■ TRAUMA

Can CT-based gap and step-off displacement predict outcome after nonoperative treatment of acetabular fractures?

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Aims

The aim of this study was to investigate the association between fracture displacement and survivorship of the native hip joint without conversion to a total hip arthroplasty (THA), and to determine predictors for conversion to THA in patients treated nonoperatively for acetabular fractures.

Methods

A multicentre cross-sectional study was performed in 170 patients who were treated nonoperatively for an acetabular fracture in three level 1 trauma centres. Using the post-injury diagnostic CT scan, the maximum gap and step-off values in the weightbearing dome were digitally measured by two trauma surgeons. Native hip survival was reported using Kaplan-Meier curves. Predictors for conversion to THA were determined using Cox regression analysis.

Results

Of 170 patients, 22 (13%) subsequently received a THA. Native hip survival in patients with a step-off ≤ 2 mm, > 2 to 4 mm, or > 4 mm differed at five-year follow-up (respectively: 94% vs 70% vs 74%). Native hip survival in patients with a gap ≤ 2 mm, > 2 to 4 mm, or > 4 mm differed at five-year follow-up (respectively: 100% vs 84% vs 78%). Step-off displacement > 2 mm (> 2 to 4 mm hazard ratio (HR) 4.9, > 4 mm HR 5.6) and age > 60 years (HR 2.9) were independent predictors for conversion to THA at follow-up.

Conclusion

Patients with minimally displaced acetabular fractures who opt for nonoperative fracture treatment may be informed that fracture displacement (e.g. gap and step-off) up to 2 mm, as measured on CT images, results in limited risk on conversion to THA. Step-off ≥ 2 mm and age > 60 years are predictors for conversion to THA and can be helpful in the shared decision-making process.

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Introduction

Minimally displaced acetabular fractures can be treated nonoperatively, consisting of non-weightbearing mobilization gradually increased to full weightbearing in two to three months.[1] Gap and step-off measurements, both representing fracture displacement, are used for clinical decision-making regarding whether to proceed with nonoperative treatment, as well as to estimate risks on requiring subsequent total hip arthroplasty (THA), but robust data are lacking. The AO manual states that fractures with < 2 mm displacement may be appropriate for nonoperative treatment.[1] However, it was not specified whether the degree of displacement applies to gaps and/or step-offs, or which image modality should be used. In a previous study on nonoperative treatment, a step-off displacement of ≥ 2 mm on pelvic radiographs was considered a predictor of a poor clinical outcome and conversion to THA.[2]

In acetabular fracture treatment, much literature is focused on clinical outcome after osteosynthesis.[3-7] The only study available on the correlation between initial fracture displacement (e.g. gaps and step-offs) and risks of conversion to THA, as well as clinical outcome at long-term follow-up

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Table I. Patient and fracture characteristics and hip survival.

Variable	Included patients total (n = 170)	THA (n = 22)	Native hip (n = 148)
Male, n (%)	144 (85)	19 (86)	125 (85)
Median age, yrs (IQR)	61 (50 to 73)	70 (60 to 74)	60 (45 to 73)
ASA grade, n (%)			
I	75 (44)	4 (18)	71 (48)
II	46 (27)	9 (41)	37 (25)
III	46 (27)	9 (41)	37 (25)
IV	3 (2)	0 (0)	3 (2)
Injury mechanism, n (%)			
Fall from standing height	99 (58)	13 (59)	86 (58)
Fall from height	20 (12)	1 (5)	19 (13)
Single-vehicle/motor accident	23 (14)	3 (14)	20 (14)
Two-vehicle/motor accident	13 (8)	0	13 (8)
Motor vehicle/cycle accident	11 (7)	3 (14)	8 (5)
Explosion	1 (1)	0	1 (1)
Compression injury	1 (1)	1 (5)	0
Unknown	2 (1)	1 (5)	1 (1)
Fracture type, n (%)			
Elementary			
Anterior column	46 (27)	3 (14)	43 (29)
Anterior wall	9 (5)	0	9 (6)
Posterior column	8 (5)	1 (5)	7 (5)
Posterior wall	17 (0)	2 (9)	15 (10)
Transverse	13 (8)	2 (9)	11 (7)
Associated			
T-shaped	12 (7)	1 (5)	11 (7)
Transverse with posterior wall	9 (5)	3 (14)	6 (4)
Posterior column with posterior wall	3 (2)	1 (5)	2 (1)
Anterior column with posterior hemi-transverse	28 (17)	6 (27)	22 (15)
Both columns	25 (15)	3 (14)	22 (15)
Median gap displacement, mm (IQR)	4 (2 to 9)	8 (4 to 16)	4 (2 to 8)
Median step-off displacement, mm (IQR)	1 (0 to 4)	4 (3 to 9)	1 (0 to 3)
Dome impaction, n (%)	53 (31)	14 (63)	39 (27)
Posterior wall involvement, n (%)	39 (23)	10 (46)	29 (20)
Posterior wall impaction, n (%)	7 (4)	2 (9)	5 (3)
Posterior luxation, n (%)	9 (5)	1 (5)	8(5)
Pre-existent osteoarthritis (Kellgren-Lawrence), n (%)			
No osteoarthritis	46 (27)	1 (5)	45 (30)
Doubtful osteoarthritis (grade 1)	79 (46)	11 (50)	68 (46)
Mild osteoarthritis (grade 2)	33 (19)	6 (27)	27 (18)
Moderate osteoarthritis (grade 3)	10 (6)	4 (18)	6 (4)
Severe osteoarthritis (grade 4)	1 (1)	0	1 (1)
Unknown	1 (1)	0	1 (1)
Deceased, n (%)	23 (14)	4 (18)	19 (13)
Median time until death, yrs (IQR)	2 (1 to 5)	4 (2 to 7)	2 (1 to 4)

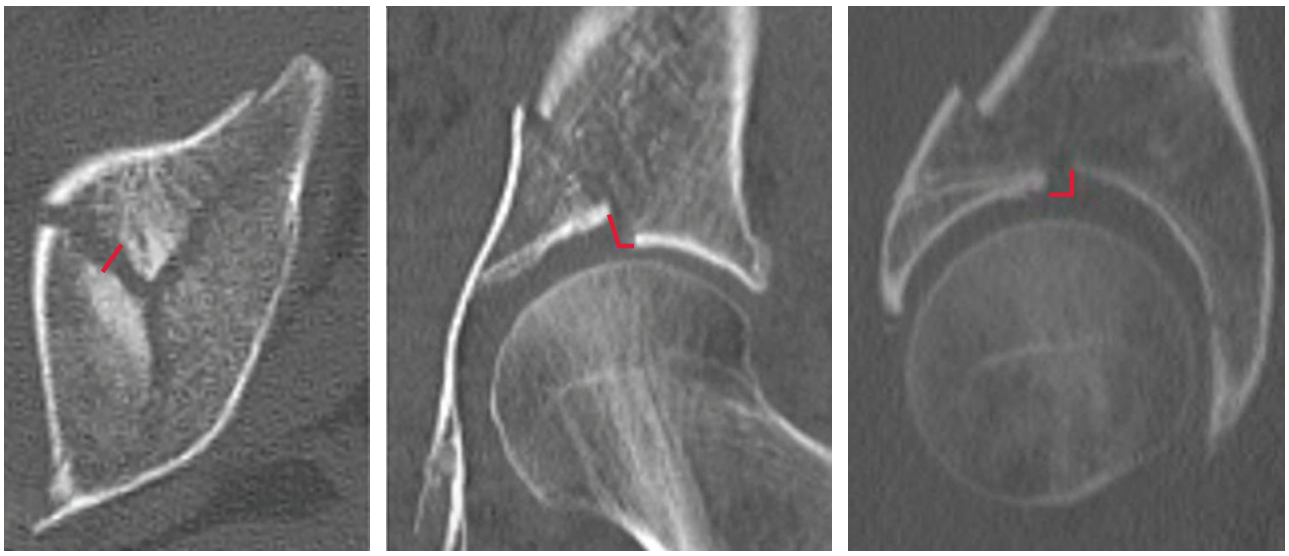
ASA, American Society of Anesthesiologists; IQR, interquartile range; THA, total hip arthroplasty.

after nonoperative treatment of acetabular fractures, used standard radiographs to measure displacement.[2] However, CT is superior to radiographs in detecting fracture displacement.[8] To our best knowledge, this is the first study reporting on the association between CT-measured fracture displacement and hip survival after nonoperative treatment of acetabular fractures.

Therefore, we posed the following research questions: what is the association between fracture displacement and survivorship of the native hip joint (i.e. free from conversion to THA) in patients treated nonoperatively for acetabular fractures?; what are predictors for conversion to THA after nonoperative treatment of acetabular fractures?; and what are the patient-reported physical functioning and quality of life findings at follow-up after nonoperative treatment of acetabular fractures in patients who still have their native hip joint, compared to those who had conversion to THA and normative data from age-matched peers in the general population?

Methods

Study design and setting. A multicentre cross-sectional study was performed including patients from three level 1



a b c

Fig. 1

Measurements of the acetabular fracture displacement of a 68-year-old woman are displayed in the a) axial (gap 4 mm), b) coronal (step-off 4 mm, gap 2 mm), and c) sagittal (step-off 3 mm, gap 3 mm) views.

trauma centres (University Medical Center Groningen, Radboud University Medical Center, and Isala Hospital, Netherlands).

Patients. Eligiblity for the study included adult patients (age ≥ 18 years) with an acute unilateral acetabular fracture without an associated pelvic ring injury, who had been treated nonoperatively from January 2000 until January 2021, with availability of a post-injury diagnostic CT scan and at least one-year follow-up. The exclusion criteria were pathological fractures, Pipkin fractures,[9] patients without contact information, and patients without available follow-up data. During the study period, a total of 250 patients were treated nonoperatively for an acetabular fracture. The Dutch Personal Records Database was checked to verify if all patients were still alive.

Of 250 patients, 23 had no available follow-up data, 20 had no available contact information, 13 refused to sign informed consent, four had an additional Pipkin fracture, and six were excluded for a variety of reasons. After exclusion, 184 out of 250 patients were eligible for follow-up analysis (Supplementary Figure a). All 184 patients were contacted by telephone and asked whether they still had their native hip free from conversion to THA. Overall, 170 out of 184 patients responded (92%) at a median follow-up of 3.0 years (interquartile range (IQR) 1.0 to 6.0). The follow-up was one to five years in 68% (116 of 170), five to ten years in 22% (38 of 170), and ten to 16 years in 9% (16 of 170) of patients. The median age at the time of injury was 61 years (IQR 50 to 73) and 85% (144 of 170) of patients were male (Table I). Patients were subsequently approached by letter to complete two valid patient-reported outcome measure (PROM) questionnaires: the Short Musculoskeletal Function Assessment (SMFA)[10] and the EuroQol five-dimension questionnaire (EQ-5D).[11] A total of 61% (104 of 170 patients) completed the questionnaires after a median follow-up of 3.0 years (IQR 2.0 to 5.8).

CT-based gap and step-off measurements. Pelvic CT scans at the time of injury were assessed by two trauma surgeons (KtD, FFAIJ) who were experienced in pelvic surgery. The axial, sagittal, and coronal plane images were studied and classified according to the Letournel classification.[12] 'Gap' was defined as a separation of fracture fragments along the articular surface. 'Step-off' was characterized as separation of fracture fragments perpendicular to the circumference of the acetabular dome. The size of the greatest intra-articular gap and step-off displacement, detected in any of the three different views, was measured in the weightbearing dome (Figure 1). The measurements were performed according to a standardized method described by Verbeek et al.[13] Measurements were performed with a digital tool (accuracy 0.1 mm) in the Carestream Vue Motion imaging system (Philips, Netherlands) of the patient file. All CT images were automatically calibrated, so it was possible to measure distances in millimetres on the images. Furthermore, the presence of dome impaction, posterior wall involvement, and posterior subluxation, and the presence of pre-existent osteoarthritis (OA) according to the Kellgren-Lawrence classification,[14] were reassessed on the pelvic radiographs and CT scan at the time of injury.

PROMs. Patients were approached by letter to complete two validated PROMs in order to evaluate the physical functioning (SMFA-NL) and health-related quality of life (EQ-5D). The SMFA-NL (Dutch version) consists of the two original indices (Function Index and Bother Index) and four additional subscales (Lower Extremity Dysfunction, Upper Extremity Dysfunction, Problems with Daily Activities, and Mental and Emotional Problems).[10,15] The 46 items are scored from 1 (poor function) to 5 (good function). Scores are calculated by summating the individual items and transforming scores on a range from 0 to 100, with higher scores indicating better function.

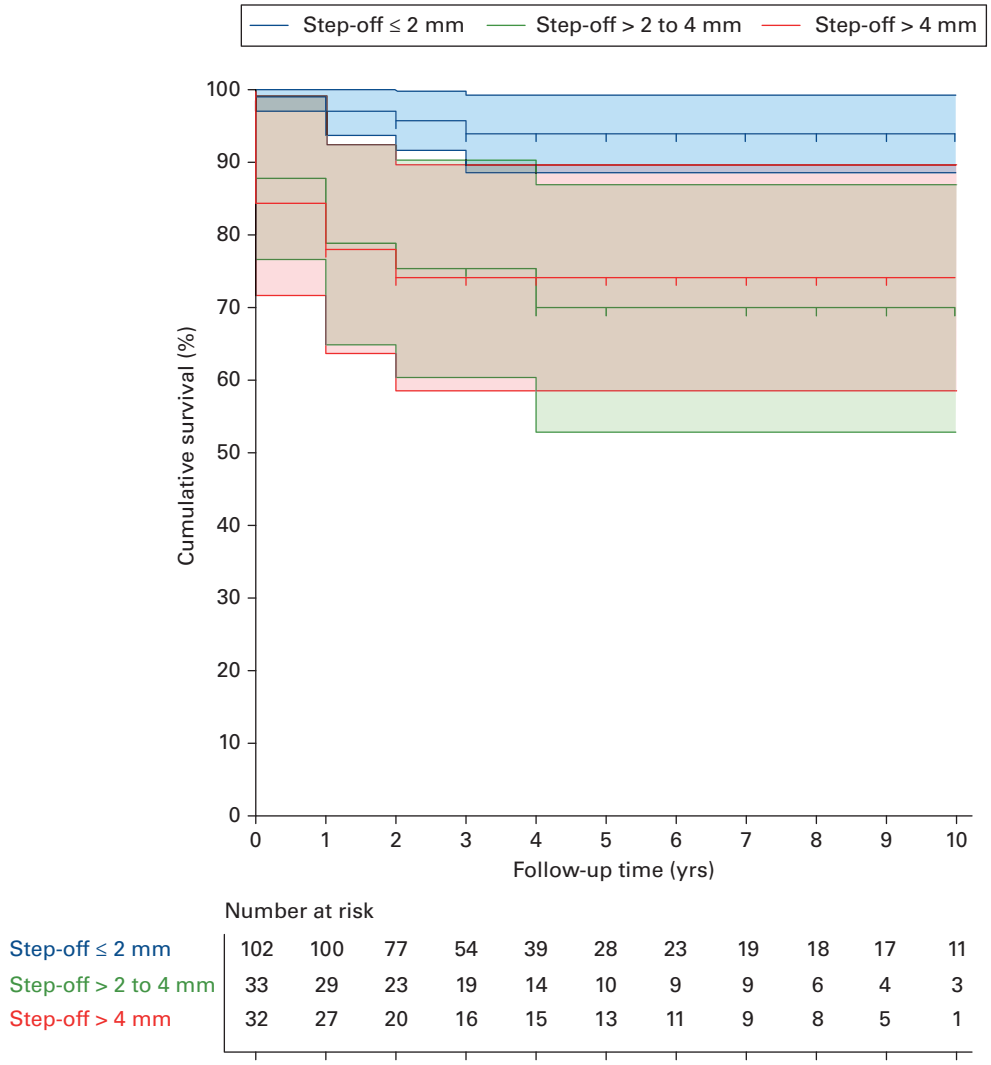


Fig. 2

Native hip survival in years stratified by step-off, including 95% confidence intervals.

The EQ-5D-NL (Dutch version) consists of five health level items (mobility, self-care, daily activities, pain/inconvenience, and fear/depression) and is expressed as a score from -0.329 (worst condition) to 1 (best quality of life).[16] Two trauma centres used the five-level EQ-5D (EQ-5D-5L) and one centre used the three-level EQ-5D (EQ-5D-3L). A non-parametric crosswalk was employed to obtain the likely 5L values.[11,17] The patients' baseline characteristics were retrieved from the medical records.

Primary, secondary, and tertiary study goals. Our primary study goal was to assess the association between fracture displacement and survivorship of the native hip joint, after nonoperative management of acetabular fractures. To achieve this, patients were divided into three groups: patients with a displacement ≤ 2 mm, > 2 to 4 mm, or > 4 mm. Patients were asked whether they had conversion to THA (primary endpoint) at follow-up, and for each group survivorship of the native hip was determined.

Our secondary study goal was to identify predictors for conversion to THA at follow-up. To achieve this, CT scans were reassessed for initial fracture displacement, dome impaction, posterior wall involvement, posterior luxation, and osteoarthritis. A multivariable Cox regression analysis was performed to identify risk factors for conversion to THA.

Third, physical functioning and health-related quality of life were assessed at follow-up after nonoperative treatment of acetabular fractures in patients with or without conversion to THA compared to normative data. To achieve this, we collected validated PROMs (SMFA-NL and EQ-5D-NL questionnaire) at follow-up.

Ethical approval. The local Medical Ethical Review Board of each trauma centre reviewed the methods employed and waived further need for approval.

Demographic details. Overall, 85% (n = 144) of the study population were men, and the median age was 61 years old (IQR 51 to 73). Of 170 patients, 14 patients were aged 18 to

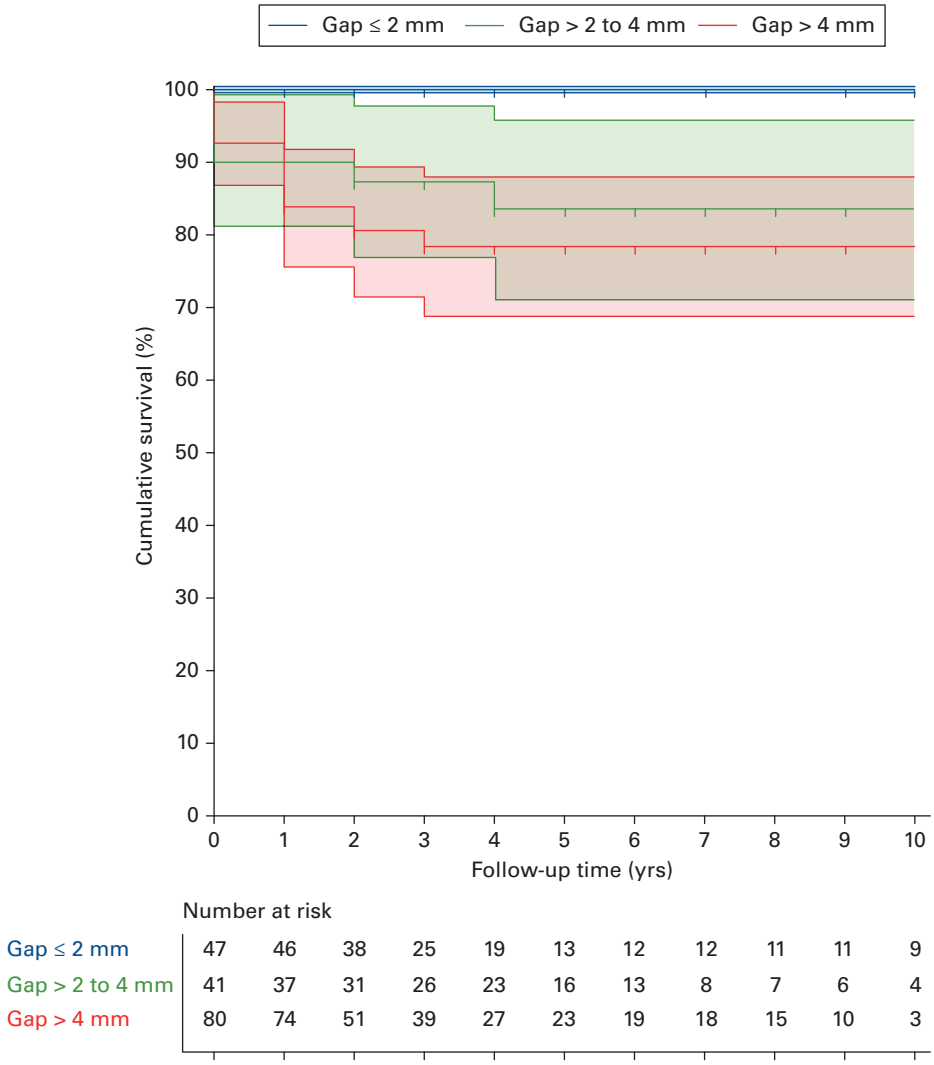


Fig. 3

Native hip survival in years stratified by gap, including 95% confidence intervals.

24 years, 28 patients were aged 25 to 49 years, 91 patients were aged 50 to 74 years, and 37 patients were aged ≥ 75 years. Regarding the American Society of Anesthesiologists (ASA) grade,[18] 75 patients were ASA I (44%), 46 were ASA II (27%), 46 were ASA III (27%), and three were ASA IV (2%). The majority of the patients experienced a fall from standing height (58%). Of all patients, 93 had an elementary fracture type, and 77 patients had an associated fracture type.

Statistical analysis. The data were analyzed using SPSS software, version 23.0 for Windows (IBM, USA). Descriptive statistics were used to describe the study population, using mean and standard deviation (SD) and median and IQR depending on the distribution. Kaplan-Meier curves stratified by gap and step-off displacement were constructed. A log rank test was performed to assess differences in the hip survival distribution for patients with a step-off ≤ 2 mm, > 2 to 4 mm, or > 4 mm. Subsequently, independent predictors for conversion to THA at follow-up were identified using a manual multivariable Cox regression analysis (method: enter). Differences in functional outcome and quality of life (SMFA-NL and EQ-5D-NL) between patients with or without THA were assessed using a Mann-Whitney U test. The SMFA-NL and EQ-5D-NL scores of the study population were compared to the normative data from the general population using Mann-Whitney U test. SMFA-NL normative data were subdivided by age and sex.[19] EQ-5D-NL normative data were subdivided by age.[16]

Analysis of non-responders. The non-response analysis showed that responders were older (median 61 years (IQR 50 to 73) vs 38 years (IQR 21 to 52); p = 0.002, Mann-Whitney U test) and more often men (85% (144/170) vs 43% (6/14); p < 0.001, chi-squared test). No difference existed in gap and step-off between responders and non-responders (median gap 4.2 mm (IQR 2.1 to 8.8) vs 2.0 mm (IQR 0.9 to 6.9); p = 0.056, Mann-Whitney U test) (median step-off 1.0 mm (IQR

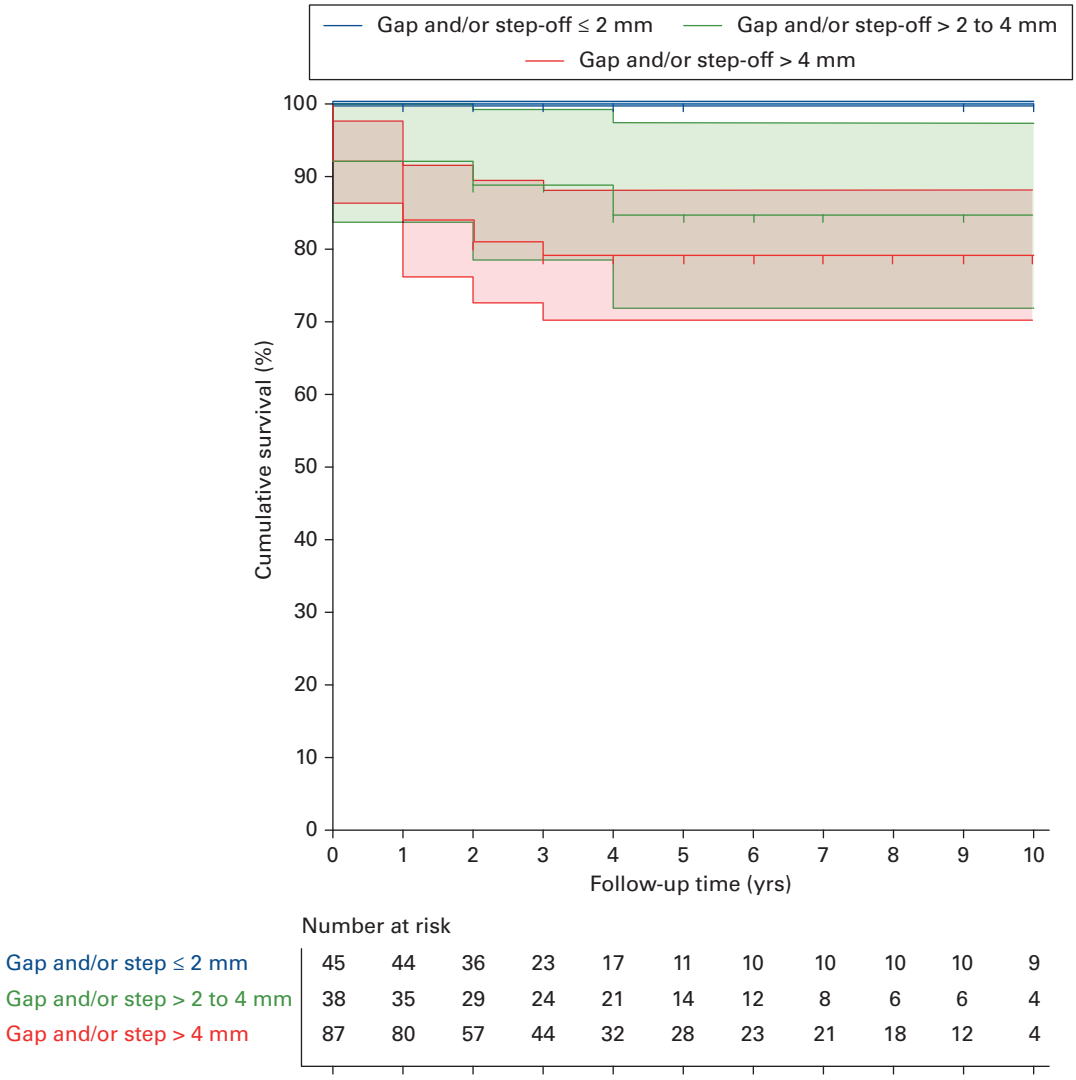


Fig. 4

Native hip survival in years stratified by gap and step combined, including 95% confidence intervals.

0.0 to 3.9) vs 0.0 mm (IQR 0.0 to 5.7); p = 0.841, Mann-Whitney U test).

Results

Hip survivorship. Of the 170 patients, 22 (13%) underwent conversion to a THA after nonoperative treatment of an acetabular fracture (Table I). Native hip survival in patients with a step-off ≤ 2 mm, > 2 to 4 mm, or > 4 mm differed at five-year follow-up (94% vs 70% vs 74%) (Figure 2 and Supplementary Table i). Native hip survival in patients with a gap ≤ 2 mm, > 2 to 4 mm, or > 4 mm differed at five-year follow-up (100% vs 84% vs 78%) (Figure 3 and Supplementary Table i). Native hip survival in patients with a step-off and/or gap ≤ 2 mm, > 2 to 4 mm, or > 4 mm differed at five-year follow-up (100% vs 85% vs 79%) (Figure 4 and Supplementary Table i).

Risk factors for total hip prosthesis. Age (≥ 60 yrs), increased step-off displacement, dome impaction, posterior wall involvement, and pre-existent OA were significant risk factors for conversion to THA in univariate analysis (Table II). A step-off > 2 mm and age of 60 years or older were independent risk factors for conversion to THA in multivariable analysis (Table II).

Physical function and quality of life. No differences were found between patients with a native hip and those with a THA on the indices and subscales of the SMFA or the EQ-5D, except for the subscale 'lower limb' of the SMFA (Table III).

Compared to the peers from the general Dutch population, patients with a THA reported a lower score on the 'function index' and on the subscales 'daily activity score' and 'lower extremity' of the SMFA (Table III). Patients with a native hip reported only differences on the SMFA subscale 'mental/emotional problems', compared to their peers. No differences on the EQ-5D were found between patients with or without THA and the general population.

Table II. Cox regression analysis for risk factors associated with conversion to total hip arthroplasty.

Variable	Univariate analysis		Multivariable analysis	
	HR (95% CI)	p-value	HR (95% CI)	p-value
Patient characteristics				
Age (≥ 60 yrs)	3.1 (1.2 to 8.5)	0.025	2.9 (1.1 to 8.0)	0.039
Sex (male)	0.85 (0.3 to 2.9)	0.787		
Fracture type (associated)	2.1 (0.9 to 5.1)	0.089		
Gap				
≤ 2 mm (n = 47)	NE*			
> 2 to 4 mm (n = 41)	Reference			
> 4 mm (n = 80)	1.4 (0.56 to 3.69)	0.445		
Step-off				
≤ 2 mm (n = 102)	Reference			
> 2 to 4 mm (n = 33)	5.8 (1.9 to 17.3)	0.002	4.9 (1.6 to 14.8)	0.004
> 4 mm (n = 32)	5.5 (1.8 to 16.7)	0.003	5.6 (1.8 to 17.3)	0.002
Dome impaction	3.9 (1.6 to 9.3)	0.002		
Posterior wall involvement	3.0 (1.3 to 6.9)	0.011		
Posterior femoral head luxation	0.96 (0.1 to 7.2)	0.971		
Kellgren-Lawrence grade				
0 (n = 46)	Reference			
1 (n = 79)	6.6 (0.8 to 51.2)	0.071		
2 (n = 33)	9.0 (1.1 to 75.1)	0.042		
3 (n = 10)	20.1 (2.2 to 180.0)	0.007		
4 (n = 1)†				

*NE: not estimable; no events occurred in this subgroup. Therefore, this group could not be used as a reference group.
†Sample size insufficient.
CI, confidence interval; HR, hazard ratio; THA, total hip arthroplasty.

Table III. Patient-reported outcome measure scores subdivided by patients who retained their native hip, versus patients who had conversion to total hip arthroplasty, versus normative data of the corresponding age group from the general population. Values are expressed as medians and interquartile ranges.

Score	Native hip (n = 88)	THA (n = 16)	Normative data	p-value (native hip vs THA)	p-value (native hip vs normative data)	p-value (THA vs normative data)
SMFA						
Function index	89.3 (73.7 to 97.1)	76.5 (48.5 to 92.6)	89.8 (88.1 to 89.8)	0.067	0.983	0.005
Bother index	87.5 (67.7 to 97.9)	79.2 (52.6 to 95.8)	86.1 (86.1 to 86.3)	0.161	0.661	0.084
Daily activity	87.5 (61.9 to 98.8)	71.3 (55.0 to 95.0)	88.4 (87.0 to 88.4)	0.141	0.844	0.044
Mental/emotional problems	84.4 (71.9 to 93.8)	85.9 (68.0 to 93.8)	82.8 (79.4 to 82.8)	0.922	0.024	0.172
Lower extremity	87.5 (91.7 to 100.0)	79.2 (56.3 to 93.8)	89.0 (87.5 to 89.7)	0.049	0.316	0.022
EQ-5D	0.9 (0.7 to 1.0)	1.0 (0.8 to 1.0)	0.9 (0.8 to 0.9)	0.109	0.241	0.059

EQ-5D, EuroQol five-dimension questionnaire; SMFA, Short Musculoskeletal Function Assessment; THA, total hip arthroplasty.

Discussion

We believe that this is the first study reporting the relationship between CT-measured fracture displacement and hip survival after nonoperative treatment of acetabular fractures. The aim of the study was to provide clinicians with prognostic information regarding native hip survival stratified by the degree of initial fracture displacement, risk factors for conversion to THA, and PROMs at follow-up after nonoperative treatment of acetabular fractures. Fracture displacement (e.g. gap and step-off) up to 2 mm, as measured on CT images, resulted in limited risk of conversion to THA. From a clinical perspective, having a gap exceeding 2 mm (e.g. 2 to 4 mm) still has a limited risk of conversion to THA and seems to have less impact on survival of the native hip than having a step-off exceeding 2 mm (e.g. 2 to 4 mm). Step-off > 2 mm and an age of 60 years or more were shown to be independent risk factors for conversion to THA. Physical functioning and quality of life were reasonable in patients with a THA compared to those who retained their native hip, however slightly decreased compared to their peers from the general population. Overall, our findings can be used as a guideline for shared decision-making when considering treatment options based on multiple factors in patients with minimally displaced acetabular fractures.

A limitation of this study is its retrospective design. Due to the long period of follow-up that is needed, it is impractical to conduct this type of research in a prospective way.[20] On the other hand, based on the availability of patients for follow-up analysis from three centres, our study findings seem generalizable, since a response rate of 92% for hip survival analysis was obtained. Another limitation may be that performing a

diagnostic CT scan in minimally displaced acetabular fractures was not standard practice during the early years of the study. As the availability of a good-quality CT scan was an inclusion criterion of our study, this may have led to a limited number of eligible patients with long-term follow-up. However, we do not think that this limitation has affected our results, because most events (e.g. conversions to THA) occurred in the first two to three years of follow-up (Figures 2 to 4). Another limitation may be attributed to the known interobserver agreement for measuring gap (ICC 0.78; 95% CI 0.67 to 0.86) and/or step-off (ICC 0.51; 95% CI 0.35 to 0.90) displacement.[13] Therefore, a standardized CT-based measurement method was used and measurements were performed by surgeons with experience in pelvic surgery until consensus was reached about each measurement.[13] Lastly, the results regarding PROMs should be interpreted with caution, because a limited number of patients (response rate 61%) returned the follow-up questionnaires.

Native hip survival in patients with a step-off ≤ 2 mm, > 2 to 4 mm, or more than 4 mm differed at five-year follow-up (94% vs 70% vs 74%). Native hip survival in patients with a gap ≤ 2 mm, > 2 to 4 mm, or more than 4 mm differed at five-year follow-up (100% vs 84% vs 78%). Few studies reported on hip survival after nonoperative treatment. Only Clarke-Jenssen et al[2] reported 94% overall native hip survival at ten years of follow-up after nonoperative treatment. Studies applying CT-measured initial displacement and the relationship with hip survival after nonoperative treatment are lacking; more literature is available about residual displacement and hip survivorship following acetabular fracture surgery. Residual gap and step displacement, as measured on CT scans, are related to long-term hip survivorship. Verbeek et al[21] found a CT-based critical cut-off value of 5 mm for gap and 1 mm for step-off displacement. In their series of 227 operatively treated patients, hip survivorship at ten years was 82% (95% CI 74.0% to 90.0%) with a residual gap < 5 mm and 80% (95% CI 71.4% to 88.7%) with a step-off < 1 mm. Our study demonstrates that in particular patients with a minimal step-off and gap (≤ 2 mm) yield good native hip survival of 94% for step-off ≤ 2 mm and 100% for gap ≤ 2 mm at five-year follow-up. This suggests that our findings regarding displacement in nonoperative treatment are in line with the limits of residual displacement (adequate reduction) after operative treatment as described by Verbeek et al.[21] Tannest et al[6] reported a cumulative hip survival of 85% at ten years after operative acetabular fracture treatment. Their large series included 810 patients with a mean residual displacement of 0.9 mm (SD 1.9) as measured on pelvic radiographs rather than CT scans as in our study. Moreover, no critical cut-off values for the extent of fracture displacement were defined.[6] Clarke-Jenssen et al[2] reported that acetabular fractures with a step-off of < 2 mm, as measured on pelvic radiographs instead of CT scans as in our study, can safely be treated nonoperatively. Overall, initial displacement as well as residual displacement are both related to long-term hip survivorship.[2,3,6,7,14]

Step-off displacement > 2 mm (> 2 to 4 mm: HR 4.9, > 4 mm: HR 5.6) and age > 60 years (HR 2.9) were independent predictors for conversion to THA at follow-up in our study. The study of Clarke-Jenssen et al[2] is the only study reporting on the predictive value of step-off measurements after nonoperative treatment: they reported a HR of 6.99 (95% CI 2.21 to 22.07) for step-off displacement ≥ 2 mm on the obturator oblique pelvic radiograph. However, results are difficult to compare because radiographs were used, whereas in our study the gap and step-off measurements were CT-based. CT is demonstrably more accurate than radiographs for the evaluation of acetabular fracture displacement.[22] The current study adds to the previous reports by providing CT-based measurements for nonoperative treatment, which is current practice for clinical decision-making. Furthermore, Clarke-Jenssen et al[2] reported on age > 60 years as a risk factor. However, in their study, age > 60 years is not an independent predictor for conversion to THA (HR 1.44 (95% CI 0.45 to 4.63; p = 0.54)), in contrast to our study. More literature is available on the predictive value of residual gap and step-off measurements after operative treatment. Verbeek et al[21] demonstrated that residual gap displacement ≥ 5 mm and step-off displacement ≥ 1 mm were predictors for conversion to THA in univariate analysis. In multivariable analysis, only a gap > 5 mm remained an independent risk factor (HR 2.3; 95% CI 1.2 to 4.4; p = 0.012) for conversion to THA. This is contrary to our study, where step-off was the most predictive factor (> 2 to 4 mm: HR 4.9, > 4 mm: HR 5.6) for conversion to THA instead of gap. Furthermore, Verbeek et al[21] found age > 50 years as a predictor for conversion to THA (HR 4.2; 95% CI 2.0 to 8.6; p < 0.001), which is consistent with our results regarding age.

There is limited literature available using valid PROMs after nonoperatively treated patients. We found some statistically significant differences in physical functioning between patients who received a THA and patients who retained their hip. However, these differences of approximately ten points in score of the lower limb subscale (native hip 87.5 vs THA 79.2) did not exceed the minimally important difference of the SMFA.[23] These differences are therefore considered not clinically relevant. Clarke-Jenssen et al[2] performed the only other study that reported on PROMs after nonoperatively treated acetabular fractures. They found that approximately 90% of the patients had good or excellent long-term outcomes, as measured by the modified Merle D'Aubigné and Postel Score[24] and the Harris Hip Score.[25] In our study, we used different but valid outcome measures, which enabled comparison of our results with normative data from the general population.

In summary, patients with minimally displaced acetabular fractures who opt for nonoperative fracture treatment should be told that fracture displacement (e.g. gap and step-off up to 2 mm), as measured on CT images, has a limited risk of conversion to THA. From a clinical perspective, having a gap exceeding 2 mm (e.g. 2 to 4 mm) still has a limited risk of conversion to THA and seems to have less impact on survival of the native hip than having a step-off exceeding 2 mm (e.g. 2 to 4 mm). Step-off > 2 mm and age > 60 years are predictors for conversion to THA, and can be helpful in the shared decision-making process. Patients with a THA have similar physical functioning and quality of life findings compared to patients who retained their native hip. Although their performance was slightly lower than their peers from the general population, these differences are not considered to be clinically relevant. Registries on acetabular fractures with high-quality data are needed to assess the influence of fracture displacement on clinical outcome in different age groups, fracture types, and more or

less displaced fractures. Moreover, further research is required to develop accurate and reproducible measurement tools for determining the degree of fracture displacement.[26,27]

Take home message

- Patients with minimally displaced acetabular fractures who opt for nonoperative fracture treatment may be informed that fracture displacement (e.g. gap and step-off) up to 2 mm, as measured on CT images, results in limited risk on conversion to total hip arthroplasty (THA).
- Step-off ≥ 2 mm and age > 60 years are predictors for conversion to THA, and can be helpful in the shared decision-making process. From a clinical perspective, having a gap exceeding 2 mm (e.g. 2 to 4 mm) still has a limited risk of conversion to THA and seems to have less impact on survival of the native hip than having a step-off exceeding 2 mm (e.g. 2 to 4 mm).

Supplementary material

Flow diagram of the patient inclusion, and an extensive table containing hip survival rates with 95% confidence intervals stratified by gap and step-off.

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