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Hemipelvis Index as a Diagnostically Significant Radiographic Criterion for Assessing Pelvic Ring Asymmetry

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ABSTRACT: Background: Interpretation of pelvic radiographs still relies largely on the qualitative, subjective assessment of the radiologist, and no universal quantitative measure of side-to-side pelvic symmetry is available in routine practice.

Aim: To develop and validate an original radiographic parameter, the hemipelvis index (HI), for the objective quantitative assessment of pelvic ring asymmetry and to determine its diagnostic accuracy in detecting pelvic ring injuries.

Methods: This retrospective study included 224 patients examined between 2023 and 2026. The control group comprised 154 patients (76 men, 78 women) without pelvic pathology, who were used to establish normative values. The main group comprised 70 patients with pelvic fractures of varying severity. The target subgroup for index validation included 30 patients, in whom the HI was calculated on standardised anteroposterior pelvic radiographs as the relative difference between the vertical dimensions of the right (R) and left (L) hemipelvis, measured between the most cranial point of the iliac crest and the most caudal point of the ischial tuberosity: $HI = (R - L(/ (R + L)/2 \times 100\%$. Diagnostic performance was assessed by receiver operating characteristic (ROC) analysis, with calculation of the area under the curve (AUC), 95% confidence intervals (CI), sensitivity, specificity and the Youden index.

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Results: The hemipelvis index showed good discriminative performance: the AUC was 0.920 (95% CI: 0.851–0.988; $p < 0.001$). The optimal cut-off value, determined by the maximum Youden index ($J = 0.757$), was 3.23%. At this threshold, sensitivity was 86.7% (95% CI: 69.3–96.2%) and specificity was 87.7% (95% CI: 81.4–92.4%).

Conclusion: The hemipelvis index is a simple, reproducible and easily applicable quantitative radiographic marker that demonstrates high diagnostic performance in detecting pelvic ring injuries and may be used as an additional criterion at the stage of initial plain radiography.

1. INTRODUCTION

Pelvic fractures remain one of the most severe injuries of the musculoskeletal system, combining high mortality with the complex three-dimensional anatomy of the pelvic ring and a substantial economic and social burden on health-care systems [5,11]. According to the Global Burden of Disease Study 2021 (GBD 2021), more than 4.5 million new cases of pelvic fracture were recorded worldwide in 2021, and the age-standardised incidence rate was 56.0 per 100,000 population, with the incidence in men exceeding that in women by a factor of 1.14; according to GBD-based forecasting models, the global burden of pelvic fractures is expected to continue to rise until at least 2046 [20].

According to the World Health Organization (WHO), many countries have recently seen a steady increase in the number of patients with pelvic ring injuries, attributable to rising road traffic injuries, occupational injuries and an increasing number of high-energy traumas [23.24].

National registry studies in recent years demonstrate a similar trend. An analysis of epidemiological trends in China for 1992–2021 showed that about 630,000 new cases of pelvic fracture were recorded in 2021 alone, with both the absolute number and the age-standardised incidence rate rising steadily [4]. Similar findings were obtained in a nationwide cohort study from South Korea: the total number of pelvic and acetabular fractures increased from 11,607 cases in 2006 to 35,691 cases in 2022, corresponding to an increase of 207.5% over 16 years, or an average of 12.9% per year [21].

Fragility fractures of the pelvis (FFP) in elderly patients with osteoporosis deserve separate attention. Epidemiological publications indicate a marked increase in the number of such patients, especially among women older than 80 years, which is associated with a decline in pelvic bone mineral density and, consequently, in its resistance to external loads [15]. According to the Aneurin Bevan Fracture Liaison Service (United Kingdom), the incidence of pelvic fractures in patients with skeletal fragility in 2024 was 36.6 cases per 100,000 population per year, with a mean patient age of 83.7 years and a 12-month mortality of 23.6% [16].

Mortality in pelvic fractures remains highly variable and depends directly on the haemodynamic status of the patient on admission and on the availability of timely imaging for the diagnosis of pelvic ring instability. Thus, in studies of unstable pelvic fractures accompanied by bleeding, overall mortality ranges from 2.8% among all patients to 32% among patients admitted in shock [7], while mortality in haemodynamically unstable patients with pelvic fractures still exceeds 30% despite advances in the management of severely injured patients [12]. At the same time, the introduction of multidisciplinary protocols and trauma centres can substantially improve outcomes: according to a Korean study, after the establishment of a trauma centre and the introduction of protocols, the time from admission to haemostatic intervention was almost halved, and mortality from acute haemorrhage decreased significantly [12]. A similar positive trend was shown in a 10-year Australian registry study: among 152 patients with severe pelvic ring injuries and haemodynamic instability, overall in-hospital mortality was 7.2%, and mortality directly attributable to haemorrhage was only 2% [13]. A 2024 meta-analysis summarising data from 29 studies of haemostatic interventions in unstable pelvic fractures showed that extraperitoneal packing, external fixation and arterial embolisation were associated with lower mortality, whereas resuscitative endovascular balloon occlusion of the aorta (REBOA), by contrast, was associated with higher mortality, which underscores the need for a differentiated, evidence-based approach to the choice of haemostatic method [22].

Contemporary epidemiological data clearly indicate a steady rise in the incidence of pelvic fractures worldwide, driven both by high-energy trauma in young and middle-aged people and by osteoporotic injuries in older age groups [15,20,21], while mortality among patients with unstable, haemorrhage-complicated injuries remains high and difficult to predict [7,12,13,22]. This makes

it highly relevant to further improve methods of early imaging diagnosis of pelvic ring injuries, aimed at the timely detection of instability and a well-founded choice of treatment strategy.

The results of Khurana et al. (2014) indicate that the use of high-resolution reconstructions improves the accuracy of fracture characterisation and reduces the likelihood of missing clinically significant injuries, including sacral fractures, for which the sensitivity of radiography, according to available data, does not exceed 10% [2,11]. Despite significant progress in imaging methods, plain anteroposterior pelvic radiography — the most accessible and widely used method of initial imaging — is still interpreted mainly on the basis of a qualitative visual assessment of cortical discontinuity and asymmetry, without a standardised quantitative criterion.

Badii et al. studied anatomical pelvic asymmetry in 323 patients using computed tomography (CT), comparing the distances from the iliac crests to the acetabula on the right and left. The authors demonstrated high reproducibility of this measurement; however, asymmetry was assessed in absolute values (mm) and was considered mainly as individual anatomical variability, without the development of a diagnostic criterion for detecting traumatic pelvic injury [1]. Subsequently, Handrich et al., analysing 150 CT examinations with three-dimensional statistical modelling, established a systematic asymmetry of various parts of the pelvic ring. The authors noted the complexity of the existing methods of quantitative assessment and the need for simpler and more reliable methods of determining pelvic asymmetry that are suitable for practical use [9].

To date, the literature contains no description of a simple, scale-independent quantitative index of hemipelvic symmetry that is based on a plain radiograph, is applicable directly at the stage of the initial radiographic examination without additional software, and has been validated in a clinically confirmed sample of patients with pelvic fractures using formal statistical methods for assessing diagnostic accuracy.

The aim of this study was to evaluate the diagnostic performance of a quantitative radiographic parameter — the hemipelvis index (HI) — based on standard anteroposterior plain pelvic radiography, to establish its reference values in a control population, and to determine the diagnostic accuracy of the index in detecting pelvic ring injuries by receiver operating characteristic (ROC) analysis, including calculation of the area under the curve (AUC), the optimal cut-off value, sensitivity and specificity.

2. MATERIALS AND METHODS

2.1. Study design and sample characteristics

This was a database-based observational study of patients aged 18–75 years in whom the hemipelvis index was assessed. A total of 224 patients were included.

Study setting and period: This retrospective study was conducted in Chirchik, Republic of Uzbekistan, at the Chirchik Medical Association and at the clinic of Tashkent State Medical University (Department of Traumatology), from 2023 to 2026.

The control group comprised 154 patients (76 men, 78 women) without clinical or radiographic signs of pelvic or hip joint pathology, who underwent pelvic radiography for indications unrelated to traumatic injury.

The main group comprised 70 patients with traumatic injuries of the pelvic bones of varying severity, confirmed by radiography and multislice computed tomography (MSCT), including stable, unstable and comminuted fractures according to the Tile and Young–Burgess classifications [17]. From the main group, a target subgroup of 30 patients who met the study criteria was selected for detailed morphometric analysis, calculation of the HI and subsequent diagnostic validation against the control group. Patients with bilateral symmetrical injury of the pelvic ring (in whom comparison of the right and left halves of the pelvis loses its diagnostic meaning), as well as patients with technically unsatisfactory positioning, were excluded from the validation subgroup.

2.2. Inclusion and exclusion criteria

Inclusion criteria for the control group were: age over 18 years; availability of a digital plain anteroposterior pelvic radiograph; absence of pelvic fractures, hip dysplasia, previous surgery on the pelvic bones and pronounced degenerative changes that impair the visualisation of anatomical landmarks; and satisfactory radiographic quality. This group was used to determine the reference range and physiological variability of the HI.

Inclusion criteria for the main group were: age ≥ 18 years; a radiographically confirmed pelvic fracture; availability of a digital plain anteroposterior pelvic radiograph; and clear identifiability of the anatomical landmarks required for measurement. Exclusion criteria were: marked pelvic deformity precluding measurement; massive metal implants in the pelvic region; unsatisfactory radiographic quality; a history of repeated reconstructive operations on the pelvic ring; and incomplete visualisation of the iliac crest or ischial tuberosity.

2.3. Development and mathematical definition of the hemipelvis index

One of the most important features of pelvic structure is the relative symmetry of its right and left halves. Under physiological conditions, both halves of the pelvis have similar linear dimensions, and existing differences are due to individual anatomical variation and do not significantly affect the function of the pelvic ring. However, in various diseases and injuries this symmetry is disturbed, accompanied by a change in the linear dimensions of one of the hemipelves.

The absence of a universal quantitative criterion substantially limits the possibility of objectively assessing the degree of pelvic asymmetry, of following patients over time and of standardising the results of imaging studies. In clinical practice, the radiologist is often forced to describe asymmetry exclusively in qualitative terms (“minor”, “moderate”, “pronounced”), which makes it difficult to compare examinations performed at different times and reduces the reproducibility of reports.

Given the above, there was a need to develop a quantitative measure that would allow the degree of difference between the right and left hemipelves to be assessed objectively, irrespective of the absolute size of the pelvis. Such a measure should be simple to calculate, reproducible on repeated measurements, independent of the scale of the digital image, and based on anatomical landmarks that are clearly visualised on standard pelvic radiography.

Taking these requirements into account, the hemipelvis index was developed as an original morphometric parameter based on a comparison of the vertical dimensions of the right and left halves of the pelvis. Two constant, well-visualised bony landmarks located at opposite poles of each half of the pelvis were chosen for its calculation: the most cranial point of the iliac crest (crista iliaca) and the most caudal point of the ischial tuberosity (tuber ischiadicum). The choice of these landmarks is based on their anatomical constancy and resistance to secondary changes, as described in classical works on pelvic anatomy and biomechanics [19]. Both landmarks are easily identified on a standard plain pelvic radiograph and are characterised by high reproducibility on repeated measurements.

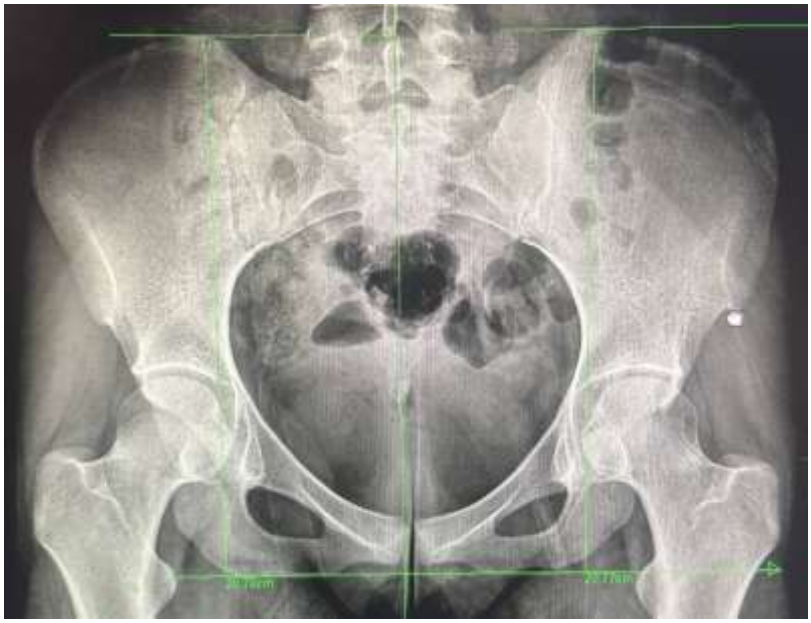


Figure 1. Anatomical landmarks for determining the hemipelvis index.

To quantify the degree of side-to-side asymmetry, the hemipelvis index (HI) was proposed, calculated using the following formula:

$$HI = (R - L) / (R + L)/2 \times 100\%$$

The dimensions obtained were designated as follows:

R — vertical dimension of the right hemipelvis;

L — vertical dimension of the left hemipelvis;

(R – L) — absolute difference between the dimensions of the right and left hemipelvis;

(R + L)/2 — arithmetic mean of the dimensions of the right and left hemipelvis.

In this formula, the numerator reflects the absolute difference between the vertical dimensions of the right and left hemipelves, whereas the denominator is their arithmetic mean. This construction normalises the result relative to the individual pelvic size of the patient and eliminates the influence of sex, age and constitutional characteristics on the interpretation of the parameter. The value obtained is expressed as a percentage and characterises the degree of side-to-side asymmetry.

2.4. Standardised measurement protocol

All measurements were performed on calibrated digital images in a certified picture archiving and communication system (PACS) using a standard scale marker. To ensure maximum reproducibility of the results, a standardised protocol of ten sequential steps was applied (Table 1).

Table 1. Standardised protocol for measuring the hemipelvis index.

Step	Procedure	Requirement / note
1. Patient positioning	The patient lies supine on the radiographic table. The lower limbs are extended, and the feet are internally rotated by 15–20° to standardise the position of the pelvis.	Mandatory
2. Radiographic technique	Anteroposterior (AP) projection of the pelvis. Source-to-image distance: 100–110 cm. Beam centring: at the midpoint between the pubic symphysis and the umbilicus.	DICOM format
3. Image quality control	Check for the absence of pelvic rotation, symmetry of the obturator foramina and iliac wings, and clear visualisation of the anatomical landmarks.	If the criteria are not met, the examination is repeated
4. Delineation of the hemipelves	The right and left hemipelves are analysed separately. Standard bony landmarks for measurement are identified on each side.	Separately for each side
5. Linear measurements	The required linear measurements are performed on the digital radiograph according to the developed methodology for determining the hemipelvis index. Each measurement is performed at least three times, and the mean value is calculated.	Measurement accuracy
6. Calculation of the index	The hemipelvis index is calculated using the developed formula and the linear parameters obtained.	Result rounded to 0.1
7. Comparison of sides	The right and left hemipelves are compared, and the magnitude of asymmetry is determined.	Difference between the sides is determined
8. Interpretation of results	The values obtained are compared with normative values, and the presence, degree and nature of hemipelvic deformity are assessed.	Taking into account the patient's sex and age

Step	Procedure	Requirement / note
9. Assessment of diagnostic significance	The index is analysed together with other radiographic signs of pelvic ring injury to determine the degree of disruption of pelvic anatomy.	Comprehensive assessment
10. Documentation	All measurements, the calculated hemipelvis index, the magnitude of asymmetry and the conclusion are recorded in the imaging report.	Mandatory

AP, anteroposterior; DICOM, Digital Imaging and Communications in Medicine.

2.5. Statistical analysis

The Shapiro–Wilk test was used to assess the distribution of quantitative variables in the main group. For normally distributed data, quantitative variables were described using the arithmetic mean (M) and standard deviation (SD) in the format M ± SD. For non-normally distributed data, the median (Me) and interquartile range were presented in the format Me [Q1; Q3].

Qualitative (categorical and binary) variables were described using absolute frequencies and relative proportions (percentages). To assess the statistical significance of differences in qualitative variables (for example, when comparing the detection rate of fractures by radiography and MSCT), Pearson's chi-squared (χ^2) test or Fisher's exact test (for small samples) was used. Two independent non-parametric samples were compared using the Mann–Whitney U test. The critical level of statistical significance when testing null hypotheses was set at $p < 0.05$.

To provide a mathematical justification for the diagnostic value of the hemipelvis index, a comparative analysis was performed between the control group (n = 154) and the target subgroup with pathology (n = 30).

The discriminative ability of the HI was assessed by receiver operating characteristic (ROC) analysis. The overall diagnostic performance was determined from the area under the ROC curve (AUC), with calculation of the 95% confidence interval (95% CI) and standard error (SE). To determine the optimal cut-off value — the HI threshold that allows natural pelvic asymmetry to be differentiated from traumatic displacement with maximum accuracy — the Youden index (J) was used, calculated as $J = \max(Se + Sp - 1)$, where Se is sensitivity and Sp is specificity.

2.6. Ethical considerations

The study was conducted retrospectively using anonymised imaging data obtained during routine clinical examination. All procedures complied with institutional ethical requirements for the use of retrospective diagnostic data.

3. RESULTS

3.1. Diagnostic performance of the hemipelvis index

The key objective of this study was to determine the diagnostic value of the hemipelvis index (HI) in the assessment of plain pelvic radiographs. The diagnostic value of the HI was assessed by comparing the control group (n = 154) with the target subgroup of patients with confirmed pelvic ring injury (n = 30). The area under the ROC curve (AUC) demonstrated an outstanding discriminative ability of the index: the AUC was 0.920 (95% confidence interval: 0.851–0.988). According to current biostatistical standards, an AUC > 0.9 indicates excellent quality of a diagnostic test.

To determine the optimal cut-off value providing the best balance between the true-positive and false-positive rates, the maximum of the Youden index was calculated. According to the ROC analysis, the optimal cut-off value of the hemipelvis index was 3.23%.

At this cut-off value, the operating characteristics of the test were as follows:

- Sensitivity: 86.7% (95% CI: 69.3–96.2%);
- Specificity: 87.7% (95% CI: 81.4–92.4%).

3.2. Clinical interpretation of the diagnostic threshold

The cut-off value obtained makes it possible to formulate a simple two-step algorithm for interpretation directly at the stage of initial radiography:

- If the HI is below 3.23%, individuals without pelvic ring injury are correctly classified in 87.7% of cases (specificity); such values may correspond to physiological asymmetry or to a stable injury without displacement.
- If the HI is ≥ 3.23%, the index identifies patients with pelvic ring injury with a sensitivity of 86.7%, which justifies further examination by MSCT even when the fracture line is not directly visualised on the plain radiograph.

4. DISCUSSION

This study assessed the diagnostic value of, and validated, the hemipelvis index as a quantitative radiographic parameter designed to convert the traditionally qualitative impression of pelvic asymmetry into an objective, reproducible numerical value obtained from a single anteroposterior plain pelvic radiograph.

Compared with previously published approaches to the quantitative assessment of pelvic symmetry, the proposed index is a methodologically different and practically simpler alternative. Badii et al. (2003) [1] demonstrated good reproducibility of measuring the distance from the iliac crest to the acetabulum in 323 patients, but expressed asymmetry in absolute millimetres reflecting individual anatomical variability rather than a validated diagnostic threshold for injury. Handrich et al. (2021) [9], applying three-dimensional statistical shape modelling to CT data from 150 patients, confirmed a consistent pattern of physiological asymmetry in different parts of the pelvic ring, while pointing to the need for simpler and clinically applicable measurement tools.

In contrast to these methods, the HI expresses side-to-side asymmetry as a relative percentage rather than an absolute linear value, which minimises the influence of individual pelvic size, sex and body build and allows direct comparison of results between patients of different constitution, as well as between radiographs obtained on different digital systems. Calculation of the index requires only two linear measurements using the built-in tools of the PACS, without specialised software, three-dimensional reconstruction or additional examination time, which is a substantial practical advantage over the CT-based morphometric methods described above.

An AUC of 0.920 corresponds to the "excellent" category of diagnostic tests and compares favourably with the sensitivity of conventional radiography obtained in the same clinical sample for individual types of fractures, as well as with the well-documented limitations of plain radiography for the posterior pelvic ring, where the sensitivity of the method for detecting sacral fractures does not exceed 10% [2,6], whereas the use of MSCT substantially improves the accuracy of assessing the nature and stability of a fracture. Applied as a supplement to, rather than a replacement for, the conventional assessment of the fracture line, the HI may help to identify radiographically subtle injuries — including in anatomically difficult-to-visualise regions — and to refer the patient for confirmatory MSCT without increasing the time or cost of the initial radiographic examination.

The results are consistent with the broader literature on the epidemiology and outcomes of pelvic fractures, which emphasises the importance of timely and accurate diagnosis for reducing mortality and complication rates [7,8,10,13,18], as well as with studies devoted to optimising emergency imaging protocols and the organisation of care for polytrauma with pelvic injury [12,14]. In particular, the persistent worldwide need for objective, easily reproducible quantitative criteria for assessing the degree of asymmetry and displacement of the pelvic ring, reflected in contemporary epidemiological studies [20,21], largely substantiates the practical value of the proposed index as a simple additional tool at the stage of primary imaging, which is the most widely used and accessible.

5. LIMITATIONS

This study has several limitations. First, the work was carried out at a single medical institution with a relatively small target subgroup (n = 30), which limits the generalisability of the results and requires prospective multicentre validation. Second, inter- and intra-observer reliability of the measurements was not assessed in this work and should be the subject of a separate study. Third, patients with bilateral symmetrical injury of the pelvic ring were excluded from the analysis, since the proposed approach is inapplicable to them by its very methodological nature, which also limits the scope of application of the index.

6. CONCLUSION

The hemipelvis index is a simple, reproducible, scale-independent quantitative radiographic parameter based on two anatomically constant landmarks on a standard anteroposterior plain pelvic radiograph. In this study, the HI demonstrated high diagnostic performance in detecting pelvic ring injuries: the area under the ROC curve (AUC) was 0.920 (95% CI: 0.851–0.988; $p < 0.001$), the optimal cut-off value was 3.23% (Youden index 0.757), sensitivity was 86.7% and specificity was 87.7%. Given its simplicity of calculation, low cost and compatibility with the routine PACS workflow, the HI may be used as a useful supplement to conventional radiographic assessment at the earliest stage of imaging of patients with pelvic trauma, helping to decide on the need for further cross-sectional imaging. Prospective multicentre validation with a formal assessment of measurement reproducibility is required before wide clinical implementation of the parameter.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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