Estimation of Measurements Uncertainty of Selected Knee Joints Parameters

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Abstract. The paper presents aspects of the evaluation of measurement uncertainty of anatomical parameters on radiological images. Measurements carried out on the basis of radiological images taken in standardized projections were evaluated. Several dozen measurement series have been made for healthy and sick patients and for the knee joint preparation. The uncertainty of the results of knee joint measurements have been assessed.

Introduction

Osteoarthritis (OA) is currently one of more important health problems. This disease is one of the most common causes of pain and disability, especially in older people [1]. It concerns usually one or several joints shown in the Fig. 1.

Degenerative changes most often occur in the knee and hip joints. The costs of health care and changes in the way of life are serious. Therefore, an early and cheap diagnosis of OA is needed. This would reduce the cost of treatment, rehabilitation or early retirement.

Fig. 1 shows the knee joint chosen for research, which is the main degenerative pathology of the human locomotion system.

Knee Joints Imaging

Degenerative changes most often occur in the knee and hip joints. The costs of health care and changes in the way of life are serious. Therefore, an early and cheap diagnosis of OA is needed. This would reduce the cost of treatment, rehabilitation or early retirement.

The examination of knee joint changes in orthopedics is carried out on the basis of visual assessment. This is usually done using an X-ray techniques. The relation between the components of the knee bones is assessed. In rare cases, the measurements are made.

Currently, the radiogram is the most economical and available tool for assessing changes in OA, in particular the joint connections. Computed tomography (CT) or magnetic resonance imaging (MRI)
are used as supplementary methods depending on the needs because they are less available and more expensive than digital radiography [2].

X-ray images of knee joints can be realized in several projections: antero-posterior in the standing position (Fig. 2), lateral or postero-anterior [3]. The map of the feet on paper is used to ensure better repeatability.

![Figure 2. Standardized projection of radiograph performance of knee joint in the standing position.](image)

Radiographs of the knee joints can vary greatly due to joint distortions. Fig. 3 shows examples of different images of knee joint structures. The reason for these differences may be a limb positioning error during the radiogram performing or degenerative changes in the joint.

![a) b) Figure 3. Examples of the knee joint radiographs of healthy (a) and ill people (b).](image)

**Measurement Technique**

For the measurement of the tibial femoral joint the method of measurement was chosen between the anterior edge of the tibia and the front edge of the femur in 1/3 of the distance between the outer extremity of the knee joint and the protuberance of the condyles (Fig. 4).

![Figure 4. Measurement method of the tibiofemoral joint space.](image)

After normalization and removing noises from the image, the courses of grays are read in places indicated by the measuring method presented above. Mathematical analysis of these courses make it possible to detect precise measuring points to determine the size of the examined articular spaces [4].
Means of Measurements Implementation

Measurements of skeletal system parameters can be made according to various methods. We can use available or dedicated tools. A system using digital radiographs of knee joints was realized to carry out the measurements (Fig. 5).

Within the system measurement algorithms and dedicated program were developed. This program extracts and measures selected parameters of the knee joint (Fig. 6), and can also be implemented in FPGA chips [5].

In the conducted research, the author used knee joint radiographs performed in the antero-posterior projection. Because of the individual differences in knee joints, measurements were carried out interactively by the operator.

Analysis of the Obtained Measurement Results

As I wrote in the article regarding measurements of hip and ankle joint parameters [6], every measurement can be burdened by errors of different provenance. Measurements performed on radiological images, also on images of joints, e.g. ankle joints [7] or else knee joints, are indirect measurements. Due to the need to measure the parameters of the knee joint by the operator and the large individual differences in the anatomical structure, the obtained measurements results may be burdened with many disturbances of a statistical nature.

According to the recommendation of the International Bureau of Weights and Measures, standard uncertainty of measurement type A is calculated for large measurement series obtained under the same conditions of measurement [8]. The estimator of this uncertainty is the standard deviation of the mean given by

$$u(\bar{x}) = u_A = \frac{s(x)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2}.$$ (1)
Wherein \( s(x) \)–sample standard deviation, \( n \)–size of the sample, \( x_i \)–observed values, \( \bar{x} \)–mean value of observations.

Because it is impossible to take a series of X-ray images in one patient due to the high sensitivity of organs to ionizing radiation, radiographs lots of patients are used for measurements. Archival radiographs of knee joints performed for female patients in the 50-60 age group were used for the study. Orthopedists, on the basis of visual assessment of radiographs, divided them into two groups: healthy persons and patients. 50 people were selected from each group to perform measurements based on their radiographs.

The results of calculations of statistical parameters (Eq. 1) based on knee joint measurements for healthy and ill persons were compared in Table 1. The measurements were carried out according to the above-described measuring method (Fig. 4) separately for the right and left knees and for the lateral and medial compartments.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Statistical Parameters</th>
<th>Right Knee Joints</th>
<th></th>
<th>Left Knee Joints</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Medial compartment</td>
<td>Lateral compartment</td>
<td>Medial compartment</td>
<td>Lateral compartment</td>
</tr>
<tr>
<td>healthy</td>
<td>( \bar{x} ) [mm]</td>
<td>5.24</td>
<td>5.94</td>
<td>5.35</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td>( u(\bar{x}) ) [mm]</td>
<td>0.14</td>
<td>0.18</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>ill</td>
<td>( \bar{x} ) [mm]</td>
<td>4.75</td>
<td>6.75</td>
<td>4.40</td>
<td>6.84</td>
</tr>
<tr>
<td></td>
<td>( u(\bar{x}) ) [mm]</td>
<td>0.29</td>
<td>0.32</td>
<td>0.26</td>
<td>0.33</td>
</tr>
</tbody>
</table>

As we can see in the above table for the examined groups of healthy and ill people, the values of standard uncertainty between the legs differ slightly, while the average values differ more, especially for the ill people. However, when we compare the values between groups of healthy and ill people, the differences were significant, both between mean values and standard uncertainty.

In addition, the results of calculations made on the basis of measurements for the preparation of knee joint are included in Table 2. However, in this case there was one object for which 50 measurements were made.

<table>
<thead>
<tr>
<th>Preparation</th>
<th>Statistical Parameters</th>
<th>Prepar</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Medial compartment</td>
<td>Lateral compartment</td>
</tr>
<tr>
<td>preparation</td>
<td>( \bar{x} ) [mm]</td>
<td>6.81</td>
<td>8.99</td>
</tr>
<tr>
<td></td>
<td>( u(\bar{x}) ) [mm]</td>
<td>0.02</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Using the calculated parameters, we can estimate whether a given actual value is within the range defined by the uncertainty. The confidence interval is estimated at a given level of confidence \( p \), which determines the coverage factor \( k_p \) [8]. The coverage factor \( k_p \) assumes values 2 or 3 for level of confidence \( p \), respectively 0.954 and 0.997. The expanded uncertainty is obtained by the formula

\[
U(\bar{x}) = k_p \cdot u(\bar{x}).
\]

(2)

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

\[
x = \bar{x} \pm U(\bar{x})
\]

or in a range of occurrence.

Assuming the level of confidence of 0.954, the ranges of values of knee joints width for healthy people were estimated, separately for right and left knee joints and for lateral and medial compartments (Table 3).
Table 3. Estimation of knee joint parameters of healthy people assuming a level of confidence of 0.954.

<table>
<thead>
<tr>
<th></th>
<th>Right Knee Joints</th>
<th>Left Knee Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medial compartment</td>
<td>Lateral compartment</td>
</tr>
<tr>
<td>range of x [mm]</td>
<td>(4.96 , 5.51)</td>
<td>(5.59 , 6.29)</td>
</tr>
</tbody>
</table>

For ill people the ranges of values of the left knee joints width e.g. for medial compartment (3.86, 4.94) and lateral compartment (6.17, 7.50) are greater.

We can see that for the used research objects, the ranges of values of the tested parameters for the left and right knee joints are convergent. On the other hand, it is difficult to compare the ranges of values of the tested parameters for ill and healthy people, therefore they should be interpreted independently. It may be interesting to note that the parameters for knee joint preparation have less uncertainty than parameters for patients.

Conclusions

The calculated standard uncertainty for the examined knee joint parameter can be used to estimate the range of values, which should contain the effective value of this parameter. These ranges of values are determined at the assumed level of confidence.

However, the designated ranges of values can be used in the group of healthy adults. The obtained estimation for a group of ill people may be used for comparison purposes.

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References


