant distances such as principal nodes. There are 53 nodes, whereas there are 189 measured and symmetrized points, therefore 28% of the totality of the points. On these principal nodes, we build a structure for the 3 pelvis groups (SF-MM-LM) and we compare visually to the measured pelvis. We can observe on the following picture the comparison of this structure for the MM geometry with 50<sup>th</sup> percentile male FE model (Figure 11).

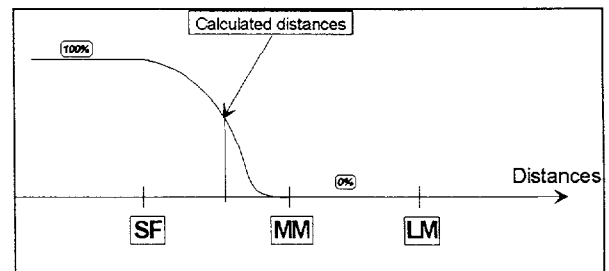


**Figure 11 : Comparison between MM geometry and 50<sup>th</sup> percentile FE model**

To have a more precise idea of the group of measured pelvis, we calculate, using our measurements, the significant distances. Then we compare them with those calculated with the Reynolds' pelvis. We give an impact to the calculated distance according to his nearness with the standard pelvis (Figures 12-13).



**Figure 12 : Impact distribution**



**Figure 13 : Impact calculation**

We add the relative impact of each group, the pelvis belongs to the group whose impact is the most significant. This procedure is automated to be carried out with each new pelvis.

We determined the significant distances on an unspecified pelvis, these distances are thus the parameters of the pelvis.

We extracted from them the principal points, they will be used for the deformation of an existing mesh for the adaptation to other geometries.

## MESH DEFORMATION

**Technique Used** - To adapt as much as possible the FE model geometry to different morphologies, we chose to deform the existing mesh by the kriging technique. This technique enables us to obtain a personalised mesh while reducing the development time, and to adapt the 50<sup>th</sup> percentile pelvis mesh to the 5<sup>th</sup> and 95<sup>th</sup> percentile morphologies.

The kriging is a interpolation technique of statistical origin applied for the first time in 1951 by D.C. Krige to estimate the resources of a gold mine. Its formalism dates from the sixties and results from G. Matheron's works.

This technique generalises the least squares method by making it possible for the model to go through the measurement points (control points).

Automatic procedures has been developed, by using MATLAB, to allow the fast application of the algorithm of kriging.

**Pelvis Kriging** - The control points of the structure are the end points of the significant distances. They are regarded as remarkable and were thus selected. Their number is 57 for the complete pelvis, whose FE mesh comprises 1219 nodes, it is thus 5% compared to the totality of the model.

The deformations carried out enable us to obtain meshes adapted to various geometries. The results are visible on the following picture (Figure 14). We can note that the kriging give not aberrant deformations on the pelvis, which indicates a judicious choice of the control points. The geometry of the meshes presents morphological differences noted during our measurements on fresh pelvis.

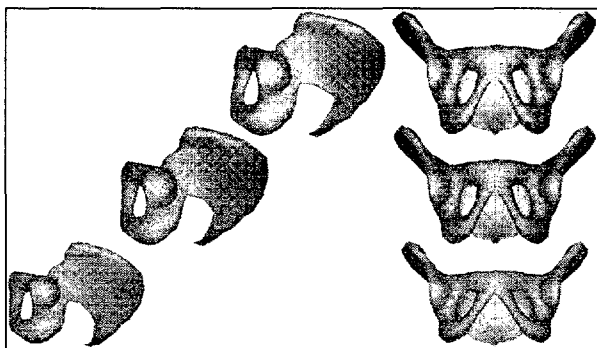


Figure 14 : 3 kriging pelvis models

## CONCLUSION

It is still necessary to validate this deformation procedure, by evaluation of the generated error on surface, and to see the geometry influence during a FE simulation.

This validation is in hand and lets predict good results.

Each dynamic test of H. Guillemot [9-10] on fresh pelvic bones was preceded by a points measurement, and could thus be simulated by taking into account of the geometry in order to gain a better appreciation of the fracture phenomenon.

Moreover this kriging technique opens the way towards the mesh of a 5<sup>th</sup> percentile female and a 95<sup>th</sup> percentile male without using homothetic deformations, prejudicial from a morphological point of view, but this technique requires the use of judiciously selected control points, which are difficult to find on the whole human body.

This work forms part of a vast program aiming at obtaining a human being FE model to predict the injuries, but also with different morphologies.

## REFERENCES

1. Trochu, F. : A contouring program based on dual kriging interpolation, *Engineering with computers*, pp 160-177, 1993
2. De Silvio, E. : Surface modelling at Serra do Madeira mine in Pitinga, Amazo, Mine planning and equipment selection, Balkema - Rotterdam, 1994
3. Lele, S. : Inner produkt matrices, kriging, and non-parametric estimation of variogram, *Mathematical geology*, 27(5), pp 673-692, 1995
4. Knoters, M., Brus, D.J. and Oude Voshaar, J.H. : A comparison of kriging, co-kriging and kriging combined with regression for spatial interpolation of horizon depth with censored observations, *Geoderma*, 67, pp 227-246, 1995
5. Asli, M. and Marcotte, D. : Comparison of approaches to spatial estimation in a bivariate context, *Mathematical geology*, 27(5), pp 641-658, 1995
6. Reynolds, H., Snow, C. and Young, J. : Spatial geometry of the human pelvis, FAA Civil Aeromedical Institute, Oklahoma City
7. Schwartz, D. : Méthodes statistiques à l'usage des médecins et des biologistes, Médecine - Sciences, Flammarion
8. Guillemot, H. : Pelvic fracture under side impact loading condition, International conference on pelvic and lower extremity injuries, Washington, 1995

9. Guillemot, H. : Pelvic injuries in side impact collisions : an accidental analysis and dynamic tests on isolated pelvic bones, 41th Stapp CAR Crash Conference, 1997
10. Guillemot, H. : Etude biomécanique du bassin en choc latéral automobile, Thèse de docteur en biomécanique, ENSAM Paris, Nov. 1997