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Rear drop: a new radiographic landmark for estimation of pelvic tilt on pelvis AP radiographs

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ABSTRACT

Estimation of pelvic tilt on anteroposterior (AP) pelvis radiograph is often done by indirect methods based on the midline pelvic landmarks. The purpose of this cadaveric study is to describe a new radiographic landmark and reference measurements to estimate the coronal tilt of the pelvis, independent of the midline references. The new radiologic reference is called 'rear drop', and its anatomic location is described with the cadaveric pelvis AP radiographs in various pelvic inclination. The parameters derived from the new reference were used to assess the pelvic tilt, and the results were compared with the previously established method using 'sacrococcygeal joint to symphysis distance' (SCSD). The shape of the new figure is used to determine the position of the pelvis, and its relationship with the previously described acetabular retroversion indicators was statistically analyzed. The new reference figure corresponds to the posteroinferior edge of the horseshoe shape of the acetabular margin. The newly derived reference parameters, rear to tear distance and rear to tear angle, changes with pelvic tilt and are strongly correlated with SCSD. The shape of the rear drop changes with the changing pelvic tilt and correlates statistically with the previously described acetabular retroversion indicators. Rear drop and its derivative measurements can be used as a reliable and reproducible indicator to estimate the coronal pelvic tilt, free of midline reference points. This new reference will be a base for future clinical studies on pelvic tilt, rotation and their application in intraoperative hip fluoroscopy.

INTRODUCTION

In addition to physical examination, the evaluation of radiographs of the pelvis has a crucial role in assessing hip problems and decision-making [1]. Moreover, to obtain an accurate diagnosis using the radiographs, the views should be taken in a standardized position with proper tilt and rotation [2]. Estimation of pelvic rotation is relatively easy through assessment of the symmetry pattern of each hemipelvis. However, analysis of pelvic tilt is challenging on anteroposterior (AP) pelvis radiographs [3]. An accurate determination of pelvic tilt requires a true lateral pelvis radiograph, which may not always be feasible for routine clinical and intraoperative use [3]. Numerous methods have been described for the estimation of pelvic tilt on AP pelvis radiograph. Currently, the most reliable estimators that have been described till now, sacrococcygeal joint to symphysis pubis distance (SCSD) [4], coccyx to symphysis distance (CSD) [2] and sacro-femoral-pubic angle (SFPA) [5] are all based on midline anatomical bony landmarks as reference points.

Nevertheless, the use of these estimators also has some limitations. The identification of coccyx and sacrococcygeal joint are not always straightforward due to obesity and intestinal interposition [6], and gonadal shields usually hide these references [7]. Furthermore, a restricted field of view in fluoroscopy makes it harder to capture the full pelvis in any one view; hence the measurement of pelvic tilt using the midline references is almost impossible intraoperatively [6, 8].

In the current literature, there is no precise method that effectively eliminates the problems described above while enabling pelvic tilt evaluation practically. The purpose of this study is to describe a new radiographic landmark in AP pelvis radiographs to help with measuring pelvic tilt, independent of the midline references. Secondly, defining and validating new reference-based measurements in assessing the pelvic coronal tilt may have a practical bearing in hip preservation surgery and hip arthroplasty.

MATERIALS AND METHODS

Six male pelves were available for our study, but their age of death was unknown. All dry bone specimens were screened to identify intact pelvis bones (sacrum and two innominate bones) stored in the institution's archive and later underwent computerized tomography (CT). Any defect in pelvis bone or deformity such as retroversion of the acetabulum were excluded. This study was conducted in the department of clinical anatomy, and it has been approved by the IRB of the authors' affiliated institutions.

Rear drop sign

The teardrop is a well-known reference point, which is described to be a radiographic projection of bony ridge running along the floor of the acetabular fossa on the pelvis radiographs [9]. We named our new reference point as 'rear drop'. It is a U-shaped cortical thickening formed by the confluence of the posteroinferior margin of the acetabular articular surface and inferior part of the posterior wall (ischium). It can be easily seen in almost all pelvis and hip views (Fig. 1).

Cadaveric study

In the first part of the study, we endeavored to determine the exact anatomic location of the 'rear drop' on the pelvis. Four radiopaque markers (21 G syringe needle) were placed to delineate the posteroinferior curve of the horseshoe of the acetabulum on the cadaveric pelvis. Markers were placed on the anterior end of the acetabular notch (No. 1), posterior end of the acetabular notch (No. 2), the apex of the inferior margin of the horseshoe-shaped U (No. 3) and proximal-most point of the U on the posterior acetabular wall (No. 4) (Fig. 2a and b). AP pelvis radiographs were taken in different pelvic tilts with the help of a

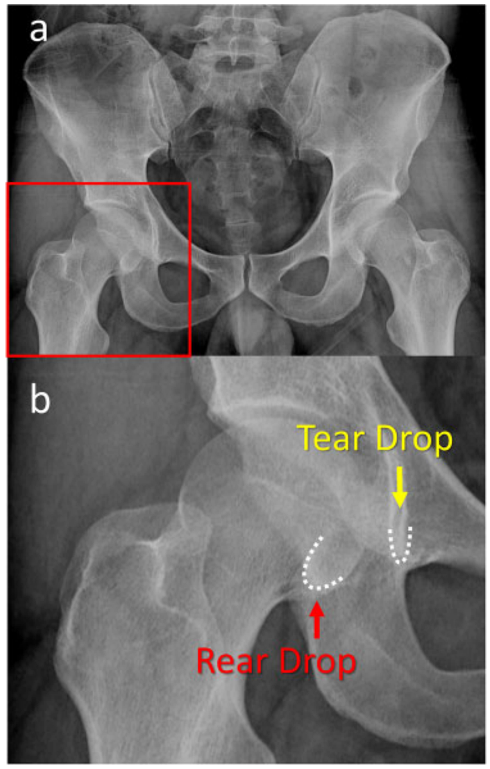

Fig. 1. (**a**) AP pelvis radiograph of a 32-year-old male. (**b**) The red square is magnified to delineate the rear drop figure better. Note the crescentic rear drop figure (red arrow) and teardrop figure (yellow arrow).

frame that holds the pelvis in the desired position (Fig. 2c). Each needle was removed sequentially, and radiographs were repeated. It was determined that needle No. 3 was the location corresponding to the rear drop figure (Fig. 2d).

In the second part of the study, all dry specimens were placed on the frame with three different pelvic tilts (10° forward, neutral and 10° backward), and AP pelvis radiographs were taken according to the described method [2] (Fig. 3). Neutral tilt was determined as described by Siebenrock *et al.* [10] for the male cadaveric pelvis. Forward and backward tilts were obtained with the aid of a 10° wedge placed under the posterior and anterior end of the frame, respectively. We had six specimens with three different tilts, thus obtaining 18 AP pelvis radiographs in total. On these radiographs, the following radiographic measurements, and assessments, were performed.

Rear drop to teardrop distance and rear drop to teardrop angle

The inferior tip of teardrop figure on each hip was marked, and a line connecting these marks was drawn. The rear

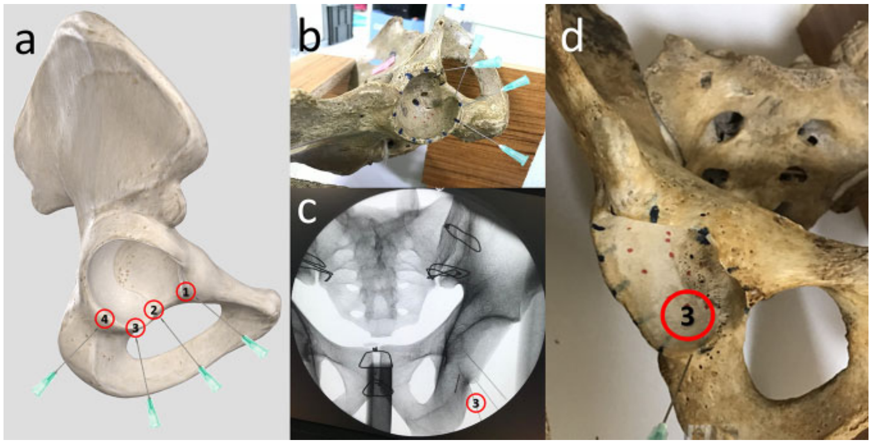

Fig. 2. Illustration showing the location of the needles (**a**) and their appearance on the dry pelvis (**b**). Radiograph with the needles in place (**c**) and No. 3 needle location, corresponding to the rear drop figure on the dry pelvic bone (**d**).

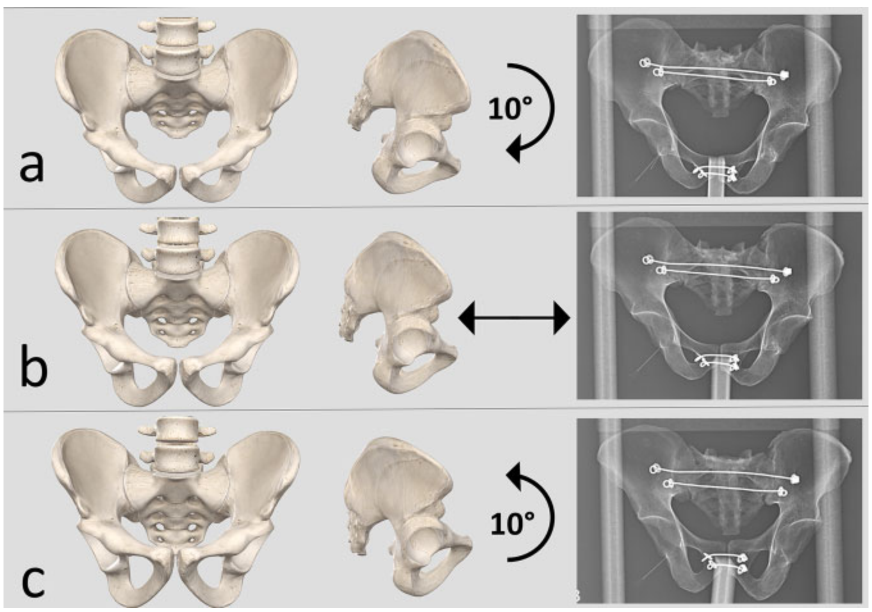

Fig. 3. Illustration of the 3D pelvis model demonstrates the 10° forward (**a**), neutral (**b**) and 10° backward (**c**) pelvic coronal tilts and the resultant AP pelvis radiographs.

drop figure's inferior tip was then marked on each hip, and a second line connecting these marks was drawn, resulting in two parallel horizontal lines. The perpendicular distance between these two lines was measured and recorded (Fig. 4). Similar to rear drop to teardrop distance (RTD) measurement, two parallel lines connecting both rear drops and teardrops were drawn. Next, a third line connecting the rear drop and teardrop was drawn on each hip joint. The angle between the second horizontal line and the third line was measured and recorded (Fig. 4). A standard pelvic radiograph is needed to accurately measure both rear drop to teardrop angle (RTA) and RTD as the reference points located on the opposite side of the acetabulum are also used. Moreover, the pelvis radiograph should be symmetric without axial rotation.

Sacrococcygeal joint to symphysis distance

The distance between the sacrococcygeal joint to symphysis pubis was measured as described by Siebenrock *et al.* [10].

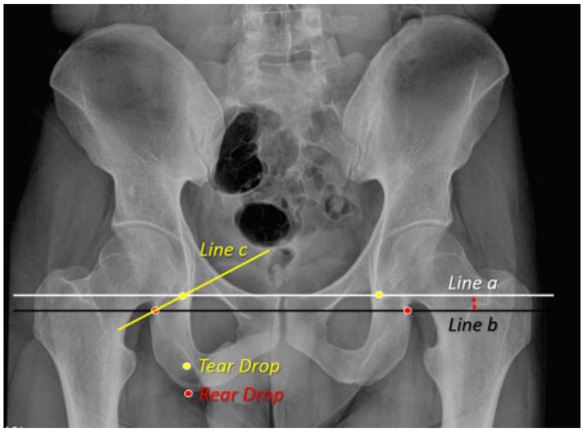

Fig. 4. Measurement of RTA and RTD on AP pelvis radiograph. RTD is the perpendicular distance between Line a and Line b. The angle between the Line b and Line c forms the RTA.

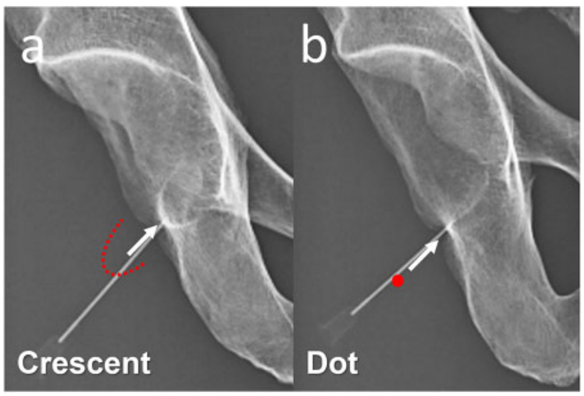

Fig. 5. The shape of the rear drop can either be in the form of a crescent (**a**) or a dot (**b**).

Assessment acetabular retroversion

The presence or absence of a cross-over sign (COS) and ischial spine sign (ISS) were recorded as described previously [11, 12].

Assessment of changes in the shape of the rear drop sign

The shape of the rear drop figure changes according to the pelvic tilt. It may be in the form of a crescent or a dot (Fig. 5), and the shape of the rear drop figure will be visible despite the femoral head superposition on pelvis radiographs (Fig. 6).

Testing inter-observer and intra-observer reliability

Two consulting orthopedic surgeons with a special interest in hip surgery took part in the study. A briefing about the measurements was given, and an agreement on the measurement technique and ratings were reached before the initiation of the study. Radiologic assessments were performed in random order by each observer on two separate occasions (t1 and t2), at least 3 weeks apart. All measurements and ratings were performed on digital radiographs using the software program RadiAnt DICOM Viewer (Ver 5.0.5, Medixant, Poznan—Poland) on the digital workstation. Observers were blinded to their previous readings. The order of the X-rays was randomized using a sequential, random number generator to prevent possible recall.

Statistical analysis

Descriptive statistics were presented as the frequency for categorical variables and mean ± standard deviation and range for continuous variables. The Kolmogorov–Smirnov test was used to determine whether the data were distributed normally. The analysis of categorical variables was carried out with the 'Chi-Square' test. A comparative analysis of two independent groups was done using the Student's *t*-test. The one-way analysis of variance was used to compare three or more independent groups. Correlation analysis between two numerical data was performed using the Pearson coefficient. The data were analyzed at a 95% confidence level, and if the *P*-values was <0.05, the tests were considered significant. Reliability analysis of the continuous variables was performed with the intraclass correlation coefficient and 95% confidence interval. Interpretation of the data was performed, according to Koo and Li [13]. Kappa statistics were used to establish a relative level of agreement on the categorical variables. Interpretation of the data was performed according to Landis and Koch [14]. Agreement was graded as slight ($\kappa = 0$–0.2), fair ($\kappa = 0.21$–0.40), moderate ($\kappa = 0.41$–0.60), substantial ($\kappa = 0.61$–0.80) and almost perfect ($\kappa = 0.81$–1).

RESULTS

The average of all measurements was similar on each occasion (Table I). Both the intra-observer and inter-observer reliability were interpreted as nearly perfect (Table II). Thus, the mean of four measurements (Observer A t1 and t2 and Observer B t1 and t2) was used for the final analysis. SCSD significantly decreased from the forward tilt position (anterior tilt) to the backward position (posterior tilt) ($P = 0.001$). Conversely, RTA ($P = 0.001$) and RTD ($P = 0.001$) increased significantly.

Rear drop sign was observed in the form of a dot in all backward tilt positions, while it was observed in the form of a crescent in all anterior tilt positions ($P = 0.002$). Similarly, the ISS and COS were rated as present in all backward tilt positions (Table III). SCSD, RTA and RTD values were significantly different according to the shape of the rear drop sign (Table IV). Finally, there was a strong

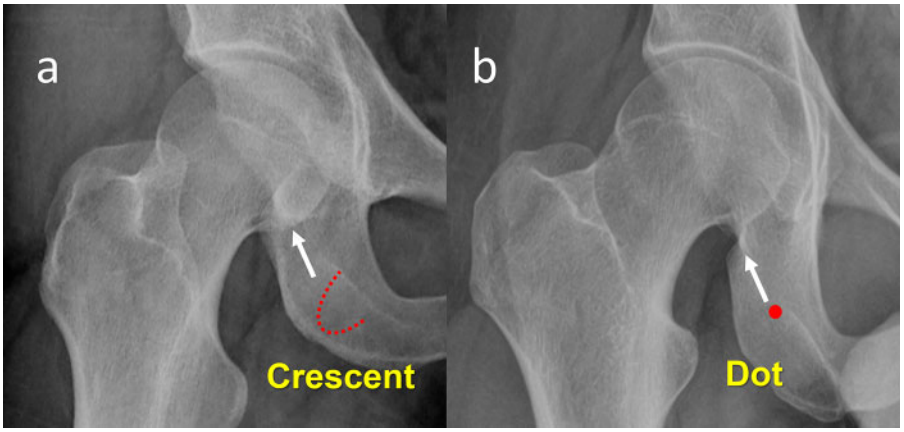

Fig. 6. The appearance of the different shapes of rear drop figures on AP pelvis radiographs with femoral head overlapping. Pelvis radiograph of a 28-year-old male showing a crescentic rear drop (**a**) and a 42-year-old female showing a dot-shaped rear drop (**b**).

Table I. Comparison of measurements performed by both observers on each occasion

Variable	*Observer A*		*Observer B*		*Significance P-value*
	Time 1	*Time 2*	*Time 1*	*Time 2*	
SCSD (mm ± SD)	23.1 ± 23.0	25.1 ± 24.9	26.2 ± 24.9	22.6 ± 22.4	0.967[a]
Range	(−10.0 to 60.9)	(−9.7 to 64.7)	(−8.0 to 69.7)	(−10.9 to 55.4)	
RTD (mm ± SD)	7.6 ± 4.6	7.6 ± 4.1	7.8 ± 3.9	8.2 ± 4.2	0.963[a]
Range	(0.0–16.9)	(1.0–15.8)	(2.0–15.8)	(2.0–16.5)	
RTA (mm ± SD)	16.3 ± 8.5	15.8 ± 7.9	16.6 ± 8.4	16.3 ± 8.2	0.995[a]
Range	(0.0–30.0)	(3.0–29.0)	(5.0–30.0)	(4.0–32.0)	

aANOVA.
ANOVA, analysis of variance; RTA, rear drop to teardrop angle; RTD, rear drop to teardrop distance; SCSD, sacrococcygeal joint to symphysis pubis distance.

inverse correlation between the SCSD and RTD and RTA, while RTD and RTA showed a strong positive correlation (Table V and Fig. 7).

DISCUSSION

In this study, a new radiographic landmark and two new radiographic measurement techniques based upon this landmark were described on AP pelvis radiographs to ease the estimation of pelvic tilt. Rear drop is a new figure that can be visualized in all pelvis AP radiographs despite the superimposition of the femoral head. This figure corresponds to the U-shaped cortical thickening formed by the confluence of the posteroinferior margin of the acetabular articular surface and the inferior most part of the posterior wall (ischium). The shape of the rear drop changes from crescent to a dot when the pelvis was tilted posteriorly and vice versa. This unique appearance would be extremely useful in a limited radiographic field of view such as, during the intraoperative fluoroscopic hip assessment. This sign will be a useful tool for rapid assessment of the pelvic tilt during the surgery, especially in the field of hip preservation surgery. Moreover, both RTD and RTA strongly predict the pelvic tilt and may reliably be used without the identification of midline references. It provides information about pelvic tilt without interfering with the use of gonadal protection. Additionally, it may reduce radiation exposure to gonads, particularly in skeletally immature patients. Due to the high predictive value, usefulness and apparent advantages, these novel methods could be recommended in clinical practice.

Evaluation of pelvic tilt is vital in the decision-making in hip dysplasia surgery and arthroplasty. Pelvic tilt has the potential to alter the diagnosis and can lead to overtreatment or undertreatment. It has been shown that a 10°

Table II. Summary of reliability analysis

Variable	*Inter-observer reliability*			
	OBS A t_1 versus OBS B t_1	*Interpretation*	*OBS A t_2 versus OBS B t_2*	*Interpretation*
SCSD[a]	0.994 (0.984–0.988)	Perfect	0.994 (0.983–0.998)	Perfect
RTD[a]	0.988 (0.967–0.995)	Perfect	0.994 (0.983–0.998)	Perfect
RTA[a]	0.986 (0.962–0.995)	Perfect	0.981 (0.949–0.993)	Perfect
Rear drop sign[b]	0.886 (0.671–1.000)	Perfect	1.000	Perfect
ISS[b]	1.000	Perfect	1.000	Perfect
COS[b]	1.000	Perfect	1.000	Perfect
	Intra-observer reliability			
	OBS A t_1 versus t_2	*Interpretation*	*OBS B t_1 versus t_2*	*Interpretation*
SCSD[a]	0.997 (0.992–0.999)	Perfect	0.991 (0.977–0.997)	Perfect
RTD[a]	0.994 (0.984–0.998)	Perfect	0.993 (0.981–0.997)	Perfect
RTA[a]	0.989 (0.969–0.996)	Perfect	0.984 (0.957–0.994)	Perfect
Rear drop sign[b]	0.886 (0.671–1.000)	Perfect	1.000	Perfect
ISS[b]	1.000	Perfect	1.000	Perfect
COS[b]	1.000	Perfect	1.000	Perfect

aIntraclass correlation coefficient and 95% confidence interval.
bKappa and 95% confidence interval.
COS, cross-over sign; ISS, ischial spine sign; OBS, observer; RTA, rear drop to teardrop angle; RTD, rear drop to teardrop distance; SCSD, sacrococcygeal joint to symphysis pubis distance.

change in the pelvic tilt may cause a 6° change in anterior center edge angle [15]. Furthermore, anterior pelvic tilt has been shown to cause erroneous interpretation of acetabular retroversion. Ross *et al.* [11] reported a significantly increased proportion of positive cross-over, posterior wall and prominent ISSs with 10 degrees of anterior pelvic tilt. Similarly, in the current study, cross-over and ISSs showed a strong correlation with the shape of the rear drop figure consistent with the tilt of the pelvis. COS or ISS were not noted in any radiographs where the rear drop sign was observed as a dot, in other words, when the pelvis was tilted posteriorly.

There are many indirect methods that have been described to estimate pelvic tilt on AP radiographs [16]. Tannast *et al.* [4] analyzing six different parameters for estimation of pelvic tilt, from AP radiographs and the distance from the sacrococcygeal joint to the symphysis pubis, was found to be more reliable in estimating the pelvic tilt, and we used the SCSD, as the reference in the analysis of the new anatomical landmark. Most of the estimation methods (SCSD [4], CSD [2] and SFPA) rely on the midline reference points of the pelvis. The new landmark has some advantages when compared with the midline reference points. With our method, visualization of sacrococcygeal joint or coccyx in the radiographs is not required, as there were already described challenges to identify these midline reference points radiographically [6, 8]. Pelvic tilt estimation without gonadal shielding is problematic with the previously described methods [7]. The newly defined landmark allows patients to use gonadal shields since it is independent of the midline reference points.

The previously described indirect methods have two different criteria when using sacrococcygeal joint to symphysis distance (SCSD) as pelvic dimensions varied between the genders [10]. In our study, the new measurements may not be affected by the aperture dimensions as they do not depend on them. However, as only male pelves were used in this study, hence gender differences could not be studied. Another advantage of the newly

Table III. The comparison of all measurements according to pelvic tilt

Variable	*10° Forward tilt*	*Neutral*	*10° Backward tilt*	*Significance*
SCSD (mm ± SD)	49.6 ± 6.8	27.5 ± 10.6	−4.3 ± 5.3	0.001[a]
RTD (mm ± SD)	4.0 ± 2.2	7.1 ± 3.0	12.3 ± 2.0	0.001[a]
RTA (mm ± SD)	9.0 ± 3.7	14.3 ± 5.6	25.5 ± 3.1	0.001[a]
Rear drop sign				0.002[b]
Crescent (*n*)	0	2	6	
Dot (*n*)	6	4	0	
ISS				0.002[b]
Yes (*n*)	0	2	6	
No (*n*)	6	4	0	
COS				0.002[b]
Yes (*n*)	0	2	6	
No (*n*)	6	4	0	

aANOVA.
bChi-square test.
ANOVA, analysis of variance; COS, cross-over sign; ISS, ischial spine sign; RTA, rear drop to teardrop angle; RTD, rear drop to teardrop distance; SCSD, sacrococcygeal joint to symphysis pubis distance.

Table IV. The comparison of measurements according to the shape of rear drop figure

Variable	*Rear drop shape*		*Significance*
	Crescent (n: 10)	*Dot (n: 8)*	
SCSD (mm ± SD)	43.2 ± 10.0	0.5 ± 10.2	0.001[a]
RTD (mm ± SD)	4.5 ± 2.0	11.9 ± 1.9	0.001[a]
RTA (mm ± SD)	10.0 ± 4.1	24.1 ± 3.7	0.001[a]

aIndependent sample *t*-test.
RTA, rear drop to teardrop angle; RTD, rear drop to teardrop distance; SCSD, sacrococcygeal joint to symphysis pubis distance.

defined figure is that it can be used intraoperatively with ease. The rear drop figure can be visualized and measured within the narrow fluoroscopic view of the hip, so it improves the understanding of the orientation of the acetabulum intraoperatively. Some authors have described their techniques to obtain a proper hip fluoroscopic view for eliminating the tilt and rotation effects during arthroscopic pincer trimming [6, 8]. Larson and Wulf [8] used the relation between the teardrop and ilioischial line on both matched intraoperative fluoroscopic view and the preoperative pelvis AP views. They recommend moving the fluoroscopy machine to the tip of the coccyx and symphysis to verify the appropriate pelvic orientation with an additional fluoroscopic image. Matsuda's [6] technique was also coccyx dependent as he described placing a coin over the palpated coccyx in cases of poorly visualized coccyx. We did not study the validity of our new references on fluoroscopy in this study, but we believe that with future studies using the measurement methods from the newly described references, estimation of the pelvic tilt may be accomplished more easily and safely on a single hip fluoroscopy image.

The newly derived reference parameters (RTD and RTA) had a strong negative correlation with the most reliable pelvic tilt estimator 'SCSD'. Moreover, the SCSD values were negatively proportional to the RTD, and RTA measurements as the pelvis tilt from anterior to posterior, the SCSD decreases and the RTD and RTA increases and vice versa. Similarly, the commonly used parameters to assess the acetabular retroversion were found to correlate well with RTD and RTA. It was noted that when the pelvis tilts anteriorly, it increases SCSD but decreases the RTD and RTA with positive ischial and COSs and vice versa when the pelvic tilts posteriorly. These findings were statistically significant and consistent with other studies showing

Table V. Summary of correlation analysis

Variable		*SCSD*	*RTD*	*RTA*
SCSD (mm ± SD)	Pearson correlation coefficient	1	−0.880	−0.891
	Significance		0.000	0.000
RTD (mm ± SD)	Pearson correlation coefficient	−0.880	1	0.974
	Significance	0.000		0.000
RTA (mm ± SD)	Pearson correlation coefficient	−0.891	0.974	1
	Significance	0.000	0.000	

RTA, rear drop to teardrop angle; RTD, rear drop to teardrop distance; SCSD, sacrococcygeal joint to symphysis pubis distance.

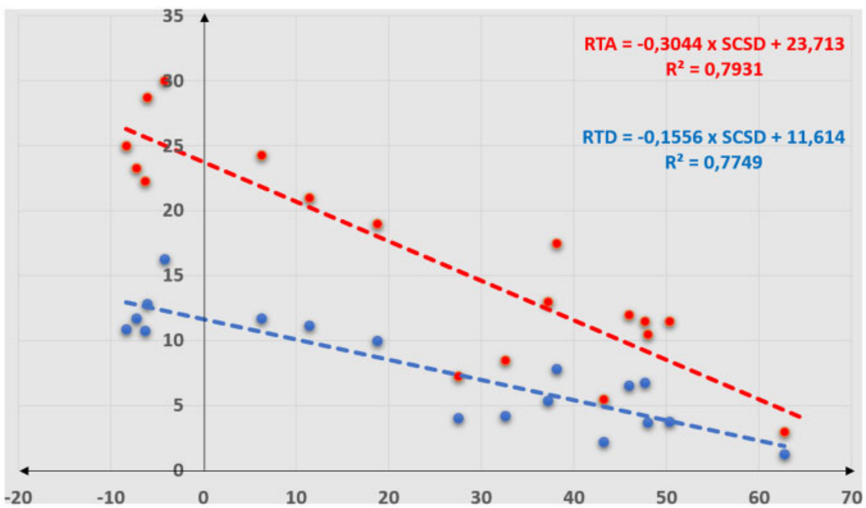

Fig. 7. Scatterplot of SCSD (*x*-axis) and RTD and RTA (*y*-axis). The inverse proportional relationship can be seen.

anterior pelvic tilt leading to acetabular retroversion with the appearance of radiographic signs of retroversion [12, 17]. The rear drop shape changed according to the pelvic inclination. When the pelvis was tilted anteriorly, increasing the SCSD, the rear drop appeared as a crescent shape, and when the pelvis tilted posteriorly, decreasing the SCSD, the rear drop shape turned into a dot. The correlation between the SCSD and rear drop shape was statistically significant.

The teardrop has been used as a reference for a variety of conditions, from the estimation of the position of the prosthetic implant to the diagnosis of pediatric disorders [18, 19]. Similarly, the rear drop can be studied in the future for estimation of the rotation of the pelvis by measuring the horizontal distance between the teardrop and rear drop and its significance in relation to developmental hip dysplasia and acetabular development.

There were few limitations to the study. This study was carried out with a relatively limited number of cadaveric pelves. However, Konishi and Mieno [16] have used similar numbers in their study on a method for the estimation of three-dimensional acetabular coverage. Samani and Weinstein [19] used three cadaveric pelves in their study of the anatomy of the teardrop, and Siebenrock *et al.* [10] used four cadavers in the description of SCSD. In our study, we did not utilize lateral pelvic radiographs to determine the pelvic inclination as it was practically rather difficult, and the images were not clear. Instead, we used SCSD as a surrogate marker of pelvic tilt and ISS and COS, which are indicators of acetabular retroversion, as reference values. In addition, all the specimens were from males, and it is well known that male and female pelves have distinct anatomic features. Finally, we did not use any advanced imaging techniques like CT in evaluating the pelvic tilt and the new parameters.

In summary, the rear drop image is routinely seen in the pelvis and hip radiographs; however, it was not studied before, and its shape changes with pelvic tilt. The newly derived reference parameters, RTD and RTA, changes with the pelvic tilt and are strongly correlated with the previously established parameter 'SCSD' in deciding the pelvic tilt. This preclinical cadaveric study can be a base for future research using this new reference figure and the described measurements in the clinical settings. Studies on the new figure's relevance to developmental hip dysplasia and acetabular development will help in furthering the understanding of these conditions in the pediatric populations.

CONFLICT OF INTEREST STATEMENT

None declared.

FUNDING

None.

DATA AVAILABILITY STATEMENT

The data underlying this article will be shared on reasonable request to the corresponding author.

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