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Disturbances of selected parameters for medical imaging systems

***Abstract**. The paper presents to aspects of measuring disturbances in the selected measurement systems based on digital radiographic images. Systems using X-ray images of the ankle or hip joint and dedicated programs and measurements algorithms were selected. The author performed an analysis of the standard uncertainty of measurement. Significant differences in uncertainty levels for the various indicators were observed, and must therefore be interpreted independently.*

***Streszczenie.** W artykule zostaną przedstawione aspekty zakłóceń pomiarów w wybranych systemach pomiarowych dotyczących zdjęć rentgenowskich. Do badań wybrano systemy wykorzystujące zdjęcia rentgenowskie stawów skokowych i biodrowych oraz własne programy i algorytmy pomiarowe. Przeprowadzono analizę poziomu niepewności standardowej pomiarów. Zaobserwowano znaczne różnice w poziomie niepewności dla różnych wskaźników i dlatego należy je interpretować niezależnie. (**Zaburzenia pomiarów wybranych parametrów dla medycznych systemów obrazowania.**).*

Keywords: hip or ankle joints, X-ray images, morphometric parameters, disturbances of measurements.
Słowa kluczowe: stawy biodrowy lub skokowy, zdjęcia rentgenowskie, parametry morfometryczne, zaburzenia pomiarów.

Introduction

The latest imaging techniques of the human skeletal system do not always provide the necessary diagnostic information. The limitation is complex and nonhomogeneous bone structure, and the fact that each component of this system must be treated as another object of measurement. The presence of large differences between individuals in the size of elements of the skeleton is also significant.

Selected for the tests hip and ankle joints (Fig.1), are extremely important human joints. One of the most common skeletal malformations in children are the defects of these joints. This could be an equine or varus deformations and hip dysplasia. The ankle joint deformities are quite common in bedridden patients, when the feet are incorrectly set.

The treatment of such deformations should be done as soon as possible after diagnosis. A number of plaster casts, foot stretching exercises and special shoes are mostly used. In extreme cases surgical treatment is applied [1].

The hip dysplasia is insufficient bone development and other elements making up the joint, especially too shallow and steep edges of the acetabulum at the hip bone, which is fixed to femur. This condition causes the femur, with increasing muscle strength and their tension, to become permanently pulled out of the acetabulum beyond the joint. It leads to dislocation of the hip joint, which does not allow a child to walk properly.

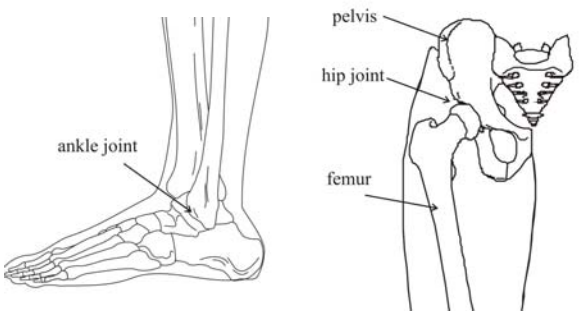


Fig.1. Structure of the ankle and the hip joints

Imaging techniques for human joints

An orthopedic examination of changes in the ankle joint or progression of treatment, especially congenital abnormalities in children, is performed by visual assessment or by palpable examination to assess the condition of skin, subcutaneous tissue, tendon or joints.

Using the X-ray examination, the relationship between the foot bone components is assessed and, in some cases, measurements are made.

A number of indicators are used for measurements of the foot or hip parameters, in medical practice often done with a ruler and compasses.

X-ray examination is the most common type of imaging of the skeletal system, in particular the joint connections. Due to the fact that the computed tomography (CT) or magnetic resonance imaging (MRI) techniques are less accessible as well as often more expensive than digital radiography, they are used as supplementary methods depending on the needs [2].

Radiographs of ankle and hip joints can be performed in a few projections: lateral (Fig. 2a), antero-posterior (Fig. 2b) and postero-anterior.

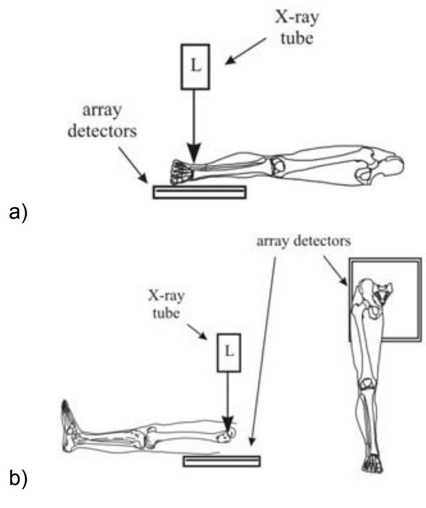


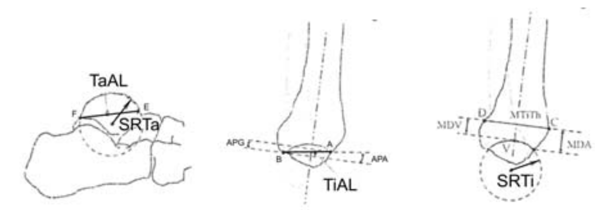
Fig.2. Standardized projections of radiographs performance of ankle (a) and hip (b) joints

Selected parameters

Several parameters are used to assess the condition of the joints and the progress of the treatment of these joints.

In order to assess the progress of ankle joint treatment several parameters are described in literature four of these parameters were measured on radiographs in the lateral projections [3]:

- TaAL – length of the segment connecting the extreme elements of the trochlea tibial bone (Fig.3a segment FE);
- SRTa – radius of the circumcircle on the arc trochlea tibial bone (Fig.3a);
- TiAL – length of the segment connecting the extreme elements of the tibial mortise. (Fig.3c segment AB);
- SRTi – radius of the circumcircle on the arc tibial mortise (Fig.3c).

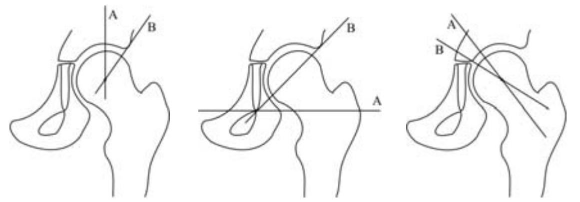


a) b) c)

Fig.3. Parameters of the ankle joint structure [3]

The most widespread parameter used to monitor the development of the hip joint in children is the angle of Wiberg [4] (Fig.4a), although many other indicators and angles have been recommended.

For the conducted analyses the following angles were selected: acetabular angle of Sharp [5] (Fig.4b) and centering angle of the femoral head [6] (Fig.4c).



a) b) c)

Fig.4. Parameters of the hip joint structure

Processing of measurements

Measurements of parameters of the skeletal system can be performed according to different schemes and algorithms depending on the tools or procedures used.

Systems using X-ray images of the ankle and hip joints, dedicated programs and measurements algorithms were selected (Fig. 5).

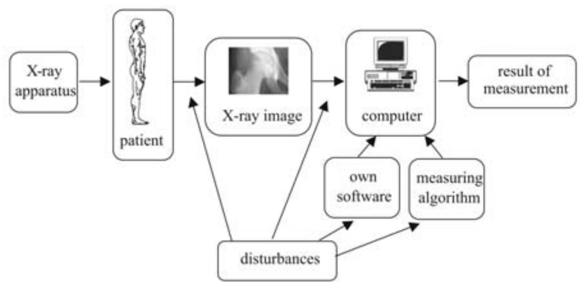


Fig.5. Structure of the imaging measurement system

The dedicated programs for the studies were developed to extract and measure the selected parameters for the ankle joint and the hip joint. In the conducted research, the author used ankle joint radiographs performed in the lateral projection (Fig. 6) and hip joint radiographs performed in antero-posterior projection (Fig. 7) of younger children and teenagers.

Fig.6. A view of the developed program for the ankle joint

Fig.7. A view of the developed program for the hip joint

Because of the individual and age differences in children's hip joints, measurements for selected angles were carried out interactively by the operator (Fig. 8).

Fig.8. An example of measured Sharp's angle

Analysis of measurement results

Every measurement could be burdened by errors of different origin. The developed measurement methods of the selected morphometric parameters are used to perform indirect measurements on radiographic images which reflect projections of the examined bone structure.

Because of the necessity to measure morphometric parameters by of an operator, the developed methods can be burdened with multiple disturbances of a statistical nature. Many elements of the measuring chain are difficult to describe analytically, therefore an analysis of the standard uncertainty of measurement was performed.

For a large sample size, the estimator of measurement uncertainty is the standard deviation of the mean [7]:

(1) $$u(\bar{x}) = u_A = \frac{s(x)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where: $s(x)$ – sample standard deviation, n – size of the sample, x_i – observed values, $\bar{x}$ – mean value of observations.

Since performing a series of hip radiographs for one patient is impossible due to the high sensitivity of the pelvic organs to ionizing radiation, radiographs of several patients of different ages are used for the measurements. For these radiographs, a series of 50 measurements of the previously described indicators was made.

The results of calculations carried out on the basis of measurements for the right hip joint are shown in Table 1, while results for the left hip joint are shown in Table 2.

Table 1. Comparison of calculated parameters for the right hip joint of patients at different ages

		Sharp's angle	Wiberg's angle	Centering angle
younger group	$\bar{x}$	40.50	21.93	11.97
	$u(\bar{x})$	0.10	0.31	0.57
older group	$\bar{x}$	38.40	23.60	7.60
	$u(\bar{x})$	0.15	0.29	0.80

Table 2. Comparison of calculated parameters for the left hip joint of patients at different ages

		Sharp's Angle	Wiberg's angle	Centering angle
younger group	$\bar{x}$	42.63	18.00	19.50
	$u(\bar{x})$	0.13	0.35	0.60
older group	$\bar{x}$	36.07	22.53	8.20
	$u(\bar{x})$	0.15	0.35	0.73

Similarly, the results of calculations carried out on the basis of the measurements for the right ankle joint contains Table 3 contains, while Table 4 shows the results for the left joint. The measured values are presented in pixels of the analyzed image because it was not yet possible to perform tested radiographs with the measurement model.

Table 3. Comparison of calculated parameters for the right ankle joint of patients at different ages

		TaAL	SRTa	TiAL	SRTi
younger group	$\bar{x}$	230.14	140.54	147.19	123.12
	$u(\bar{x})$	0.83	3.49	1.29	2.67
older group	$\bar{x}$	174.58	175.80	182.91	150.91
	$u(\bar{x})$	1.05	6.99	1.16	4.49

Table 4. Comparison of calculated parameters for the left ankle joint of patients at different ages

		TaAL	SRTa	TiAL	SRTi
younger group	$\bar{x}$	227.54	151.64	176.70	209.17
	$u(\bar{x})$	0.51	3.37	1.10	6.67
older group	$\bar{x}$	261.32	140.34	192.26	141.72
	$u(\bar{x})$	0.35	1.45	0.31	2.85

Significant differences in uncertainty levels for the various indicators were observed, and must therefore be interpreted independently.

To estimate whether a given actual value is within the uncertainty range, the confidence interval is estimated with the particular level of confidence p, which determines the coverage factor k_p. The expanded uncertainty is obtained by the formula [7]:

(2) $$U(\bar{x}) = k_p \cdot u(\bar{x})$$

where: $u(\bar{x})$ – standard uncertainty of measurement, k_p – coverage factor.

An estimation of selected parameters for the assumed level of confidence can be written as:

(3) $$x = \bar{x} \pm U(\bar{x})$$

where: $\bar{x}$ – mean value of observations, $U(\bar{x})$ – expanded uncertainty,
or in a range of occurrence.

Assuming a level of confidence of 0.954, an estimate of the range was obtained, for example, Wiberg's angle of the right hip joint (21.31 , 22.56) for the younger patient and (35.45 , 36.49) for the older patient, while SRTi indicator of the left ankle joint (195.83 , 222.51) for the younger patient and (136.01 , 147.43) for the older patient.

Estimates of remaining parameters for the hip joint are given in Table 5, while the estimates for the ankle joint are given in Table 6.

Table 5. Estimations of the hip joint parameters

		Right hip joint	Left hip joint
Sharp's angle	younger group	(40.29 , 40.71)	(42.37 , 42.90)
	older group	(33.31 , 33.96)	(34.52 , 35.01)
Wiberg's angle	younger group	(21.31 , 22.56)	(17.30 ,18.70)
	older group	(35.45 , 36.49)	(27.11 , 28.01)
Centering angle	younger group	(10.82 , 13.12)	(18.30 , 20.70)
	older group	(18.45 , 22.22)	(5.93 , 9.07)

Table 6. Estimations of the ankle joint parameters

		Right ankle joint	Left ankle joint
TaAL	younger group	(228.48 , 231.81)	(226.51 , 228.56)
	older group	(172.48 , 176.68)	(260.61 , 262.03)
SRTa	younger group	(133.55 , 147.52)	(144.91 , 158.37)
	older group	(161.82 , 189.78)	(137.45 , 143.24)
TiAL	younger group	(144.60 , 149.77)	(174.50 , 178.91)
	older group	(180.60 , 185.22)	(191.65 , 192.88)
SRTi	younger group	(117.78 , 128.47)	(195.83 , 222.51)
	older group	(141.94 , 159.88)	(136.01 , 147.43)

For the used research objects in rare cases there can be observed an occurrence of convergence ranges in tested parameters for left and right limbs.

It is much more complex to compare ranges for younger and older patients, therefore they should be interpreted independently.

Conclusions

By calculating the uncertainty $u(\bar{x})$ for the tested ankle and hip joint parameters, one can estimate the range of values, which should be the actual value of this parameter, determined by this uncertainty at the assumed level of confidence.

However, in order to be able to use the estimated ranges, it is necessary to split the examined cases into different age groups.

Thus created sets of compartments could be the basis of specific comparative base for estimating the correct value of ankle and hip anatomic parameters with adequate age division.

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