Measurement repeatability of radiographic and biomechanical parameters in anterior-posterior pelvic radiographs

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Abstract

The measurement of a three-dimensional structure (pelvis) from a two-dimensional source (radiograph) is one of the main limitations of the radiograph analysis. The aim of our paper is to evaluate the measurement repeatability of the same hip in different radiographs. In particular, we are interested in determining the relative influence of the magnification and the specific radiographic parameters on the repeatability of the estimated peak contact hip stress. The study sample consisted of 15 adult patients with hip dysplasia who were operated upon in the years 1987-1994 (osteotomy according to Ganz). The study only included the hips that have NOT undergone any operation. Radiographic and biomechanical parameters of each hip were measured
on the preoperative and the postoperative anterior-posterior radiograph. The resultant hip force and the hip stress distribution was computed by using a previously developed analytical three-dimensional biomechanical model. The two consecutive measurements of a given parameter in an individual patient were normalized and the standard deviation of the normalized values was taken as an indicator of the measurement repeatability. It was found that the highest discrepancies between consecutive measurements of the same hip are seen in the vertical coordinate of the trochanteric insertion point and the Wiberg centre-edge angle. This phenomenon is reflected in a relatively good repeatability of the resultant hip force and low repeatability of the peak contact hip stress. We conclude that the standardization of the radiographic magnification only solves one part of the repeatability problem. Further improvement in this direction would have to employ methods for more accurate positioning of human pelvis on the radiographic film and possible use of radio-opaque markers.
1 INTRODUCTION

Pelvic radiographs have been used in the past as the basis for the estimation of the biomechanical status in the hip joint. Several biomechanical models have been developed that enable the computation of the resultant hip force and the stress distribution from the measured radiographic parameters of pelvic geometry. The analytical models with non-uniform stress distribution seem to be a useful compromise between the complexity of the finite-element models and the simplicity of the radiograph analysis in clinical practice [Brand et al., 2001]. In this way the biomechanical status of the hip in different groups of patients has been studied and orthopaedic surgical procedures were evaluated both clinically and biomechanically.

The measurement of a three-dimensional structure (pelvis) from a two-dimensional source (radiograph) is one of the main limitations of the radiograph analysis. Errors in determination of radiographic and biomechanical parameters derive from unknown magnifications of radiographs and from errors in the determination of the geometrical parameters due to different distances of the selected points from the plane of the radiographic film. Within the validity of the model, the error in the peak contact hip stress computation has been estimated to amount up to 20 per cent [Daniel et al., 2001]. The aim of our paper is to evaluate the measurement repeatability of the same hip in different radiographs. In particular, we are interested in determining the relative influence of the magnification and the specific radiographic parameters on the repeatability of the estimated peak contact hip stress.

2 PATIENTS AND METHODS

2.1 Patients

In order to check the measurement repeatability one would ideally need as many radiographs of the same pelvis as possible and the pelvic structure should not change with time. Healthy patients with consecutive pelvic radiographs taken in a short time interval are very difficult to find. Therefore, the study subjects were selected from among the group of 55 adult patients with hip dysplasia who were operated upon in the years 1987-1994 (osteotomy according to Ganz). The study only included the hips that have NOT undergone any operation and had both the preoperative and the postoperative anterior-posterior pelvic radiograph available. The final sample consisted of 15 hips, whereby radiographic and biomechanical parameters of each hip were measured on the preoperative and the postoperative anterior-posterior radiograph. The average time interval between the two consecutive radiographs was equal to 3.4 years (range 0-10 years).
2.2 Measurement of radiographic parameters

The pelvic bone contours were analyzed manually and the following radiographic parameters were measured [Mavcic et al., 2002]: the interhip distance $l$, the pelvic height $H$, the pelvic width laterally from the femoral head center $C$, the point coordinates $T_x$ and $T_z$ of the insertion point of abductors on the greater trochanter in the frontal plane, the radius of the femoral head $r$ and the Wiberg centre-edge angle $\delta_{CE}$. Because the radiographs were taken in the supine position, the line between the centers of the femoral heads was defined as the arbitrary reference for the horizontal level. The three-dimensional reference coordinates of the muscle attachment points were taken from the paper of Dostal and Andrews (1981) and they were adjusted by linear scaling with regard to the radiographic pelvic parameters ($l$, $H$, $C$, $T_x$, $T_z$) for each individual hip. In addition, all of the measured parameters except $\delta_{CE}$ were corrected with regard to the presumed magnification of 10% since exact magnifications were not known.

2.3 Computation of biomechanical parameters

The peak stress estimation in healthy hips was based on a previously developed analytical three-dimensional biomechanical model [Iglic et al., 1993; Ipavec et al., 1999; Mavcic et al., 2002]. The model can be used to estimate the resultant hip force and the stress distribution in the hip joint from an anterior-posterior pelvic radiograph, whereby the computed biomechanical parameters correspond to the static one-legged stance. The solution of the vector equations for the equilibria of forces and torques yielded the three components of the resultant hip force $R$ and the tensions in the abductor muscles. From known values of the femoral head radius $r$, the Wiberg center-edge angle $\delta_{CE}$, the magnitude of the resultant hip force $R$ and the inclination of the resultant hip force with respect to the vertical $\delta_R$, the peak stress on the weight-bearing surface was computed for every individual hip [Ipavec et al., 1999].

The results of the resultant hip force and the peak contact hip stress are reported normalized to the body weight of each subject ($R/W_B$ and $p_{max}/W_B$), since due to the retrospective nature of the study the data on patients' body weights were not available in most cases. Nevertheless, by using $p_{max}/W_B$ it is possible to emphasize the influence of pelvic geometry on hip pathology without other confounding factors (body weight, physical activity, profession). The normalized stress $p_{max}/W_B$ has already been acknowledged as the relevant biomechanical parameter in previous studies [Brinckmann et al., 1981].
2.4 Statistical Analysis

For a given parameter in a patient, each of the two consecutive measurements $m_1$ and $m_2$ was normalized to the average of the two measurements as

\[ n_1 = \frac{2m_1}{m_1 + m_2}, \]

\[ n_2 = \frac{2m_2}{m_1 + m_2}. \]

Eventually, the normalized measurements of all the patients for a given parameter were analyzed together as a single group. The average of the normalized measurements for a given parameter was equal to 1.00, of course, but the standard deviation of the normalized values was taken as an indicator of the measurement repeatability (the lower the standard deviation, the better the repeatability).

3 RESULTS

3.1 Repeatability of radiographic parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>$l$</th>
<th>$H$</th>
<th>$C$</th>
<th>$T_x$</th>
<th>$T_z$</th>
<th>$r$</th>
<th>$\varphi_{CE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>0.02</td>
<td>0.02</td>
<td>0.07</td>
<td>0.43</td>
<td>0.07</td>
<td>0.03</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Table 1: The standard deviation of the normalized measurements of all the patients for the seven radiographic parameters

3.2 Repeatability of biomechanical parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>$R/W_B$</th>
<th>$\varphi_R$</th>
<th>$\Theta$</th>
<th>$p_{max}/W_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>0.04</td>
<td>0.16</td>
<td>0.44</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Table 2: The standard deviation of the normalized measurements of all the patients for the four biomechanical parameters
4 DISCUSSION AND CONCLUSIONS

Our analysis shows that the repeatability among radiographic parameters is the best in $l$, $H$, $r$, $C$ and $T_z$ whereas the highest discrepancies between consecutive measurements of the same hip are seen in $T_x$ and $\vartheta_{CE}$. This phenomenon is reflected in the repeatability of biomechanical parameters as well. $R/W_B$ depends entirely on $l$, $H$, $C$, $T_x$, $T_z$ and has a relatively good repeatability, the repeatability of $\vartheta_R$ is less pronounced due to the variability of $T_x$. The high values of the standard deviation of $p_{max}/W_B$ and $\vartheta$ can be attributed to high variability of $\vartheta_{CE}$ and $\vartheta_R$.

These findings have direct implications for further improvements in the measurement of radiographic and biomechanical parameters from anterior-posterior pelvic radiographs. It has been argued that the magnification variability is one of the main culprits for the differences in the peak stress [Vengust et al., 2000], but our data only partially support this conclusion. Different magnification influences the values of $l$, $H$, $C$, $T_x$, $T_z$ and $r$, but it does not affect the $\vartheta_{CE}$ as one of the least repeatable parameters. Also, when the two consecutive sets of measurements in a single patient were adjusted to the same magnification (by taking $l$ or $r$ as the reference value), the standard deviation of the peak contact hip stress was still higher than 0.20. We can conclude that the standardization of the radiographic magnification only solves one part of the repeatability problem. Further improvement in this direction would have to employ methods for more accurate positioning of human pelvis on the radiographic film and possible use of radio-opaque markers. In particular, the pelvic rotation in all three degrees of freedom and the repeatability of the $\vartheta_{CE}$ measurement are probably going to be the most difficult problems to solve.

References

