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Original Research

A Novel Method to Calculate Functional Pelvic Tilt Using a Standing Anteroposterior Pelvis Radiograph

Jeffrey J. Frandsen, MD [a, *], Joshua P. Rainey, MD [a], Timothy L. Kahn, MD [b], Brenna E. Blackburn, PhD [a], Christopher E. Pelt, MD [a], Lucas A. Anderson, MD [a], Jeremy M. Gililland, MD [a]

[a] Department of Orthopaedics, University of Utah, Salt Lake City, UT, USA
[b] St. Mark's Hospital, Salt Lake City, UT, USA

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ABSTRACT

Background: Functional patient-specific acetabular component positioning is important in total hip arthroplasty. We preoperatively evaluate the pelvic tilt (PT) on standing anteroposterior (AP) pelvis radiographs using a novel measurement and then recreate this intraoperatively using imaging. The purpose of this study was to determine if there is a linear correlation between this novel measurement and the actual PT.

Methods: A retrospective study of 200 patients was performed, measuring PT on standing lateral radiographs as the angle between the anterior superior iliac spines and the pubic symphysis. On the AP pelvis radiographs, the trans-teardrop (TT) line was drawn between the teardrops. The vertical distance between the TT line and the top of the pubic symphysis (TTPS) was then measured. A ratio was made between the lengths of both lines to account for the overall size of the pelvis (TTPS/TT). Linear regression analysis was then performed between PT and TTPS/TT.

Results: There was a strong linear correlation between the TTPS/TT ratio on AP pelvis radiographs and PT on lateral radiographs ($r = 0.785$, $r^2 = 0.616$, $P < .001$). On subanalysis of the female cohort, the correlation became even stronger ($r = 0.864$, $r^2 = 0.747$, $P < .001$). Using regression analysis, a linear equation was created (PT = 97.32 [TTPS/TT] - 5.51), to calculate the PT using the TTPS/TT ratio.

Conclusions: There is a strong linear correlation between the TTPS/TT ratio and PT. Using this information, a surgeon can reliably use the distance between the TT line and the superior pubic symphysis on an AP radiograph to recreate the patient's functional PT intraoperatively, allowing for a more accurate patient-specific placement of the acetabular component.

Introduction

Instability is one of the most common complications following total hip arthroplasty (THA). It is found in approximately 2% of THA cases and is among the most common causes of revision in THA [1–4]. Acetabular component malposition is the most common cause of instability in THA [2,5].

In a commonly cited study, Lewinniek et al. described the traditional safe zones of acetabulum cup placement in 1978 [6]. He described a safe zone of 40 ± 10 degrees of inclination and 15 ± 10 degrees of anteversion. Recent studies have questioned this, though, demonstrating that Lewinniek safe zones may not be protective against dislocations [2,7–10]. Therefore, it has been suggested that either the true safe zones are narrower or that traditional safe zones do not properly account for functional pelvic tilt (PT) in abnormal native anatomy and/or spinopelvic immobility.

There is a significant amount of variability in functional PT across the population. A patient can have a neutral pelvis, an inlet pelvis (ie, flexed, anteverted, anteriorly tilted), or an outlet pelvis (ie, extended, retroverted, posteriorly tilted) (Fig. 1). Optimal acetabular component orientation is patient-specific and requires a preoperative evaluation of functional PT [11]. The pelvis can rotate an average of 5.5 degrees posteriorly from supine to standing, 3.7

* Corresponding author. Department of Orthopaedics, University of Utah, 590 Wakara Way, Salt Lake City, UT 84103, USA. Tel.: +1 208 360 3920.
E-mail address: frandsen.jeff@gmail.com

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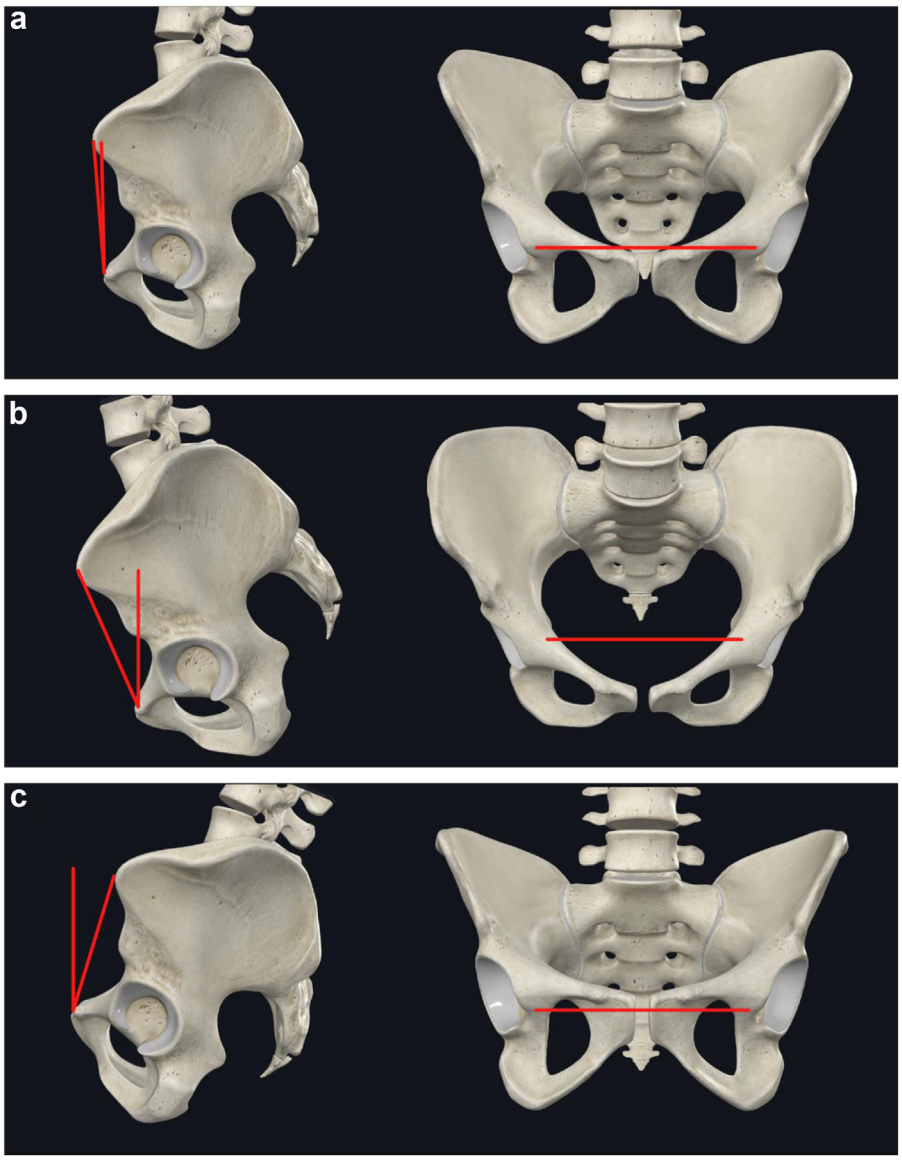

Figure 1. (a) Neutral pelvis, (b) inlet pelvis (ie, flexed, anteverted, anteriorly tilted), (c) outlet pelvis (ie, extended, retroverted, posteriorly tilted).

degrees posteriorly from supine to flexed seated, and anteriorly 1.8 degrees from standing to a flexed seated position [11]. These variations of pelvic rotation in different positions could lead to functional malpositioning for the acetabular component when the patient is supine on the operating room table.

When PT changes, the perceived acetabular anteversion and inclination changes. A posterior PT (pelvic reclination) of 1 degree will lead to a functional acetabular anteversion of approximately 0.7-0.8 degrees [12,13]. PT also leads to a functional acetabular inclination change. Although this relationship is not linear, in general, as the pelvis rotates posteriorly, the acetabular cup appears to have a higher abduction angle. Thus, if the patient has a different PT on the table in the operating room than they do functionally, the surgeon can mistakenly place the acetabular component in a different version and inclination than intended. For this reason, it is paramount for the surgeon to understand the preoperative functional PT and to recreate it intraoperatively to place the acetabular component accurately and precisely.

Understanding functional PT and pelvic mobility is especially important for the spinopelvic patient. This is an increasingly recognized pathology in patients presenting for a THA and has been shown to be a significant risk factor for postoperative dislocation [14–17]. Therefore, it has been recommended that all patients undergoing a THA should have a preoperative spinopelvic assessment in order to more accurately place the acetabular component and reduce the risk of dislocation.

Although previous work has demonstrated the importance of using lateral pelvic radiographs to evaluate PT preoperatively [11,16,18], standing anteroposterior (AP) pelvic radiographs are more commonly available and can be more easily replicated intraoperatively. One method previously described is calculating PT via the pubic symphysis to sacrococcygeal junction distance [19,20]. This has some limitations to its use, however, as the sacrococcygeal junction can be difficult to visualize on radiographs, and it was found to have a correlation coefficient of only 0.68 for men and 0.61 for women [19].

We propose a novel, easily reproducible, and accurate method to evaluate PT preoperatively and to recreate it intraoperatively, allowing for patient-specific cup placement into the functional safe zone. This method uses the trans-teardrop (TT) line to superior

pubic symphysis distance as a marker of PT and can be utilized in any clinical and surgical setting, requiring only a standing AP pelvis.

Material and methods

Following institutional review board approval, a retrospective imaging review of 200 patients who underwent a primary direct anterior total hip arthroplasty was performed at a single institution. Preoperative standing lateral scoliosis and standing AP pelvis radiographs were analyzed. On the lateral radiograph, functional PT was measured as the angle between a line starting halfway between the anterior superior iliac spines and a vertical line from the superior margin of the pubic symphysis, as has been previously described (Fig. 2) [21,22].

On the AP pelvis radiograph, the TT line was drawn between the most inferior points on the teardrops. The vertical distance between the TT line and the superior margin of the pubic symphysis was then measured, which we call the trans-teardrop to pubic symphysis (TTPS) line (Fig. 3). A ratio of the TTPS over the TT was made using the length of both lines (TTPS/TT). All radiographic reads were performed by 2 independent observers. Reliability statistics were performed on a subset of the data, calculating the kappa coefficients and 95% confidence interval for the interobserver reliability (Table 1).

Statistical analysis was performed at our institution comparing the TTPS/TT ratio and PT as measured on the lateral radiograph. A linear regression analysis was then performed on the cohort as a whole, and a subanalysis was performed on separated male and female cohorts. R and R^2 values were calculated, and a linear equation was made using the regression analysis.

Results

Overall, the average PT of all patients was −10.7° (SD = 9.8°); only 25 patients had an anterior PT. In subanalysis by gender, the average PT was −9.7° (SD = 10.1) in females and −12.3° (SD = 9.0) in males. The average distance from the TT line to the top of the TTPS was −6.3 mm (SD = 9.7 mm). In the patients with a TTPS of approximately 0 mm, the average PT was −6.0° (SD = 5.5°). In those patients with a PT within 3° of neutral (25 patients), the average TTPS was 1.5 mm (SD = 6.9 mm).

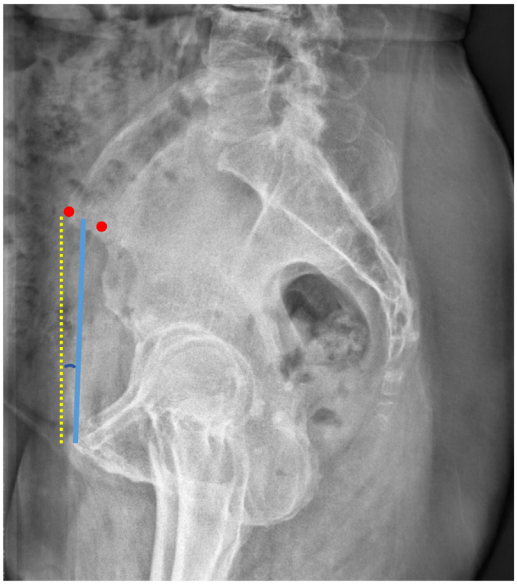

Figure 2. A dot is placed at the anterior superior iliac spine (ASIS) of both ilia; a line (light blue) is then drawn from the pubic symphysis to a point halfway between the 2 visualized ASISs. The functional pelvic tilt (PT) is the angle between this line and the vertical (dashed yellow line).

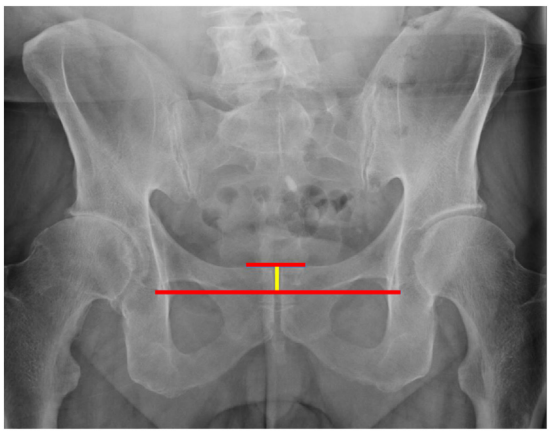

Figure 3. The top red line is the superior aspect of the pubic symphysis (PS), the bottom red line is the trans-teardrop line (TT), and the yellow line is the distance between the TT and PS (TTPS).

The average TTPS/TT ratio was −0.054 (SD = 0.079; range: −0.26 to 0.13). There was a strong correlation between the TTPS/TT on the AP radiographs and the PT on the lateral radiographs (r = 0.785, r^2 = 0.616, $P < .001$; Fig. 4). For a subanalysis of only female patients, this correlation was even stronger (r = 0.864, r^2 = 0.747, $P < .001$; Fig. 5). Subanalysis of male patients also demonstrated a significant correlation (r = 0.723, r^2 = 0.522, $P < .001$; Fig. 6).

Using regression analysis, a linear equation was created for calculating PT using the TTPS/TT ratio (y = 97.32x − 5.51). A linear equation was also created through regression analysis for the male and female cohorts (y = 98.43x − 2.8; y = 119.0x − 6.62, respectively).

Discussion

A proper evaluation and understanding of a patient's PT is important for several reasons. Firstly, it allows for categorization of the patient's preoperative pelvic position when standing; a retroverted pelvis is especially important to note as this has implications for potential anterior instability in the standing position [23]. Secondly, it allows for proper evaluation of acetabular component positioning (both intraoperatively and postoperatively) as version and inclination change with PT. For instance, an acetabular component that is in 20° of anteversion and 40° of inclination (traditional safe zones) in a radiograph of a highly retroverted pelvis would be significantly retroverted and adducted relative to that pelvic position. Thirdly, it is important to be able to recreate the standing PT intraoperatively (or at least account for differences between preoperative and intraoperative radiographs).

In this study, we demonstrated that PT (as judged by a lateral radiograph) can be reasonably estimated using only an AP radiograph, which has implications for both preoperative evaluation and

Table 1
Reliability statistics.

Variable	Kappa	95% Confidence interval for interobserver reliability
Pelvic tilt	0.87	(0.81, 0.93)
Trans-teardrop (TT) length	0.86	(0.77, 0.96)
TT to symphysis	0.89	(0.77, 1.00)

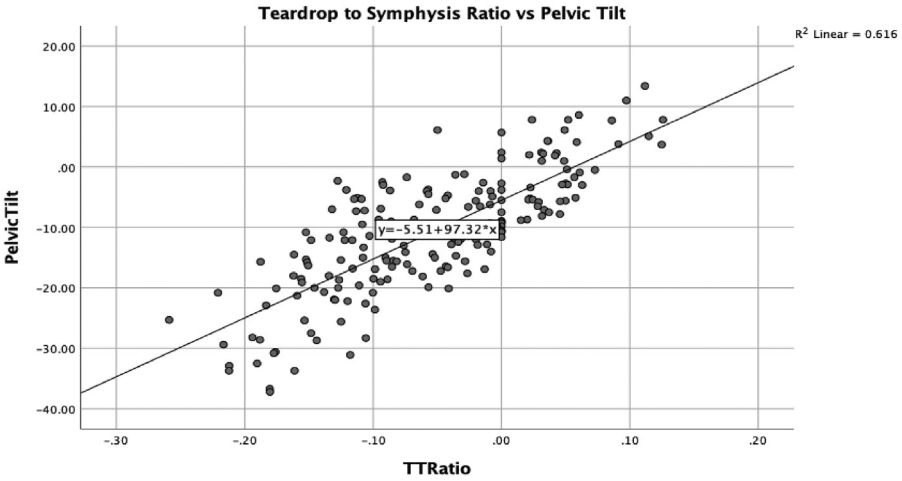

Figure 4. Scatterplot of pelvic tilt for given TTRatio in all included patients with associated line of best fit.

intraoperative imaging. While standing lateral pelvic radiographs allow for direct measurement of PT, they are not routinely obtained by arthroplasty surgeons. Furthermore, they can be difficult to obtain intraoperatively and are not typically used for determining acetabular component positioning. Therefore, in our practice, we find that utilizing AP radiographs for evaluation of PT and recreating this intraoperatively is an effective and utilitarian method for accounting for PT.

While the relationship between PT and acetabular component positioning was not directly evaluated in this study, it could be expected that by combining our findings with knowledge of the effects of PT on acetabular version and inclination, proper acetabular component positioning could be estimated for a patient's given PT on an AP radiograph alone. This would be especially useful when judging intraoperative component positioning, as is typically done with either fluoroscopy in the supine position or with an AP pelvis radiograph in the lateral position.

Other methods of determining PT from AP radiographs have been described. Tannast et al. described several methods for determining PT and found that the distance between the upper border of the symphysis and the sacrococcygeal joint had the strongest correlation with PT (0.68 in males and 0.61 in females) [19]. Atilla et al. describe a radiographic landmark ("rear drop") to estimate PT and found a strong correlation between this method and the symphysis to sacrococcygeal joint method [24]. In this study, the TTPS/TT ratio had a strong correlation with PT and is also an easily reproducible measurement on nearly all AP pelvic radiographs. While there are multiple methods that can be used to estimate PT, the simplicity and reproducibility of the method are crucial for clinical utilization.

Limitations

There are several limitations to this study. Firstly, while PT was evaluated in the standing position, we did not attempt to correlate PT with sit/stand pelvic radiographs. Sit/stand lateral imaging is the most common method for evaluating spinopelvic stiffness and is a useful method for determining optimal acetabular component positioning. However, the goal of this study was to evaluate standing PT rather than spinopelvic stiffness, so the analysis was limited to only standing AP and lateral radiographs. Secondly, acetabular component positioning was not evaluated on

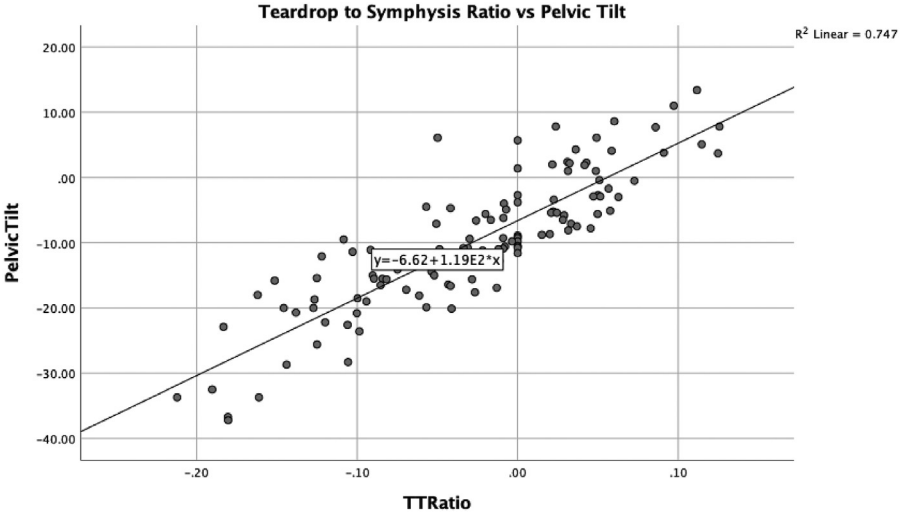

Figure 5. Scatterplot of pelvic tilt for given TTRatio in female patients with associated line of best fit.

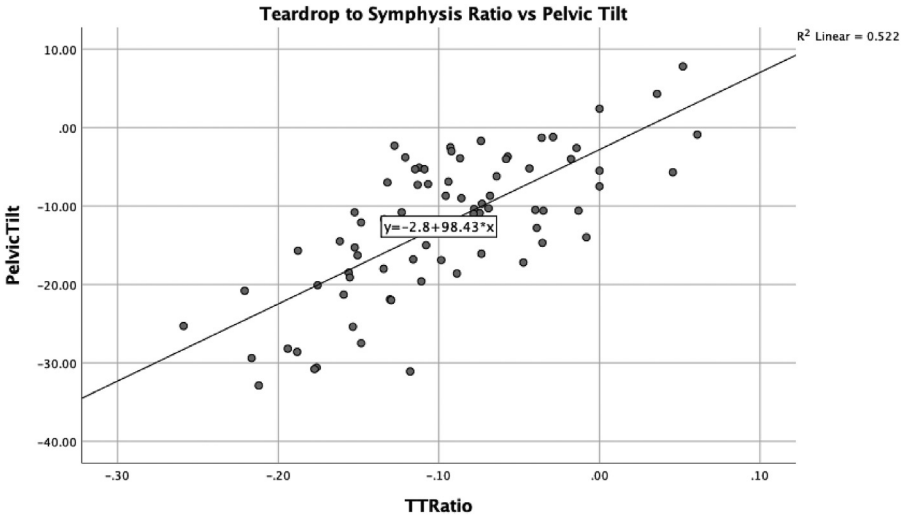

Figure 6. Scatterplot of pelvic tilt for given TTRatio in male patients with associated line of best fit.

radiographs, as most radiographs were preoperative. Further studies evaluating acetabular component position as related to PT measurements on AP radiographs would be useful in further validating the methods in this study.

Conclusions

There is a strong linear correlation between the TTPS/TT ratio on AP radiographs and PT. Using this information, a surgeon can better understand the functional PT on standing AP pelvis radiographs and may be able to use this information to more accurately recreate the functional PT intraoperatively. Furthermore, the ability to determine PT from AP pelvic imaging may help improve the accuracy of acetabular component positioning when using intraoperative imaging.

Conflicts of interest

1. Royalties from a company or supplier (The following conflicts were disclosed) Total Joint Orthopedics, OrthoGrid, Zimmer/Biomet, Smith and Nephew.
2. Speakers bureau/paid presentations for a company or supplier (The following conflicts were disclosed) Zimmer Biomet, Total Joint Orthopedics, Smith and Nephew, 3M/KCI.

3A. Paid employee for a company or supplier (The following conflicts were disclosed) none.

3B. Paid consultant for a company or supplier (The following conflicts were disclosed) Zimmer Biomet, Total Joint Orthopedics, Smith and Nephew, 3M/KCI, Medacta, OrthoGrid, Stryker, DJO, ConvaTec.

3C. Unpaid consultants for a company or supplier (The following conflicts were disclosed) none.

4. Stock or stock options in a company or supplier (The following conflicts were disclosed) Joint Development Inc, OrthoGrid, Connextions, Muve Health.
5. Research support from a company or supplier as a Principal Investigator (The following conflicts were disclosed) Zimmer/Biomet, Stryker, Peptilogics.
6. Other financial or material support from a company or supplier (The following conflicts were disclosed) none.
7. Royalties, financial or material support from publishers (The following conflicts were disclosed) none.
8. Medical/Orthopaedic publications editorial/governing board (The following conflicts were disclosed) Editorial board of Journal of Arthroplasty, Journal of Hip Preservation.
9. Board member/committee appointments for a society (The following conflicts were disclosed) AAOS, AAHKS Committee Member, AAHKS Program Committee, Knee Society.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101145.

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