Repeatability of biomechanical computations based on pelvic radiographic measurements of adult dysplastic hips

Blaž Mavčič[a,b], Marko Kralj[a], Vane Antolič[a], Aleš Iglič[c] and Veronika Kralj-Iglič[b,c]

ABSTRACT

Background

While measurement repeatability of individual pelvic radiographic parameters has already been evaluated, there have been no reports on the repeatability of biomechanical computations from such measurements. The aim of our study was to evaluate the repeatability of computations of the resultant hip force and the peak contact hip stress from seven pelvic radiographic parameters in adult dysplastic hips.

Methods

We performed a retrospective analysis of 18 nonoperated adult dysplastic hips with a series of three anteroposterior pelvic radiographs for each hip. The participants were adult patients treated with unilateral Bernese periacetabular osteotomy at our institution in the years 1987–1995, and only their nonoperated hips without osteoarthritis were included. Radiographic measurements and biomechanical computations were performed with the previously developed HIPSTRESS method on each of the three radiographs for each individual, and repeatability was assessed with the intraclass correlation coefficients.

Results

We found high repeatability of the measured Wiberg center-edge angle, pelvic width, the horizontal coordinate of the abductor insertion point on the greater trochanter, intermediate repeatability of the interhip distance and low repeatability of the femoral head radius, pelvic height and the vertical coordinate of abductor insertion point on the greater trochanter. The intraclass correlation coefficients of the resultant hip force and the peak contact hip stress were 0.88 and 0.94, respectively.

Conclusions

The repeatability of biomechanical computations from pelvic radiographic measurements is comparable to the repeatability of the present methods for assessment of hip dysplasia.

Keywords

hip biomechanics, hip dysplasia, peak contact hip stress, pelvic radiography

[a]*Department of Orthopaedic Surgery, University Medical Center Ljubljana, Slovenia*

[b]*Laboratory of Clinical Biophysics, Faculty of Medicine, University of Ljubljana, Slovenia*

[c]*Laboratory of Physics, Faculty of Electrical Engineering, University of Ljubljana, Slovenia*

Correspondence to Blaž Mavčič, MD, PhD, Department of Orthopaedic Surgery, University Medical Center Ljubljana, SI-1000 Ljubljana, Slovenia Tel: +386 41 280 385; fax: +386 15 222 474; e-mail: blaz.mavcic@kclj.si

INTRODUCTION

Anteroposterior pelvic radiographs are widely used in clinical practice as diagnostic tools for assessment of residual hip dysplasia in adults.[1] Evaluation of the hip joint has been based primarily on morphological measurements of radiographic parameters. With advances in knowledge on hip dysplasia, mathematical models were introduced to complement hip evaluation with estimation of biomechanical parameters.[2,3] Recently, an analytical method, HIPSTRESS, has been developed that enables computation of the resultant hip force and the contact hip stress distribution from seven measured radiographic parameters on an anteroposterior pelvic radiograph.[4,5] The method has been used in clinical cross-sectional studies of normal and dysplastic hips.[6,7] Also, by using this method orthopaedic surgical procedures in the hip joint were studied biomechanically.[8,9]

If a method is to be used for clinical evaluation of the hip, it should have acceptable repeatability, i.e. pelvic radiographic measurements and biomechanical computations of the same unchanged hip from radiographs taken at different occasions should give the same results. Errors in measurement of pelvic radiographic parameters and computation of biomechanical parameters can arise from unknown magnifications of radiographs,[10] different distances of the selected points from the plane of the radiographic film due to variations in the positioning of the pelvis,[11] and the intraobserver/interobserver measurement variability.[12] Studies of other authors on repeatability of radiographic measurements in dysplastic hips, which have mainly focused on errors due to different observers[12,13] and errors due to different positioning of the pelvis on different radiographs, have only been studied on cadavers.[11] There have been no reports on the repeatability of biomechanical computations from such pelvic radiographic measurements.

The aim of our paper was to evaluate the repeatability of biomechanical computations based on pelvic radiographic measurements of anteroposterior radiographs of adult dysplastic hips. In particular, we were interested in determining the repeatability of the resultant hip force computation and the peak contact hip stress computation from repeated radiographs of individual hips.

MATERIALS AND METHODS

Patients

The study subjects were selected from among a group of 55 adult patients with hip dysplasia who were treated with a unilateral Bernese periacetabular osteotomy at the

Department of Orthopaedic Surgery, University Medical Center Ljubljana, Slovenia, in the years 1987–1995. The study only included the nonoperated hips of patients who had at least three anteroposterior pelvic radiographs available. Hips with osteoarthritis or any other progressive pathology noted on the radiographs were excluded. The final analysis sample consisted of 18 nonoperated hips with three radiographs of each hip. All 54 radiographs were taken at the same institution. The median age of the study patients at their earliest radiograph was 30 years (range, 18–47 years). The radiographs were taken at the same institution in the intervals of a few years; the median time interval between two successive radiographs of a single patient was 6 years (range, 0–15 years).

Measurement of Pelvic Radiographic Parameters

All measurements on the 54 radiographs were performed manually by one researcher (BM). The following seven pelvic radiographic parameters (Figure 1) were measured in accordance with the HIPSTRESS method:[4–6] the Wiberg center-edge angle ϑ_{CE}, the interhip distance l, the pelvic width laterally from the femoral head center C, the pelvic height cranially from the femoral head center H, the vertical coordinate T_x and the horizontal coordinate T_z of the insertion point of abductors on the greater trochanter in the frontal plane and radius of the femoral head r. The measurement coordinate system for the pelvic parameters C, H and ϑ_{CE} was adjusted according to the referential horizontal line through the centers of the femoral heads. The abductor insertion on the greater trochanter was defined by the point (T) where the right bisector of the line between the superior-most and the lateral-most trochanteric points crosses the trochanteric bony contour. It was measured with regard to the femoral head center in a coordinate system parallel to the longitudinal axis of the corresponding femoral shaft on each side. The center of femoral head on the earliest radiograph of a patient was determined with Mose circles, and the centers in the remaining two radiographs of the same patient were determined by superimposition with the earliest radiograph. Length measurements were corrected with regard to the presumed magnification of 10% because exact radiographic magnifications were not known.

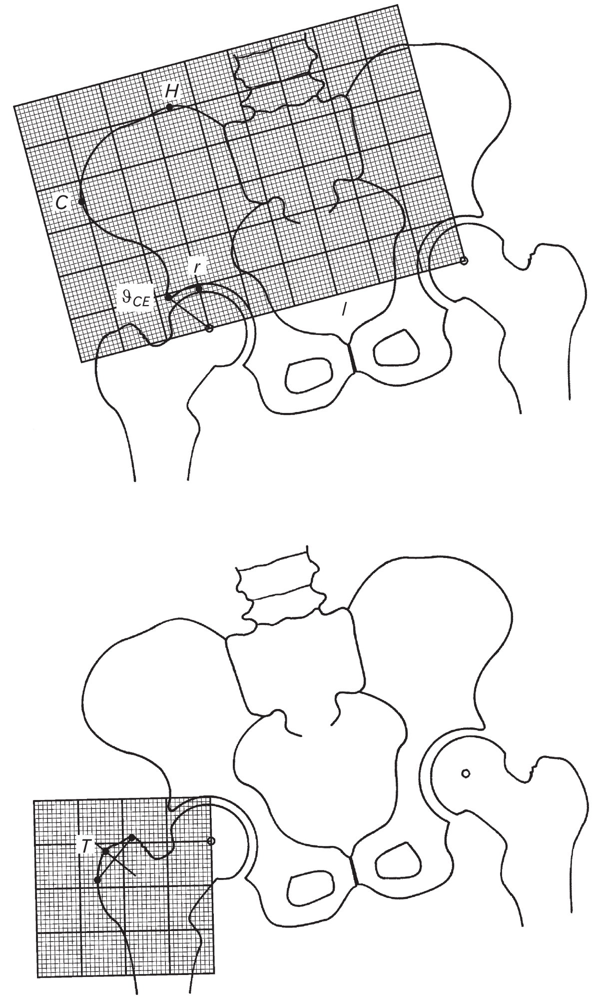

FIGURE 1. The Wiberg center-edge angle ϑ_{CE}, the interhip distance l, the pelvic width C, the pelvic height H and the radius of the femoral head r were measured according to the referential horizontal line through the centers of the femoral heads. The insertion point of abductors on the greater trochanter T was defined as the intersection of the trochanteric bony contour with the symmetral to the line connecting its most superior and most lateral points. Its coordinates were measured in a coordinate system parallel to the longitudinal axis of the femur.

Computation of Biomechanical Parameters

Computation of the resultant hip force and the peak contact hip stress was based on the HIPSTRESS mathematical model.[4–6] The input parameters of the model include the above mentioned seven pelvic radiographic parameters (ϑ_{CE}, l, C, H, T_x, T_z, r). The model can be used to estimate the resultant hip force and the contact stress distribution in the hip joint in static one-legged stance from an anteroposterior pelvic radiograph. Three-dimensional reference coordinates of the muscle attachment points were taken from the case study of a single cadaver,[14] and they were adjusted by linear scaling with regard to specific pelvic radiographic parameters of each individual hip. The solution of the vector equations for the equilibria of forces and torques yielded the three components of the resultant hip force and the tensions in the abductor muscles.[4] From known values of the femoral head radius r, the Wiberg center-edge angle ϑ_{CE} and the magnitude/inclination of the resultant hip force R, the peak contact hip stress was computed for every individual hip.[5] 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) to assess the repeatability of the measurements without the confounding influence of the body weight.

Statistical Analysis

Repeatability of pelvic radiographic measurements and the biomechanical parameters computed were quantified with the intraclass correlation coefficient (ICC). This coefficient is based on the estimation of variance components in analysis of variance. ICC quantifies the proportion of overall variance of ratings due to between-group variation and within-group variation. ICC values close to 1 (ICC >0.75) indicate satisfactory repeatability.[15] In the presented repeatability analysis the class/group was defined as series of measurements of a given parameter in a single hip from three different radiographs. The differences between the three measurements of a parameter in a single hip were regarded as within-group variation, and the differences between the 18 hips were regarded as between-group variation.

RESULTS

Mean, standard deviation and range of the measured parameters in all 54 radiographs was 23°±7° (6°–37°) for the Wiberg center-edge angle ϑ_{CE}, 211±10 mm (192–234 mm) for the interhip distance l, 48±9 mm (31–65 mm) for the pelvic width C, 154±9 mm (127–167 mm) for the pelvic height H, 10±7 mm (−10 mm–21 mm) for the vertical trochanter coordinate T_X, 57±8 mm (32–71 mm) for the horizontal trochanter coordinate T_Z and 27±2 mm (24–30 mm) for the femoral head radius r. Mean standard deviation and range of the computed biomechanical parameters were 3.0±0.4 (2.4–4.7) for the magnitude of the resultant hip force normalized to the body weight R/W_B and 4.0±1.5 kPa/N (2.0–7.6 kPa/N) for the peak contact hip stress normalized to the body weight p_{max}/W_B. The corresponding intraclass correlation coefficients are shown in Table 1.

DISCUSSION

Our analysis shows that measurement repeatability of pelvic radiographic parameters using the HIPSTRESS method is high for the Wiberg center edge angle ϑ_{CE}, pelvic width C, the horizontal trochanteric coordinate T_z, intermediate for interhip distance l and low for vertical trochanteric coordinate T_x, pelvic height H and femoral head radius r. High repeatability of ϑ_{CE} can be attributed to the fact that angles do not change with different radiographic magnifications while distances can change significantly. Determination of the center or femoral head by superimposition of successive radiographs of a given patient also has improved the repeatability of the ϑ_{CE} angle measurements. Although such a procedure cannot be employed within a single radiograph, it can be useful in serial radiographic analyses and follow-up of individual patients. Cadaver studies have shown significant effects of rotation and inclination on the ϑ_{CE} angle and emphasized the need for standardization of patient positioning when taking pelvic radiographs.[11] High repeatability of the ϑ_{CE} angle in this study, therefore, also reflects the quality of radiographic positioning at our institution and not the quality of the measurement method alone. Similarly, low repeatability of H may be explained by difficult control over variability of pelvic tilt in the sagittal plane at patient positioning.[11] Symmetrical positioning of the patient in the frontal plane (left-right symmetry) is easier to achieve, and this is reflected in high repeatability of C. In the determination of the insertion point of the abductors on the greater trochanter[4–6] any displacement along the steep superolateral trochanteric bony contour causes considerably larger change of the vertical coordinate in comparison with the horizontal coordinate and, therefore, predisposes the vertical coordinate to larger measurement error. Our results are consistent with this assertion because they show high repeatability of the horizontal trochanteric coordinate T_z and low repeatability of the vertical trochanteric coordinate T_x. High repeatability of the computed normalized peak contact hip stress p_{max}/W_B can be attributed to high repeatability of ϑ_{CE} and R/W_B. Although p_{max}/W_B is proportional to the inverse square of the femoral head radius $(1/r^2)$,[5] and the femoral head radius was shown to have lower repeatability, this did not considerably influence the repeatability of p_{max}/W_B because of the small standard deviation of r values in the studied population.

In our paper we have only assessed variability of the HIPSTRESS method due to positioning of the patients on different radiographs while all the radiographs were measured once by one observer. Other authors have found that intraobserver-interobserver variability is in fact a larger source of measurement error in pelvic radiographs. A study on a population of dysplastic adult hips with mean and range of the measured ϑ_{CE} angles similar to our population found the intraobserver ICC values for ϑ_{CE} 0.88–0.92 and the interobserver ICC values for ϑ_{CE} 0.85–0.88.[12] It has been found that repeatability of radiographic hip measurements is lower before skeletal maturity, but results can be improved if the radiographs are analyzed in series.[16,17] The variability of the parameters in our paper, therefore, describes only a minor part of the total measurement variability that would include different observers measuring parameters from several radiographs of the same patient on different occasions.

We conclude that biomechanical computations based on pelvic radiographic measurements show sufficient repeatability to be used for serial analyses of anteroposterior radiographs and follow-up of individual patients. The computed resultant hip force and peak contact hip stress are not

TABLE 1. Intraclass correlation coefficients with 95% confidence intervals for seven measured pelvic radiographic parameters (l, T_Z, T_X, H, C, r, ϑ_{CE}) and two computed biomechanical parameters (R/W_B, p_{max}/W_B)

Parameter	Intraclass correlation coefficient	95% confidence interval
Wiberg center-edge angle (ϑ_{CE})	0.96	0.92–0.99
interhip distance (l)	0.81	0.64–0.92
pelvic width (C)	0.89	0.78–0.95
pelvic height (H)	0.76	0.56–0.89
vertical trochanteric coordinate (T_X)	0.76	0.56–0.89
horizontal trochanteric coordinate(T_Z)	0.86	0.73–0.97
femoral head radius (r)	0.76	0.55–0.89
resultant hip force magnitude (R/W_B)	0.88	0.76–0.95
peak contact hip stress (p_{max}/W_B)	0.94	0.87–0.97

considerably affected by variations in patient positioning and radiographic magnification if standardized procedures of pelvic positioning are properly applied and the repeatability of biomechanical parameters is comparable to the repeatability of ϑ_{CE} angle that has been regarded as a reliable parameter for assessment of hip dysplasia.[12,18]

REFERENCES

1. Delaunay S, Dussault RG, Kaplan PA, *et al*. Radiographic measurements of dysplastic adult hips. *Skeletal Radiol*. 1997; 26:75–81.
2. Brinckmann P, Frobin W, Hierholzer E. Stress on the articular surface of the hip joint in healthy adults and persons with idiopathic osteoarthrosis of the hip joint. *J Biomech*. 1981; 14:149–156.
3. Brand RA, Iglič A, Kralj-Iglič V. Contact stress in the human hip, implications for disease and treatment. *Hip Int*. 2001; 11:117–126.
4. Iglič A, Srakar F, Antolič V. Influence of the pelvic shape on the biomechanical status of the hip. *Clin Biomech*. 1993; 8:223–224.
5. Ipavec M, Brand RA, Pedersen DR, *et al*. Mathematical modelling of stress in the hip during gait. *J Biomech*. 1999; 32:1229–1235.
6. Mavčič B, Pompe B, Antolič V, *et al*. Mathematical estimation of stress distribution in normal and dysplastic human hips. *J Orthop Res*. 2002; 20:1025–1030.
7. Mavčič B, Slivnik T, Antolič V, *et al*. High contact hip stress is related to the development of hip pathology with increasing age. *Clin Biomech*. 2004; 19:939–943.
8. Herman S, Jaklič A, Herman S, *et al*. Hip stress reduction after Chiari osteotomy. *Med Biol Eng Comput*. 2002; 40:369–375.
9. Dolinar D, Antolič V, Herman S, *et al*. Influence of contact hip stress on the outcome of surgical treatment of hips affected by avascular necrosis. *Arch Orthop Trauma Surg*. 2003; 123:509–513.
10. Conn KS, Clarke MT, Hallett JP. A simple guide to determine the magnification of radiographs and to improve the accuracy of preoperative templating. *J Bone Joint Surg*. 2002; 84(B):269–272.
11. Jacobsen S, Sonne-Holm S, Lund B, *et al*. Pelvic orientation and assessment of hip dysplasia in adults. *Acta Orthop Scand*. 2004; 75:721–729.
12. Nelitz M, Guenther KP, Gunkel S, *et al*. Reliability of radiological measurements in the assessment of hip dysplasia in adults. *Br J Radiol*. 1999; 72:331–334.
13. Pedersen DR, Lamb CA, Dolan LA, *et al*. Radiographic measurements in developmental dysplasia of the hip: reliability and validity of a digitizing program. *J Pediatr Orthop*. 2004; 24:156–160.
14. Dostal WF, Andrews JG. A three-dimensional biomechanical model of hip musculature. *J Biomech*. 1981; 14:803–812.
15. Fleiss JL. Statistical methods for rates and proportions. 2nd edn. New York: Wiley and Sons; 1981.
16. Broughton NS, Brougham DI, Cole WG, *et al*. Reliability of radiological measurements in the assessment of the child's hip. *J Bone Joint Surg*. 1989; 71(B):6–8.
17. Boniforti FG, Fujii G, Angliss RD, *et al*. The reliability of measurements of pelvic radiographs in infants. *J Bone Joint Surg*. 1997; 79(B):570–575.
18. Omeroglu H, Bicimoglu A, Agus H, *et al*. Measurement of center-edge angle in developmental dysplasia of the hip: a comparison of two methods in patients under 20 years of age. *Skeletal Radiol*. 2002; 31:25–29.