Acetabular Ventroversion with Double Pelvic Osteotomy Versus Triple Pelvic Osteotomy: A Cadaveric Study in Dogs

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Objective: To determine which of 3 different plate angles (20°, 25°, 30°) used in double pelvic osteotomy (DPO) would result in the most similar acetabular angle (AA) achieved with a 20° triple pelvic osteotomy (TPO) technique in dogs.
Study Design: Experimental anatomic study.
Animals: Cadaveric canine pelves (n = 8).
Methods: Transverse plane computed tomographic images of cadaveric pelves with intact sacroiliac joints, mounted in a custom jig, were made (baseline) and again after DPO (20°, 25°, 30°) and TPO (20°) and pelvic angles measured in 6 transverse planes. Pelvic angles of the 3 DPO techniques were compared with TPO using concordance correlation to determine which DPO angle resulted in an acetabular ventroversion angle closest to TPO.
Results: Mean $\pm$ SD AAs were 32.89 $\pm$ 2.23 (baseline), 47.39 $\pm$ 4.39 (20° DPO), 51.43 $\pm$ 5.06 (25° DPO), 54.75 $\pm$ 4.38 (30° DPO), and 50.20 $\pm$ 5.76 (20° TPO). Concordance correlations for the AA compared with 20° TPO were 0.027 (baseline), 0.721 (20° DPO), 0.902 (25° DPO), and 0.593 (30° DPO). A concordance correlation of $\geq$0.8 indicates good correlation.
Conclusions: A 25° DPO is most similar in acetabular ventroversion to 20° TPO (concordance correlation, 0.902).

Untreated canine hip dysplasia (CHD) can result in secondary osteoarthritis that may cause pain and dysfunction.[1,2] Triple pelvic osteotomy (TPO) increases the dorsal acetabular coverage of the femoral head in young dogs thereby eliminating hip subluxation to prevent progression of osteoarthritis early in the course of CHD.[3] Ideal candidates for TPO have palpable hip joint laxity, radiographic incongruity, absence of arthroscopic evidence of degenerative joint disease, and are most often < 1 year of age.[4,5] When effective, TPO can greatly reduce limb dysfunction resulting in 86–92% normal or near normal function in operated limbs based on owner observation.[6,7] Even in dogs that did not return to full function, up to 12% of dogs had improved limb function compared with preoperative function.[7] TPO minimizes development of osteoarthritis.[8]

However, despite its benefits, dogs that are eligible for TPO are young, active large breed dogs with less cortical bone density than adult dogs and therefore may be at higher risk for implant-related complications. Complications were reported to occur in up to 8 of 12 dogs after TPO.[9] Screw loosening resulting in implant instability is the most common complication and can occur as early as 10 days after surgery.[10] In an effort to reduce the rate of implant-related complications associated with TPO, the procedure has been modified using 2 rather than 3 osteotomies of the pelvis.[5,11,12] Potential advantages of double pelvic osteotomy (DPO) include greater postoperative stability of the hemipelvis, improved immediate postoperative comfort, and a much lower morbidity rate for unilateral or bilateral DPO compared with TPO.[5]

DPO involves osteotomies of the ilium and pubis to allow ventroversion of the acetabulum with a specifically designed bone plate. Transection of the sacrotuberous ligament at its insertion on the ischiatic tuberosity has been reported to facilitate manipulation of the ischiatic table.[12] Performing only 2 osteotomies may result in a more biomechanically stable construct that will better withstand the forces produced by young, active large breed dogs and result in less implant loosening and failure than TPO. However, because the structural integrity of a pelvis after DPO is different than with TPO, the magnitude of ventroversion required (ie, selection of appropriate plate angle) to produce the same effect as TPO is unknown. Haudiquet and Guillon[11] using an in vitro radiographic study, reported

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that a 25° DPO would result in the most similar femoral head coverage to a 20° TPO.

Our purpose was to compare the acetabular ventroversion achieved after DPO using 3 different plate angles (20°, 25°, 30°) with that achieved by conventional 20° TPO. Secondarily, pelvic bone angles were compared using 6 anatomic references pre- and postoperatively for each technique to identify the relative anatomic location of the hemipelvic torsion caused by DPO. Based on previous work by Haudiquet and Guillon,[11] our hypothesis was that 25° DPO would result in a degree of acetabular ventroversion most similar to 20° TPO. A secondary hypothesis was that ventroversion of acetabular segment of the hemipelvis after DPO results from rotation of the pubic symphysis because an ischial osteotomy is not performed.

MATERIALS AND METHODS

Large breed canine cadavers (n = 8) were obtained after euthanasia for reasons unrelated to this study. None of the dogs had a previous history of musculoskeletal malformation, systemic disease, or trauma based on verbal history and physical examination.

Specimen Collection

The entire pelvis was dissected free by transecting between the 6th and 7th lumbar vertebrae (L7), amputating the tail caudal to the 4th caudal vertebra, and disarticulating the femora from the coxofemoral joints by incisions in the joint capsule, ligamentum teres, and supporting musculature. Soft tissues were removed from each specimen being careful to leave the lumbosacral and sacroiliac articulations, and both of the sacrotuberous ligaments intact and undisturbed. Care was taken to not damage the bone or any of the tissues particularly around the pubic symphysis and acetabulae. The articular cartilage and periarticular soft tissues of each coxofemoral joint were inspected for signs of osteoarthritis, malformation, or trauma. During dissection, each specimen was moistened repeatedly with isotonic saline (0.9% NaCl) solution. After dissection, the pelves were wrapped in moist towels, double wrapped in plastic, and frozen at −20°C.

Specimen Preparation

For the experiment, specimens were thawed in a room temperature water bath over night. During each step in the procedure, a spray bottle with physiologic saline solution was used to keep the specimens moist. In each hemipelvis, bilateral holes were drilled from lateral to medial at one-third the distance from the dorsal most aspect to the ventral most aspect of the iliac crest. A commercially available aiming device (Synthes Vet, West Chester, PA) was used to ensure that the bone tunnels were drilled accurately from 1 iliac crest to the other. A 1/4 in. threaded nylon rod was screwed by hand into both iliac crests. The dorsal spinous process of L7 was removed with rongeurs to prevent impingement of the nylon rod. The rod was used to suspend the pelvis in a U-shaped acrylic custom jig.

Each specimen was securely mounted from the iliac crests cranial and dorsal to L7 and effectively outside the weight-bearing axis of the pelvis (Fig 1). The nylon rod did not contact the pelvis anywhere other than the tunnels in the iliac crests. A groove in the jig allowed the rod to be raised and lowered so that the pelvis could be mounted with the long axis of the ilium at 40° from horizontal, after which the rod was locked to the jig by two 1/4 in. nylon washers and two 1/4 in. nylon nuts on each side.

Ventrodorsal and lateral radiographic projections of mounted specimens were used to confirm normal bony anatomy and conformation. The pelvis and jig were positioned in a computed tomography (CT) scanner (Picker PQ 6000, Philips Healthcare, Andover, MA) with the aid of crossed lasers to ensure repeatability in positioning between CT sessions. During the initial CT scan (subsequently referred to as Baseline), initial slices were taken to be sure the pelvis was mounted level to the dorsal plane. Once this was confirmed, acrylic glass struts were securely

A B

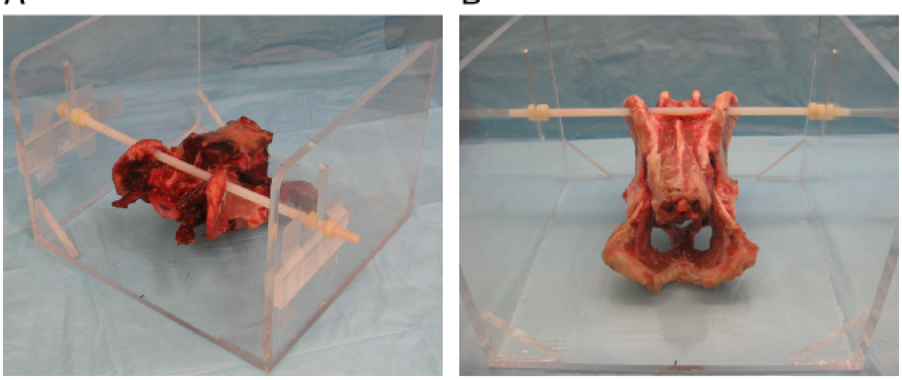

Figure 1 Photos from the craniolateral (A) and caudal (B) direction of a dissected pelvis and mounted in the custom acrylic jig before the 1st computed tomography scan.

fashioned with adhesive tape (Scotch® Magic™ tape, 3M, St. Paul, MN) to the jig to support the rod before the nuts were tightened. These struts ensured that the pelvis was mounted identically between CT sessions. Two nylon nuts were tightened against each other and positioned against the jig at a fixed location on the nylon rod so that the medial to lateral position of the pelvis and jig did not vary between CT sessions.

Contiguous 1 mm transverse CT slices (80–120 kVp, 160 mA) were taken of the entire pelvis from the most cranial aspect of the iliac crest to the most caudal aspect of the ischium with the gantry in the vertical position as described by Wang et al.[13]

After baseline CT scan, the 1st specimen had DPO with a 20° plate (20° DPO) performed on the right hemipelvis. A coin toss was used to select which side was operated first. Each successive pelvis had the procedure performed on the opposite side so that DPO was performed on the right side of 4 specimens and the left of 4 specimens.

For DPO, a pubic ostectomy that excised the entirety of the iliopubic eminence was performed using an oscillating sagittal saw. The sacrotuberous ligament was then removed only from the operated side. Finally, iliac osteotomy was performed as described for TPO.[14] The dorsoventral iliac osteotomy was oriented 20° in the caudal direction from a line perpendicular to the long axis of the ilium by use of a custom made jig.[15] A 20° plate (locking TPO plate, New Generation Devices, Glen Rock, NJ) was fastened with three 3.5 mm cortical bone screws to the caudal segment with the osteotomy in contact with the step in the plate and the ventral aspect of the plate level with the ventral margin of the ilium. The cranial aspect of the plate was then fastened to the cranial ilium again at the ventral aspect with three 3.5 mm cortical bone screws. Fixed 90° angle drill guides (3.5 mm locking drill guides, New Generation Devices) specifically designed for use with the plate were used to drill all screw holes. All screws engaged both cortices of the ilium without penetrating the sacrum. The same 6 plates (1 left 20°, 1 right 20°, 1 left 25°, 1 right 25°, 1 left 30°, and 1 right 30°) were used throughout the experiment, so that all 4 left DPO20 and left TPO20 used the same left 20° plate, all 4 right DPO30 used the same right 30° plate, etc. The pelvis was repositioned in the jig on the previously secured struts with the double nut against the jig to ensure its position in the jig was identical to the 1st CT (Baseline). Lasers were used to reposition the jig in the CT. A 2nd CT scan (subsequently referred to as 20° DPO) was performed identically to the first.

To mimic a DPO of 25°, the pelvis was removed from the jig. The 20° plate was carefully removed and replaced with a 25° plate (New Generation Devices) that accommodated screws in the same position. Pelvis positioning was performed again for a 3rd CT scan (25° DPO). A 4th CT (30° DPO) was performed with a 30° plate (New Generation Devices) to mimic a DPO of 30°. Finally, to mimic a TPO of 20°, the 30° plate was removed, an osteotomy of the ischium into the lateral limit of the obturator foramen was made in the sagittal plane using an oscillating saw as described.[16] Bone tunnels were drilled on either side of the osteotomy so that a loop of #1 braided suture (Polysorb, Covidien, Mansfield, MA) could be placed to mimic the hemicerclage wire typically used in clinical practice. The pelvis was positioned and imaged by CT scan (20° TPO).

Measurements

Six measurements were made from each CT study (Fig 2). The iliac crest angle was measured on the most caudal image of the iliac crest that did not include any portion of the sacroiliac articulation. The preacetabular angle (PreAce) was measured from the most caudal image cranial to the acetabulum that did not include any of the widening of the iliac body as it transitions into acetabular bone. The acetabular angle (AA) was measured from the 1st image cranial to the fovea capitis that included the ventral acetabular rim. The postacetabular angle (PostAce) was the 1st image

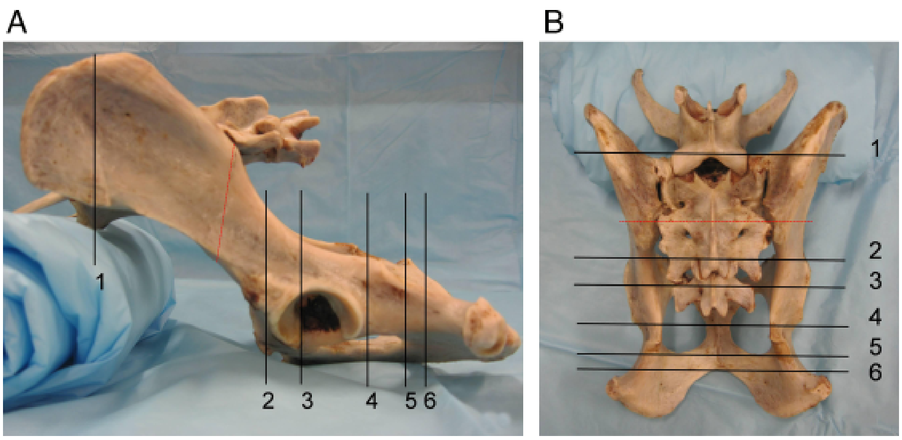

Figure 2 Lateral (A) and dorsal (B) views of a canine pelvis and sacrum with black lines to represent the computed tomography slices for the angles. (1) Iliac crest (2) preacetabular (3) acetabular angle (4) postacetabular (5) cranial ischial (6) caudal ischial. A dashed red line indicates the location and direction of the iliac osteotomy.

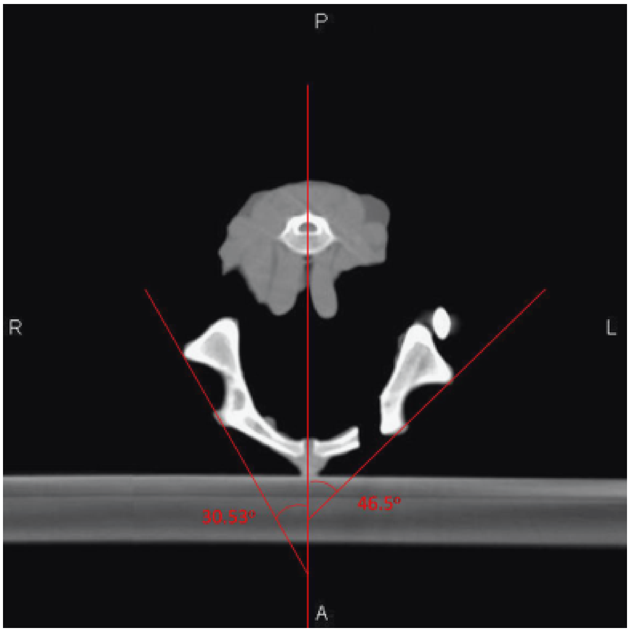

Figure 3 Computed tomographic image illustrating a line drawn to represent the midline of the pelvis and lines drawn to represent the acetabular angles for each hemipelvis.

caudal to the acetabulum, but otherwise similar to the PreAce. Cranial (CrIs) and caudal ischial (CdIs) angles were measured from the most cranial and caudal images, respectively, that included the symphysis pubis.

All measurements were made in relation to a midline drawn from the AA image and defined as a line that bisected the symphysis pubis, vertebral canal, and dorsal spinous process. The software used to make the angle measurements (reViewMD, v2.0, 2002, Digisoft LLC, Philadelphia, PA), allowed for the same midline to be transferred onto the other CT images so that the exact midline representing the median plane was used to calculate the other 5 angles for each CT study. The AA was drawn as described in an anatomic study of the canine pelvis by Wang et al,[13] except that instead of the AA being a single measurement combining the angles from both acetabulae, the value was calculated as an angle from midline for each acetabulum (left and right; Fig 3). The other 5 angles were created by drawing a line representing the medial cortex of the ilium to intersect the midline.

For the 20° TPO, CrIs and CdIs angles were measured using a line along the ischial cortex still contacting the symphysis pubis. Lines that were drawn toward the midline in a dorsoventral direction were designated as positive angles whereas those directed away were considered negative. For change in ventroversion measurements between CT studies, an increase in ventroversion was deemed to be a positive change. All 6 measurements were made bilaterally (operated and unoperated hemipelvis) for each CT study. This measurement protocol was repeated in each of the 8 pelves.

Statistical Analysis

To evaluate the agreement between angle measurements for TPO and the 3 DPO procedures, the concordance coefficient, ρ_c, was used.[17,18] The concordance coefficient measures the correlation between 2 measurements (eg, angles) from the same sample (eg, dog) by measuring the variation departing from perfect agreement (which is a 45° line through the origin, known as the concordance line). The mathematical formula for ρ_c is complex, but in its essence is a Pearson's correlation multiplied by a bias correction factor. Interpretation of the coefficient is similar to that of Pearson's correlation: values of 1 imply perfect agreement, whereas values of -1 imply perfect reverse agreement (ie, disagreement). Estimates of the concordance coefficient and associated 95% confidence intervals (95% CI) were computed using a custom macro written for use with software (SAS software, version 9.2, SAS Institute Inc., Cary, NC).

RESULTS

Cadaver weights ranged from 13.2–19.2 kg (mean, 16 kg). Dogs were aged 6–8 months of age (mean, 6.5 months); and there were 2 intact males and 6 intact females.

AA measurements (mean ± SD) for Baseline, 20°, 25°, 30° DPO, and 20° TPO were 32.89 ± 2.23, 47.39 ± 4.39, 51.43 ± 5.06, 54.75 ± 4.38, and 50.20 ± 5.76, respectively. Figure 4 illustrates the AA for both operated and unoperated hemipelves. Tables 2 and 3 are calculated values from Table 1 and enumerate the change in angulation for that technique compared with the same unoperated hemipelvis (Baseline) and the change in angulation compared with the previous step in the experimental procedure (eg, 25–30° DPO), respectively. In particular, 20°, 25°, 30° DPO, and 20° TPO increased AA ventroversion by 14.51 ± 2.83, 18.55 ± 3.05, 21.86 ± 2.56, and 17.32 ± 3.70, respectively. Changes in AA from the previous technique were

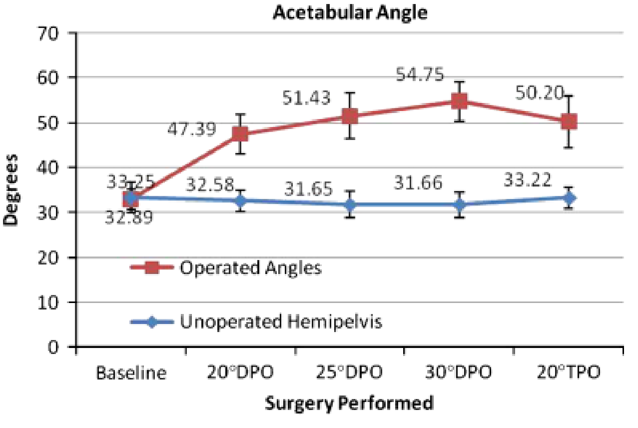

Figure 4 Line graph comparing the average acetabular angle values of the operated to unoperated hemipelvis for each of the surgical techniques.

Table 1 Mean ± SD Anatomic Angle Measurements for Baseline and After Double Pelvic Osteotomy (DPO at 20°, 25°, 30°) and Triple Pelvic Osteotomy (TPO at 20°)

Angles	Baseline	20° DPO	25° DPO	30° DPO	20° TPO
IlCr	− 2.78 ± 4.73	− 7.11 ± 4.44	− 7.90 ± 6.14	− 9.38 ± 5.78	− 5.57 ± 7.66
PreAce	0.84 ± 1.14	16.40 ± 5.09	19.64 ± 5.35	24.83 ± 6.50	17.89 ± 7.73
AA	32.89 ± 2.23	47.39 ± 4.39	51.43 ± 5.06	54.75 ± 4.38	50.20 ± 5.76
PostAce	− 1.20 ± 2.46	11.72 ± 5.56	16.12 ± 6.43	20.63 ± 6.19	16.77 ± 7.61
CrIs	61.06 ± 4.75	73.70 ± 7.07	77.48 ± 8.72	80.50 ± 8.19	70.52 ± 6.35
CdIs	60.35 ± 5.07	74.99 ± 6.20	78.52 ± 8.55	83.40 ± 7.24	68.22 ± 4.54

IlCr, iliac crest angle; PreAce, pre acetabular angle; AA, acetabular angle; PostAce, postacetabular angle; CrIs, cranial ischial angle; CdIs, caudal ischial angle.

14.51 ± 2.83, 4.04 ± 2.19, 3.32 ± 1.49, and − 4.55 ± 2.71 for Baseline to 20° DPO, 20–25° DPO, 25–30° DPO, and 30° DPO–20° TPO, respectively. The ventroversion obtained from 25° DPO compared with Baseline at PreAce, AA, PostAce, CrIs, and CdIs were 18.80 ± 4.86, 18.55 ± 3.05, 17.32 ± 5.62, 16.43 ± 5.06, and 18.17 ± 5.90, respectively. Concordance correlation results are summarized in Fig 5. Compared with TPO20, concordance correlation coefficient (95% CI) for Baseline, 20°, 25°, and 30° DPO were 0.027 (− 0.059 to 0.113), 0.721 (0.283–0.910), 0.902 (0.636–0.977), and 0.593 (0.174–0.830).

DISCUSSION

Based on the in vitro work of Dejardin et al,[19] the maximum recommended ventroversion of the acetabular component for TPO is 20°, as measured by applying a custom made plate that was able to adjust its degree of angulation. Results of that study discouraged the use of more angulated plates for TPO because of the perceived risk of increased morbidity with increased plate angle size. This recommendation has been given more support by a clinical study by Tomlinson and Cook[20] who reported no difference in Norberg angles and percent coverage of the femoral head immediately postoperatively and at subsequent rechecks between dogs that had 20° TPO compared with those that had 30° TPO.

Because of this, we used 20° TPO as the standard technique to replicate with different angled DPO. We found CT to be an accurate and repeatable tool for measurement of AAs to quantify the acetabular ventroversion resulting from each procedure. We found that 25° DPO compared most similarly with 20° TPO with a highly favorable concordance correlation (ρ_c = .90). This result directly correlates to the findings of previous radiographic and clinical studies comparing TPO and DPO.[5,11] We found that 25° DPO resulted in a mean ventroversion angle 1.23° greater than that of the 20° TPO (51.43° versus 50.20°). Concordance correlation (ρ_c = 0.72) supports 20° DPO as the 2nd most likely procedure to mimic the results of 20° TPO.

Table 2 Mean ± SD Change in Anatomic Angle Measurements from Baseline After Double Pelvic Osteotomy (DPO at 20°, 25°, 30°) and Triple Pelvic Osteotomy (TPO at 20°)

Angles	20° DPO	25° DPO	30° DPO	20° TPO
IlCr	− 4.33 ± 2.99	− 5.12 ± 3.56	− 6.60 ± 3.27	− 2.79 ± 5.63
PreAce	15.56 ± 4.35	18.80 ± 4.86	23.99 ± 5.79	17.06 ± 7.26
AA	14.51 ± 2.83	18.55 ± 3.05	21.86 ± 2.56	17.32 ± 3.70
PostAce	12.92 ± 4.78	17.32 ± 5.62	21.83 ± 5.05	17.96 ± 6.27
CrIs	12.64 ± 4.87	16.43 ± 5.06	19.44 ± 5.26	9.46 ± 3.41
CdIs	14.64 ± 5.27	18.17 ± 5.90	23.05 ± 5.13	7.87 ± 2.98

Angle abbreviation key provided with Table 1. A positive angle change represents an increase in ventroversion.
IlCr, iliac crest angle; PreAce, pre acetabular angle; AA, acetabular angle; PostAce, postacetabular angle; CrIs, cranial ischial angle; CdIs, caudal ischial angle.

The choice of the concordance coefficient for evaluating the agreement between the procedures was critical, as many commonly used statistical measures of agreement (eg, Pearson's correlation, Spearman's correlation, paired t-test, or least-squares analysis of slope = 1 and intercept = 0) have shortcomings that, if used in our current settings, would overstate the *extent* of agreement between procedures, as well as the *nature* of the agreement.[18] For example, Pearson's or Spearman's correlation would indicate perfect agreement even though each pair of angles differed by 10°, which is clearly not an acceptable property in our setting. The concordance coefficient does not have this flaw. Lin gives graphical illustrations of the shortcomings for other methods used in scenarios similar to this current study.[18]

Plastic deformation of the pelvis caused by DPO is a source of potential error in our results. Because TPO requires an ischial osteotomy and DPO does not, to perform the same technique on the same specimens, TPO had to be performed last. Because DPO relies on deformation of the hemipelvis caudal to the osteotomy to achieve ventroversion, and our experimental technique involved DPO of 20°, 25°, and 30° before TPO, it is likely that the acetabular segment was plastically deformed to some degree before TPO. If plastic deformation occurred in the iliac body cranial to the acetabulum or in the acetabulum itself, the deformation would have affected our results by artificially increasing the observed AA by 20° TPO.

In looking at the change in ventroversion from PreAce, AA, and PostAce for 20° TPO, the values were 17.06, 17.32, and 17.96, respectively. This 0.9° increase in ventroversion between the cranial measurement of PreAce to the more caudal measurement of PostAce suggests that there was potentially 0.9° of plastic deformation of the

Table 3 Mean ± SD Change in Anatomic Angle Measurements between Successive Osteotomy Techniques Angle Abbreviation Key provided with Table 1

	Baseline–20° DPO	20–25° DPO	25–30° DPO	30° DPO–20° TPO
IlCr	− 4.33 ± 2.99	− 0.79 ± 2.72	− 1.48 ± 2.51	3.81 ± 3.70
PreAce	15.56 ± 4.35	3.24 ± 4.18	5.19 ± 2.89	− 6.93 ± 3.90
AA	14.51 ± 2.83	4.04 ± 2.19	3.32 ± 1.49	− 4.55 ± 2.71
PostAce	12.92 ± 4.78	4.40 ± 2.24	4.51 ± 1.52	− 3.86 ± 2.23
CrIs	12.64 ± 4.87	3.78 ± 2.89	3.01 ± 2.29	− 9.98 ± 7.10
CdIs	14.64 ± 5.27	3.53 ± 2.93	4.88 ± 2.56	− 15.80 ± 7.05

A positive angle change represents an increase in ventroversion.
IlCr, iliac crest angle; PreAce, pre acetabular angle; AA, acetabular angle; PostAce, postacetabular angle; CrIs, cranial ischial angle; CdIs, caudal ischial angle.

acetabular segment itself. If this assumption is true, the corrected AA measurement for 20° TPO would be 49.30°. Compared with 47.39° for 20° DPO, and 51.43° for 25° DPO, we would still recommend 25° DPO rather than 20° DPO. Given the option of over rotating the acetabulum by 2.13° to increase coverage of the femoral head versus under rotation of 1.91°, seemingly over rotation would be preferable to increase acetabular contact area, preventing coxofemoral subluxation and secondary osteoarthritis. Dejardin et al[19] found increases in articular contact area with acetabular ventroversion of up to 30°, but warned of the potential for increased morbidity after the significant initial benefit of the 20° plate for TPO. Use of a 20° plate for DPO results in acetabular ventroversion, but 1.91° lower than 20° TPO on average. This acetabular under rotation may still be clinically efficacious for prevention of coxofemoral subluxation in some dogs, but results in a ventroversion much closer to the cutoff (17.2 ± 1.3°) ventroversion angle to increase articular contact area as recommended by Dejardin et al.[19] Therefore, based on our results a 25° plate for DPO would be preferable.

In evaluating the anatomic measurements of the ilium and ischium in different CT slices with DPO, there is evidence that supports our hypothesis of acetabular ventroversion mostly occurring because of rotation or flattening at the pubic symphysis (Fig 6). In looking at the increase in ventroversion from baseline (Table 2), the average change in ventroversion between each portion of the anatomy is similar (18.80, 18.55, 17.32, and 16.43 moving from cranial [PreAce] to caudal [CrIs] for the 25° DPO, for example) with a gradual 2.37° decrease in ventroversion between PreAce and CrIs. If ventroversion occurred solely because of torsion within the iliac body and acetabulum, one would expect a dramatic change in measured ventroversion over the length of the ilium and acetabulum. In fact, ventroversion occurred almost as much in the ischium as it did more cranially. The gradual slight decrease in ventroversion between measurement points moving from a cranial point (PreAce) to a caudal point (CrIs; 2.37° for a 25° plate) illustrates iliac torsion as a much smaller component of the ventroversion created by the DPO technique, and perhaps represents 12% (2.37/18.8) of the overall ventroversion (18.8°). However, most (88%) ventroversion appears to

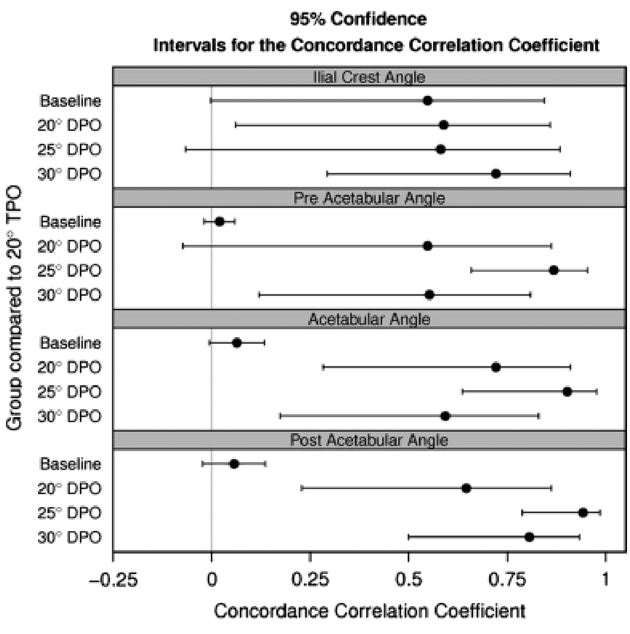

Figure 5 Ninety-five percent confidence intervals for the concordance correlation coefficient.

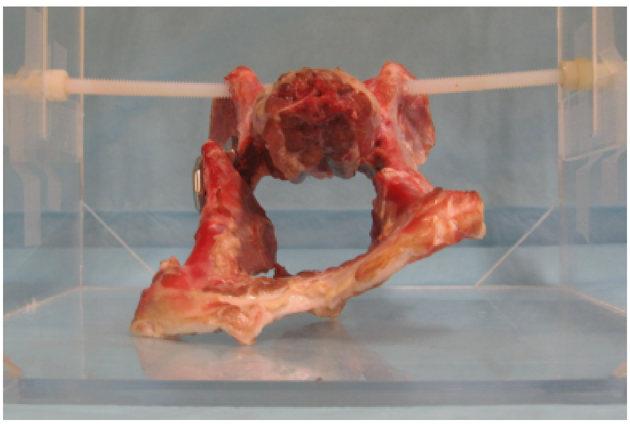

Figure 6 Photo from the caudal direction of a mounted specimen after having a double pelvic osteotomy of 30° (30° DPO). Note that acetabular ventroversion is achieved secondary to rotation of the symphysis pubis.

occur at the level of the symphysis pubis. Both of the ischial angles show dramatic and similar degrees of ventroversion with each of the DPO techniques. CrIs angles before (baseline) and after DPO increase by a mean of 12.64 ± 4.87, 16.43 ± 5.06, and 19.44 ± 5.26, and the CdIs angles by 14.64 ± 5.27, 18.17 ± 5.90, and 23.05 ± 5.13 for 20°, 25°, and 30° DPO, respectively. The unoperated hemipelvis' CrIs and CdIs showed no significant change in angles compared with baseline (data not shown) resulting in a measurable rotation at the pubic symphysis.

By comparison, TPO increased mean ventroversion of PreAce, AA, and PostAce 17.06°, 17.32°, and 17.96°, respectively. These very similar values illustrate the way that TPO causes ventroversion of the acetabulum by ventroversion of the entire segment as a single unit, causing dorsal wedging of the ischial osteotomy. As mentioned earlier, we attribute the 0.9° difference to plastic deformation secondary to torsion induced by the previous DPO technique.

When evaluating the numerical data for acetabular ventroversion angles, it may be surprising that a 20° plate did not increase acetabular ventroversion by 20° in either DPO or TPO, and each 5° increase in plate size did not increase ventroversion by 5° either. This trend can be explained by the fact that the long axis of the canine hemipelvis is oriented at 40° from the frontal plane. When an iliac osteotomy is made at an angle other than 40°, rotation about the osteotomy results in rotation in the frontal plane as well as the transverse plane. Graehler et al[15] recommended a 20° iliac osteotomy as a compromise between minimizing acetabular lateralization and preservation of sufficient bone stock in the acetabular segment for the placement of screws for plate fixation. We used this recommendation in our study design. To minimize the variation of acetabular ventroversion by variation in iliac osteotomy angle, a custom Plexiglas cutting jig was used to make all iliac osteotomies in our study.

Our study was designed to mimic the clinical technique for DPO and TPO in an effort to make this study as clinically applicable as possible; however, there are several limitations to consider in the analysis of these results. The pelves we used were from dogs with normal hip conformation, did not include the femoral portion of the coxofemoral joint, and did not evaluate the techniques' ability to prevent dorsolateral subluxation of the coxofemoral joint. Abnormal conformation in dogs with CHD may alter the anatomic alterations secondary to the DPO technique. We did not examine each technique's ability to prevent dorsolateral subluxation, perhaps a better functional measure of the techniques' clinical applicability. We cannot comment on the temporal functional stability of the DPO modified pelvis. We believe that the DPO initially causes elastic deformation of the hemipelvis thus avoiding the need for ischial osteotomy. Further studies are needed to examine the ability of the DPO technique to decrease postoperative implant-related complications or patient pain.

Summarily, DPO performed with a 25° plate results in an acetabular ventroversion angle most similar to TPO performed at the recommended 20°. Because DPO is a technique that has been adopted by some surgeons in an effort to decrease implant-related complications and patient morbidity, these recommendations may guide a surgeon in the selection of a plate that may improve the clinical outcomes of the DPO technique.

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