Genij Ortopedii. 2022. Vol. 28, no. 5. P. 698-703.

Original article

https://doi.org/10.18019/1028-4427-2022-28-5-698-703

Determining congruence of the standard hemispherical acetabular component and post-traumatic acetabulum in primary total hip arthroplasty (experimental study)

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Abstract

Introduction An original ASPID classification was developed for primary total hip arthroplasty in the presence of post-traumatic acetabular deformity at the Vreden National Medical Research Centre for Traumatology and Orthopaedics. We aimed to explore how the extent of displacement and localization of acetabular deformity as classified by the original ASPID grading system can affect the coverage area of the acetabular component. **The purpose** of the study was to determine the congruence of the standard hemispherical acetabular component and the post-traumatic acetabular deformity in the experiment. **Material and methods** Computer 3D models of 92 post-traumatic acetabulums were formed, followed by simulated implantation of a standard hemisphere of the appropriate size in compliance with permissible values of the spatial orientation of the acetabular cup in total hip replacement. The congruence of the deformed acetabulum and the standard hemisphere of the corresponding size was determined with simulated implantation. Formula for the acetabular deformity was determined for each case using the original classification. With formula identified for each acetabular deformity and the magnitude of congruence, the data were compared to determine the relationship between congruence, bone displacement and the extent of bone displacement. **Results** The mean congruence value in the group was 59.5 ± 16.83 %. The sum of the scores A+S+P+I+D was compared with the percentage of congruence. The statistical analysis showed that the congruence of the hemispherical acetabular component and the post-traumatic acetabulum was less than 70% with a sum of parameters greater than four. The continuation of the study will allow for a more global analysis and identification of more patterns to improve surgical approaches to primary total hip arthroplasty in specific cases. **Conclusion** Screws can be recommended for reliable primary mechanical fixation of the pelvic component in target patients, and cavitary bone defects can be repaired with autobone chips to allow greater congruence at the bone-implant interface.

Keywords: ASPID, congruence, acetabulum, deformity

For citation: Tsybin A.V., Lyubchak V.V., Falkovich A.S., Bilyk S.S., Shilnikov V.A. Determining congruence of the standard hemispherical acetabular component and post-traumatic acetabulum in primary total hip arthroplasty (experimental study). *Genij Ortopedii*, 2022, vol. 28, no. 5, pp. 698-703. DOI: 10.18019/1028-4427-2022-28-5-698-703.

INTRODUCTION

Acetabular fractures are severe intra-articular injuries that usually occur in young patients following high-energy injuries and in older individuals following low-energy trauma in the presence of osteoporosis [1]. Surgical treatment using open reduction and internal fixation is recommended for displaced acetabular fractures to ensure congruence of the articular surfaces and regain joint function reducing the likelihood of complications at a long term [2]. However, post-traumatic coxarthrosis grade III stage and avascular necrosis of the femoral head can develop over time [3].

Relatively low survival rate and more frequent complications were reported by many authors after total hip arthroplasty (THA) in post-traumatic acetabular deformities. Z. Morison et al. [4] reported that the 10-year survivorship after THA was lower in patients with a previous acetabular fracture than in the matched cohort. P. von Rot et al. [5] reported fair implant survivorship of THA performed for posttraumatic arthritis after an acetabular fracture. A persisting trend of lower survival rate of THA in patients with post-traumatic deformities compared to other pathological conditions that necessitate THA can be observed in Russian and foreign publications. There is a paucity of information on the factors affecting the results of arthroplasty in patients with post-traumatic coxarthrosis and deformities of the acetabular walls [6]. One of the main factors may be the lack of a generally recognized system for assessing post-traumatic deformities of the acetabular walls and an algorithm for choosing a surgical approach in primary THA. Various classifications are used worldwide to describe pelvic bone defects with specific characteristics and purpose [7].

The purpose of a classification is to accurately describe the location and degree of displacement of the supporting structures prior to intervention facilitating adequate treatment and preoperative planning. The classifications are aimed at a uniform universal description of each specific case in order to create a large-scale database for exploring the deformity structure, analyzing surgical outcomes and developing clinical recommendations [8].

The classifications that are commonly used worldwide to describe injuries of the acetabulum include AO/ASIF [9] and J.W. Young & A.R. Burgess [10] for acute pelvic injury, W.G. Paprosky [11], DGOT [12] and AAOS [13] for revision arthroplasty. The grading systems used to classify acetabular bone defects fail to provide accurate description of deformities and the use can be inadequate in such cases [14]. The majority of classifications are normally based on preoperative radiographs supplemented with intraoperative findings. Computed tomography can be added with 3D models that is generated by CT scanners. The current use of the above imaging techniques can be problematic. Radiographs represent a two-dimensional image and the exact location and extent of the defect are difficult to establish. The 3D CT imaging has a large number of focuses in presence of metal constructs and fails to give a clear idea of the bone condition.

The choice of surgical strategy, implants, and additional intraoperative options is limited to standard designs and instrumentation sets, and the manufacture of individual acetabular components requires special equipment, software and can only be performed in large federal centers. An accurate preoperative classification of post-traumatic deformities of the acetabular walls would help the surgeon to make the best choice from the available list of implants or transfer the patient to a higher-level facility in the unavailability.

An original ASPID classification was developed for primary total hip arthroplasty in the presence of post-traumatic acetabular deformity at the National Vreden Medical Research Centre for Traumatology and Orthopaedics (NVMRC TO) [15]. It allows description of the localization and degree of displacement of the acetabular walls, and the alphanumeric code facilitates collection and systematization of the findings for further analysis. An undercovered area is known to be one of the most important factors for stable fixation of the acetabular component. Yu.G. Konoplev et al. [16] reported about 30 % as the critical value for undercovered acetabular component, that is in line with the data of other authors [17], with the minimum cup coverage required to be at least 70 % of the surface area [18]. We aimed to explore how the extent of displacement and localization of acetabular deformity as classified by the original ASPID grading system can affect the coverage area of the acetabular component. The purpose of the study was to determine the congruence of the standard hemispherical acetabular component and the post-traumatic acetabular deformity in the experiment.

MATERIAL AND METHODS

The experimental study included computed tomography (CT) exams of 92 patients who were admitted to the hospital of the NVMRC TO for grade III post-traumatic coxarthrosis treated with primary THA between 06.11.2013 and 06.06.2017. There were 31 female (34 %) and 61 male (66 %) patients. The average age of patients at the time of primary THA was 48 years and 7 months (± 3 years and 6 months). All patients had an acetabular fracture in the history that was repaired with open reduction, plating and screws in 15 (16.3 %) patients. Patients were recruited in the study using two inclusion criteria: an acetabular fracture in the history and available CT scan prior to primary THA. A CT exam was performed for each patient to explore the formula of acetabular deformity using the original ASPID grading system of post-traumatic acetabular deformities [15].

Multiplanar reconstructions were performed in three mutually perpendicular planes with additional control of the initial pelvic position using 3D reconstructions to determine the deformity formula with CT measurements of displacement on axial sections. Acetabular displacement was measured between two parallel planes (lines) passing tangentially to the most distant points of the defects resulting from bone displacement. Computer 3D models of 92 post-traumatic acetabulums were formed, followed by simulated implantation of a standard hemisphere of the appropriate size in compliance with permissible values of the spatial orientation of the acetabular cup in THA [19]. The congruence of the deformed acetabulum and the standard hemisphere of the corresponding size was determined with simulated implantation using special software tools, and the contact area of the altered acetabulum and standard fixation of press-fit acetabular component measured in percent. The data entered in a table included patient's full name, age, acetabular deformity formula, displacement of each wall scored 0 to 2 (the cell was not filled in absent wall deformity), presence and localization of metal construct, congruence in percentage and other parameters for subsequent analysis of long-term outcomes of THA. Materialize Mimics Research v21.0 and Materialize 3-matic Research v. 13.0 image processing software were used to simulate acetabular models and implantation of the acetabular component. An image created from the CT scan of a patient is shown in Figures 1 and 2.

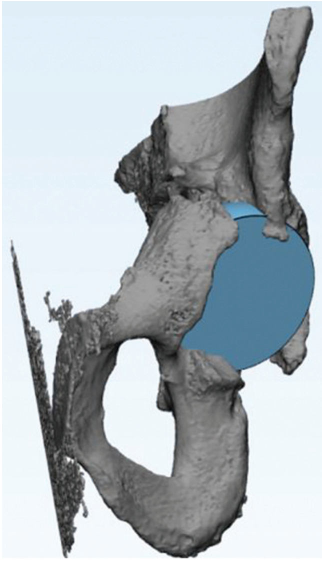

Fig. 1 3D pelvic image created from the CT scan with an implanted acetabular component

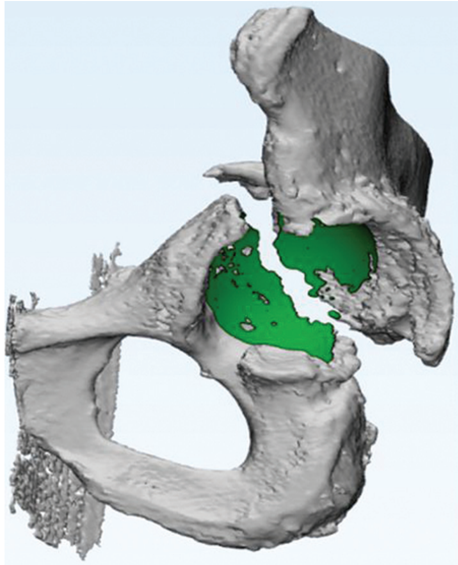

Fig. 2 Determination of the contact area of the standard acetabular component and the acetabulum (marked in green)

With the deformity formula and the magnitude of congruence determined for each case, the tabulated data were compared to identify the relationship between congruence, bone displacement and the extent of bone displacement. Statistical analysis of the data was performed [20, 21]. The data presented were recoded so that additive statistical models could be applied. Columns A, S, P, I, D included values scored 0, 1, 2 and were increased by one with spaces replaced by zeros. The extent of displacement were coded as 1 with displacement measuring less than 5 mm, as 2 with displacement measuring 6-15 mm and as 3 with displacement measuring more than 15 mm. Measurements of pelvic stability in column D scored 0 with intact pelvic integrity and 2 with impaired pelvic integrity. The sum of the scores A+S+P+I+D was compared with the percentage of congruence. The Mann-Whitney rank test (U-test, Wilcoxon-Mann-Whitney test) was used for statistical analysis to test the hypothesis about the difference between the two samples. Patients were ranked in ascending percentage of congruence and a serial number ("rank") was assigned to each. Then the patients were divided into two groups: those with congruence less than 70 % (n = 62) and congruence equal to or greater than 70 % (n = 30). The sums of ranks were calculated in each group R_1, R_2 and *U*-statistics U_1 and U_2 using the formulas:

$$U_1 = n_1 \cdot n_2 + \frac{n_1(n_1+1)}{2} - R_1,$$

$$U_2 = n_1 \cdot n_2 + \frac{n_2(n_2+1)}{2} - R_2,$$

where n_1 and n_2 were numbers of patients in the groups.

Table 1

Mann-Whitney calculations in groups with congruence greater than and less than 70 %

Grouping of patients by congruence	Number of patients n_1, n_2	Sum of ranks R_1, R_2	Statistics U_1, U_2
< 70	62	3164	649
> 70	30	1114	1211

The least of the two numbers $U_e = \min(U_1, U_2)$ was chosen as the Mann-Whitney U-statistic. With the value of the Mann-Whitney statistic U_e less than the tabular value, the null hypothesis about the absence of differences between the two samples was rejected and the alternative hypothesis accepted, and the difference between the two samples was considered statistically significant. The tables of threshold (criteria) Mann-Whitney values did not provide values for n greater than 60. It was recommended to calculate these values taking into account the fact that for n_1, n_2 > 20 the criterion conformed with a normal distribution with the mathematical expectation *M(U)* and variance *D(U)*:

$$D(U) = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}; \quad M(U) = \frac{n_1 n_2 - 1}{2}.$$

The algorithm for calculating the threshold value of the Mann-Whitney criterion was as follows. A confidence level of 0.05 or 0.01 was chosen. Using normal distribution tables, we calculated the value of the normal distribution function for the selected confidence level with the mean being equal to zero and the standard deviation being equal to one.

Since for a standardized normal distribution

$$-|\widetilde{U}| = \frac{U - M(U)}{\sqrt{D(U)}} = \frac{U - \frac{n_1 n_2 - 1}{2}}{\sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}}$$

threshold values U were calculated by the formula:

$$U = -|\widetilde{U}| \cdot \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} + \frac{n_1 n_2 - 1}{2}.$$

The minus sign and the modulus were included in the formula because values were given as positive in some tables and as negative in other tables including EXCEL.

The value of the Mann-Whitney statistic U_e, = 649 was less than the tabulated value not only for the 0.05 significance level, but even for the 0.01 significance level. Therefore, the difference in the sums of parameters A, S, P, I, D for groups of patients with congruence less than 70 % and more than 70 % was statistically significant with a high level of significance.

Table 2

Calculation of threshold values for the Mann-Whitney test for sample sizes > 60

Significance level	Normal distribution function	Threshold values for $n_1 = 62$, $n_2 = 30$
0.05	1.6448	732
0.01	2.3263	650

RESULTS

The congruence or contact area of the traumatically deformed acetabulum and the standard hemisphere positioned at acceptable safe angles of inclination and horizontal deviation was measured in the 92 cases. The average congruence in the group was 59.5 ± 16.9 % (range, 18 to 90.4 %). The 92 cases were divided into three groups according to congruence measuring 30.1 % (n = 18) in group I, 60.0 % (n = 30.3) in group II and 90.4 % (n = 62) in group III. The grouping was based on the results of studies featuring a fundamentally significant area of undercovered acetabular component of 30 % [16]. Three cases were identified in group I including two cases diagnosed with impaired pelvic integrity (Table 3). The extent of displacement measured with the ASPID grading system graded 0 with displacement measuring 0-5 mm, graded 1 with displacement measuring 6-15 mm and graded 2 with displacement measuring greater than 15 mm (displacement or absence of a bone fragment).

Table 3

Displacement of the acetabular walls in group 1 with the congruence of 18–30.1 %

Extent of displacement	Acetabular walls			
	A	S	P	I
0				1
1	1	1	1	
2		2	1	1

Three cases were identified in group I as AS2PI0D1, AS2P1I2D1 and A1S1P2ID with a grade 2 displacement of the superior acetabular wall and an impaired pelvic integrity diagnosed in two cases. The average contact area was 24.4 ± 16.0 % in group I. There were 45 cases identified in group II with two diagnosed with an impaired pelvic integrity. ORIF was performed for seven cases prior to THA. Table 4 indicates to prevailing grade 1 (6–15 mm) displacement of the anterior, superior and posterior acetabular walls in the group.

Table 4

Displacement of the acetabular walls in group II with the congruence of 30.3–60.0 %

Extent of displacement	Acetabular walls			
	A	S	P	I
0	6	6	5	6
1	11	25	14	5
2	1	8	7	3

The contact acetabulum-hemisphere area (congruence) ranged from 50 % to 60 % (average 55 %) in 22 cases (49 %). The average contact area measured 47.5 ± 16.5 % in group II. There were 44 cases identified in group III with three patients diagnosed with impaired pelvic integrity. ORIF was performed for eight cases prior to THA. Table 5 indicates to prevailing grades 0 and 2 (6–15 mm) displacements of the superior wall and grade 1 displacement of the posterior wall in group III. The average contact area in the group was 73.96 ± 16.84 %.

Table 5

Displacement of the acetabular walls in group III with the congruence of 60.1–90.4 %

Extent of displacement	Acetabular walls			
	A	S	P	I
0	5	15	6	7
1	6	16	12	8
2	3	1	5	4

The statistical analysis revealed with high reliability that the congruence of the hemispherical acetabular component and the post-traumatically deformed acetabulum was less than 70 % with a sum of parameters greater than four.

DISCUSSION

Placement of the acetabular component is challenging in primary and revision THA of patients with acetabular bone loss and post-traumatic acetabular deformities. Classifications of retroacetabular osteolysis are essential to formulate surgical strategy algorithms for revision procedures, and current imaging modalities provide an accurate bone assessment for the placement of endoprosthetic components. The grading systems are practical for arranging primary data collection to explore the pathology structure and the results of surgical interventions aimed at improvement of joint replacement surgery and survival of joint replacements. Despite modern advances, there is no unified system for a reliable pre-operative grading of post-traumatic acetabulum, and results of arthroplasty in patients with post-traumatic coxarthrosis are not involved in a structured generalized process. Publications on the results of arthroplasty in the specific cohort of patients are fragmented and unrelated with little informative characteristics of the clinical material.

An original classification developed at NVMRC TO for post-traumatic acetabular deformity is based on three criteria including localization of the deformity, extent of displacement and configuration of the pelvic ring) and can provide an accurate description of a case through alphanumeric formula (alphanumeric code), data analysis and the pathology structure filling in large series of parameters. Despite the relatively small sample the experiment and data analysis performed with high reliability allowed for identification of several patterns in the congruence of the standard hemispherical acetabular component and the post-traumatic acetabulum. Continuation of the study and novel research findings processed statistically would allow for a more comprehensive analysis and identification of additional patterns that would be practical for surgeons in understanding the structure of post-traumatic acetabular deformity to improve surgical approaches in primary THA in the specific cohort of patients.

CONCLUSION

Screws can be recommended for reliable primary mechanical fixation of the pelvic component with the mean contact area of the standard hemispherical “press-fit” fixation and the post-traumatic acetabulum of 59.5 % being less than 70 % and cavitary bone defects can be repaired with autologous chips to improve congruence at the bone-implant interface. With the sum of parameters A, S, P, I and D being greater than four measured with ASPID grading system of post-traumatic acetabular deformities, the congruence of the standard hemispherical acetabular “press-fit” fixation component and the post-traumatic acetabulum is less than 70 %, and two units are added for impaired pelvic integrity (zero for D without an index and two points for D_1).

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The article was submitted 22.06.2022; approved after reviewing 07.07.2022; accepted for publication 30.08.2022.

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