

Double pelvic osteotomy for the treatment of hip dysplasia in young dogs

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Keywords

Juvenile hip dysplasia, DPO, TPO, corrective pelvic osteotomy, double pelvic osteotomy, triple pelvic osteotomy

Summary

The aim of this study was to evaluate the feasibility of the double pelvic osteotomy (DPO) (osteotomy of the ilium and pubis) to treat clinical cases of hip dysplasia in young dogs instead of performing a triple pelvic osteotomy (TPO) (osteotomy of the ilium, pubis, and ischium). Candidates for DPO were 4.5- to nine-month-old dogs with coxofemoral joint subluxation and laxity, indicative of susceptibility to future development of severe hip dysplasia. The angle of reduction (AR) and angle of subluxation (AS) with Ortolani's sign, Norberg angle (NA), percentage of femoral head (PC) covered by the acetabulum, and the pelvic diameters and their relationships were measured clinically and radiographically before and after surgery. The surgical technique was similar to the TPO technique, but excluded ischiatic osteotomy. A DPO was carried out in 53 joints of 34 dogs; AR and AS values immediately postoperatively and at the one- and two-month follow-up examinations were significantly lower than the preoperative values ($p < 0.01$). The complications en-

countered were mainly represented by implant failure (3.5%), partial plate pull-out (9.4%), and incomplete fracture of the ischial table (7.5%). Changes in PC and NA values obtained immediately after surgery and at the first and second follow-up examinations were significantly greater ($p < 0.01$ both) than values obtained before surgery. Sufficient acetabular ventroversion was achieved to counteract joint subluxation and the modifications of AR and AS. The NA and PC direct postoperative values reflected a significant improvement in the dorsal acetabular coverage.

Clinical relevance: Restoration of normal joint congruity (PC from 50 to 72%) and maintenance of the pelvic geometry without pelvic narrowing were the most intriguing features of DPO. The complications observed were greatly reduced when using dedicated DPO plates. Based on our experience, the morbidity after unilateral and bilateral DPO was lower than after TPO because elimination of the ischiatic osteotomy allowed for increased stability of the pelvis. The surgical technique of DPO was a little more demanding than TPO because of the difficulty in handling and rotating the acetabular iliac segment, but this difficulty was offset by elimination of ischiatic osteotomy.

Introduction

Hip dysplasia is a frequent orthopaedic condition that affects medium- to large-breed dogs, characterised by early joint subluxation during growth and subsequent degenerative changes later in life. In younger patients, surgical techniques such as juvenile pubic symphysiodesis (JPS) and triple pelvic osteotomy (TPO) are aimed at arresting or minimising joint subluxation and the development of hip dysplasia by modifying the dorsal acetabular rim (DAR) angle (1–4). The improvement in joint stability and congruity is achieved by ventroversion of the DAR, which increases coverage of the femoral head. In TPO, the acetabulum is isolated by osteotomy of the ilium, ischium and pubis and rotated ventrally to achieve the desired ventroversion (1–4).

Although considered a successful surgical technique since its introduction by Slocum in 1986, TPO has been modified and new plates have been designed in an effort to reduce complications (6–9). The postoperative complication rate associated with TPO ranges from 35% to 70%, with loosening of the screws being the most common problem (7, 10–13). Pelvic canal narrowing, excessive head coverage by the acetabular roof and subsequent impingement of the femoral head, delayed healing of the iliac and ischial osteotomies, and high morbidity, especially after simultaneous bilateral surgery, have been frequently reported in the veterinary literature (3, 4, 13–15). In September 2006, at the 13th ESVOT Congress in Munich, Germany, P.H. Haudiquet and J.F. Guillon described an *in vitro* study in which osteotomy of the ilium and pubis, but not the ischium, achieved significant ventroversion of the acetabulum with lateral rotation

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of the ilium and torsion and deformation of the ischium (16). The purpose of this new technique called double pelvic osteotomy (DPO) was to simplify TPO and reduce the rate of complications and morbidity. The results were encouraging with regard to acetabular coverage of the femoral head; DPO with 25° of iliac rotation appeared to have the same radiographic effect in terms of acetabular coverage as TPO with 20° of rotation. The degree of rotation of the ilium distal to the osteotomy was dependent on deformation of the ischial table, and possibly on a bending of the cartilaginous pubic symphysis in growing dogs. The rotation appeared to be about five degrees less than the amount of rotation obtained at the level of the iliac osteotomy (16, 17).

The purpose of this retrospective study was to investigate the feasibility of this new surgical technique to treat clinical cases of hip dysplasia in young dogs. The study also investigated the effects of DPO on joint subluxation, pelvic morphology, and complications in the short-term period.

Materials and methods

The medical records were searched for dogs undergoing unilateral and bilateral DPO from September 2006 to October 2008 at the Vezzoni Veterinary Clinic, Cremona, Italy. The following criteria had to be fulfilled for dogs to be included in the study: privately owned, a complete clinical examination and functional hip assessment with sedation preoperatively and postoperatively, and re-evaluation a minimum of two months postoperatively. The operations were carried out by the same veterinary surgeon (AV) in all cases. Candidates for DPO were 4.5- to nine-month-old dogs that had coxofemoral joint subluxation and laxity, which were indicative of susceptibility to future development of severe hip dysplasia (HD), no or minimal signs of osteoarthritis (OA), no or minimal acetabular filling, a preserved lateral border of the DAR, an angle of subluxation not >25° and a distraction index of up to 1.

Preoperative evaluation and radiographic measurements

The dogs were sedated with butorphanol (0.2 mg/kg IM) and medetomidine (5 mcg/kg IM) for preoperative evaluation, which included: Ortolani's test, measurement of the angle of reduction (AR) and angle of subluxation (AS) using a digital electronic goniometer with three consecutive measurements, radiographic assessment of hip joints in a ventrodorsal view with extended legs, frog view, DAR views with measurement of the DAR angle and evaluation of the integrity of its lateral border, and a distraction view with measurement of the distraction index (DI). Measurement of the Norberg angle (NA) was performed on ventrodorsal views in which the legs were extended. An additional measurement described by McLaughlin and used by Tomlinson was made in the same view to assess acetabular coverage (18–20). The coverage of the femoral head was expressed as a percentage of the femoral head that was covered by the acetabulum in relation to the total area of the femoral head (PC). The PC was calculated on a ventrodorsal radiographic view by dividing the area of the femoral head covered by the acetabulum by the total area of the femoral head and multiplying by 100.

For determination of possible postoperative narrowing of the pelvic canal attributable to DPO, we measured the distance between the right and left iliac wings (A), the distance between the right and left ischiatic tuberosities (B) and the distance between the right and left craniolateral acetabular borders (C). These distances were measured on the ventrodorsal radiographs. To minimise changes in these measurements due to skeletal growth, the ratios of three different combinations of values were used: A:B, C:B and A:C.

Surgical technique

Dogs were premedicated with morphine (0.15 mg/kg IM) and acepromazine (0.02 mg/kg IM). Anaesthesia was induced with propofol (3–6 mg/kg IV) and maintained with isoflurane after endotracheal intubation.

Analgesia was provided by a target-controlled infusion (TCI) of fentanyl at a plasma concentration of 1.2–1.6 ng/ml. Cefazolin sodium (20 mg/kg, IV) was given prior to surgery and amoxicillin (20 mg/kg/TID PO) was prescribed for four days after surgery. A purse string suture was placed around the anus and the hair was routinely clipped from the entire limb to be operated. Postoperative pain management consisted of meloxicam (0.1 mg/kg PO) for seven days. The degree of required acetabular ventroversion was determined using the same criteria established for TPO (1–4); five degrees was added to the measured AS to prevent subluxation. The correction was increased an additional five degrees based on Haudiquet's *in vitro* results (16). A standard approach to the ventral aspect of the pubis was used and a pubic osteotomy was performed as described for TPO, leaving the pectineous muscle intact. A 5 mm wide segment of pubic bone medial to the ileopectineal eminence was removed with a rongeur after periosteal elevation. The ilial osteotomy was then carried out using the method described by Slocum for TPO, keeping the osteotomy perpendicular to the long axis of the ilium and just behind the sacral apex. Because the ischium was left intact, the distal iliac segment was less mobile compared with TPO. When the required rotation was difficult to achieve, release of the sacrotuberous ligament at its insertion over the ischial tubercle was carried out through a small skin incision perpendicular to the ischiatic arc. The iliac osteotomies were stabilised with the various bone plates available in our hospital: 20° locking New Generation Devices (NGD)^a TPO plates with seven holes, 25° locking NGD-TPO^a plates with eight holes, 25° and 30° locking NGD-DPO^a plates, 20° Fixin plates^b, 20° to 25° to 30° Bioimpianti^c plates or 30° Slocum^d plates. Proximal screws were not intended to purchase deeply into the sacral bone. An additional cerclage

^a Triple pelvic osteotomy plates: New Generation Devices, Glen Rock, NJ, USA

^b Fixin plates: Veterinary Instrumentation, Sheffield, UK

^c Bioimpianti plates: Gruppo Bioimpianti s.r.l., Milano, Italy

^d Slocum plates: Slocum Enterprises, Eugene, Oregon, USA (*Company now closed*)

wire, 1.0 mm in diameter, was placed proximally and distally through holes in the plate in more active dogs, while in heavier dogs an additional ventral plate (Fixin with four 2.5-mm holes, or 2.7 mm veterinary cuttable plates^e with four holes, or 2.7 mm locking Königsee plates^f with four holes) was placed instead of the cerclage wire. Some dogs diagnosed with bilateral hip dysplasia of different severity underwent unilateral DPO as well as total hip replacement in the other limb, in the same surgical session or in a second one. Bilateral DPO was always carried out in the same surgical

session using the same surgical approach with or without release of the sacrotuberous ligament. In bilateral simultaneous DPO, pelvic rotation on the second side required more effort.

Immediate postoperative and follow-up clinical assessments

Postoperative evaluation included clinical and radiographic assessment using the same preoperative protocol previously described. The ability to urinate, defecate and stand and walk without assistance and the occurrence of neurological deficits were monitored in all dogs after surgery. Post-

operative care included close confinement and leash walking for four to six weeks. Owners were asked to return their dogs for a clinical and radiographic follow-up at one, two and six months, and at one year postoperatively. At each follow-up assessment, limb function, owner satisfaction, healing of the osteotomies, and implant stability were evaluated. Additionally, the dogs were sedated to assess Ortolani's sign; the AR and AS were subsequently measured if the sign was positive. To facilitate comparison of the AR and AS values from the preoperative evaluation with the immediate postoperative, first follow-up (one month), second follow-up (two months) and third follow-up (6 months) evaluations, the AR and AS values of each dog were divided into five different groups as shown in ►Table 1.

^e Veterinary cuttable plates: Synthes, Bettlach, Switzerland

^f Königsee locking plates: Königsee Implantate GmbH, Allendorf, Germany

Angle of subluxation	Angle of reduction
Group 1 = negative Ortolani's sign	Group 1 = negative Ortolani's sign
Group 2 = from -10° to 0°	Group 2 = from 0° to 10°
Group 3 = from 1° to 10°	Group 3 = from 11° to 20°
Group 4 = from 11° to 20°	Group 4 = from 21° to 30°
Group 5 = >20°	Group 5 = >30°

Table 1
Group classification of angles of reduction and angles of subluxation values.

Postoperative radiographic measurements

The PC and NA were measured three times after surgery: immediately postoperatively, one month postoperatively (first follow-up exam) and two months postoperatively (sec-

Table 2 Allocation of dogs to groups with different angles of reduction and angles of subluxation recorded preoperatively, immediately postoperatively, one month postoperatively and two months postoperatively.

	Preoperative	Postoperative (PO)	1 month PO	2 months PO
Group classification: Angle of subluxation				
Group 1: Negative Ortolani's sign	n = 0 (0%)	n = 12 (22.6%)	n = 13 (24.5%)	n = 17 (32.1%)
Group 2: From -10° to 0°	n = 0 (0%)	n = 29 (54.7%)	n = 21 (39.6%)	n = 19 (35.8%)
Group 3: From 1° to 10°	n = 15 (28.3%)	n = 10 (18.9%)	n = 14 (26.4%)	n = 14 (26.4%)
Group 4: From 11° to 20°	n = 34 (64.2%)	n = 2 (3.8%)	n = 4 (7.6%)	n = 2 (3.8%)
Group 5: >20°	n = 4 (7.5%)	n = 0 (0%)	n = 1 (1.9%)	n = 1 (1.9%)
TOTAL	n = 53 (100%)	n = 53 (100%)	n = 53 (100%)	n = 53 (100%)
Group classification: Angle of reduction				
Group 1: Negative Ortolani's sign	n = 0 (0%)	n = 12 (23%)	n = 13 (24.5%)	n = 17 (32.1%)
Group 2: From 0° to 10°	n = 0 (0%)	n = 20 (38.5%)	n = 16 (30.2%)	n = 13 (24.5%)
Group 3: From 11° to 20°	n = 5 (9.4%)	n = 13 (23.1%)	n = 14 (26.4%)	n = 14 (26.4%)
Group 4: From 21° to 30°	n = 23 (43.4%)	n = 7 (13.5%)	n = 6 (11.3%)	n = 7 (13.2%)
Group 5: >30°	n = 25 (47.2%)	n = 1 (1.9%)	n = 4 (7.6%)	n = 2 (3.8%)
TOTAL	n = 53 (100%)	n = 53 (100%)	n = 53 (100%)	n = 53 (100%)



Fig. 1 Preoperative radiographs of a six-month-old male Labrador Retriever weighing 26 kg: **a)** standard ventrodorsal view, **b)** distraction view with distraction index 0.65 at right and 0.56 at left, **c)** frog ventrodorsal view, **d)** dorsal acetabular rim (DAR) view with DAR angle of eight degrees right and left. Ortolani values: right and left angle of reduction (AR) 30° and angle of subluxation (AS) 15°.

ond follow-up exam). The same measurements were made at further follow-up examinations at six months and one year postoperatively in those dogs that were available. The same pelvic diameter measurements performed before surgery were repeated immediately after surgery and at the two-month follow-up examination.

Statistical analysis

All statistical analyses were carried out using statistical software[§]. Descriptive statistics were reported as mean \pm standard deviation for all variables. Changes in PC and NA values during the follow-up period were analysed by repeated measures analysis of variance (GLM REP). The outcome variables AS and AR were allocated to one of five categories. The predictor variable was the time of postoperative re-evaluation. To examine the association between

predictor and outcome variables, the SPSS Ordinal Regression procedure was used. The ratios of A:B, C:B and A:C were compared by univariate analysis of variance (UNIANOVA) using Bonferroni's correction for multiple comparisons.

Results

Clinical evaluations

The inclusion criteria were fulfilled in 34 dogs that underwent a total of 53 DPO operations. There were 20 male and 14 female dogs, with a mean of 6.6 months in age (range 4.5–9 months, median 6.5 months) and a mean body weight of 24.5 kg \pm 5.3 kg (range 15–35 kg, median 25 kg) at the time of surgery. Breeds included 11 Labrador Retrievers, six Golden Retrievers, five German Shepherds, two Rottweilers, three Border Collies, two Bernese Mountain dogs, one Dogue de Bordeaux, one Boxer, one Beauceron, one Appenzell Mountain dog, and one mixed-breed dog. Of the 34



Fig. 2 Double pelvic osteotomy plate produced by New Generation Devices® with holes for two locking screws on each side dorsally, which hold divergent screws to increase bone purchase. Regular screws are placed ventrally to achieve plate compression on the bone.

dogs, 19 underwent bilateral DPO at the same time, 12 had unilateral DPO, and three had unilateral DPO combined with cementless total hip replacement^h in the opposite limb.

In the preoperative clinical assessment, the mean AR was 31.87° \pm 7.18° and the mean AS 14.32° \pm 5.77°. ▶ Table 2 shows the distribution of the values in the five groups for the AR and AS. The mean distraction index value was 0.68 \pm 0.12, and the mean DAR angle was 9.28° \pm 3.03° (▶ Fig. 1).

In all cases, more effort was required to rotate the acetabular iliac segment compared to our experience with TPO. Plates with different degrees of inclination were used: 20° plates were used in five cases (9.4%), 25° plates in 26 cases (49.1%), and 30° plates in 22 cases (41.5%). Different brands of bone plates were also used: two locking NGD-TPO plates with seven holes (3.8%), 12 locking NGD-TPO plates with eight holes (22.6%), 12 locking NGD-DPO new plates (22.6%), 25 Bioimpianti TPO plates (47.2%), one Fixin TPO plate (1.9%), and one Slocum TPO plate (1.9%). The new DPO plates (NGD®) with two divergent locking screws and two compression holes for regular screws per side were designed specifically for this procedure (▶ Fig. 2).

Sacro-tuberous ligament release was carried out in 34 cases. In three cases a ventral plate was applied, in 21 cases cerclage wire was placed proximally and distally through

[§] SPSS 17.0 for Windows: SPSS Inc, Chicago IL, USA

^h Kyon Inc., Zurich, Switzerland

holes in the plate, and in a further 21 cases, a distal cerclage wire alone was used.

Immediately postoperatively, the Ortolani sign was negative in 12 cases, and in the remaining 41 hips, the mean AR was $13.17^\circ \pm 13.3^\circ$ and the mean AS was $\text{minus } 3.4^\circ \pm 9.5^\circ$ (► Fig. 3A). Four cases were poor candidates due to rounding of the lateral border of the dorsal acetabular rim and a preoperative AS of close to 25° .

Dogs that underwent bilateral or unilateral DPO were able to stand, sit and walk eight to 18 hours postoperatively, and they were all discharged from the hospital the day after surgery. In the immediate post-

operative period, owners reported some weakness during walking, but no restlessness or signs of discomfort.

Immediate postoperative complications included transient neurological deficits in two cases (3.7%), which resolved spontaneously three to four weeks postoperatively.

At re-evaluation two months postoperatively, Ortolani's sign was negative in 17 cases (32%), and in the 36 cases in which the Ortolani's sign was positive, the mean AR was $17.47^\circ \pm 9.8^\circ$ and the mean AS was $3.7^\circ \pm 7.5^\circ$, significantly lower than the preoperative values ($p < 0.01$) (► Fig. 3B). The

graphs in ► Figures 4A and 4B show the AR and AS during the study period in the cases in which Ortolani's sign did not become negative. While AR and AS values immediately postoperatively and at the one- and two-month follow-up examinations were significantly lower than the preoperative values ($p < 0.01$), AR and AS values at the two-month follow-up examinations were significantly higher than the immediate postoperative value ($p < 0.05$), and AS at the one-month and two-month follow-up examinations were significantly higher than the immediate postoperative value ($p < 0.01$). ► Table 2 shows the changes in the AR and AS from the preoperative evaluation to the re-evaluation two months postoperatively; there was a significant progression of the cases from the group with higher values to groups with lower values ($p < 0.01$).

Thirty operations in 21 dogs re-evaluated at six months postoperatively showed that Ortolani's sign was negative in an additional six hips (► Fig. 5). In the remaining cases, the mean AR was $21.1^\circ \pm 12.3^\circ$ and the mean AS was $8.8^\circ \pm 10.6^\circ$. The AR was significantly lower than the immediate postoperative value ($p < 0.01$) and the first follow-up examination value ($p < 0.05$), while AS was significantly lower than only the immediate postoperative value ($p < 0.001$).

Radiographic evaluations

Radiographic evaluation two months postoperatively revealed complete healing of the osteotomies in 42 cases and advanced but incomplete ossification in the remaining 11.

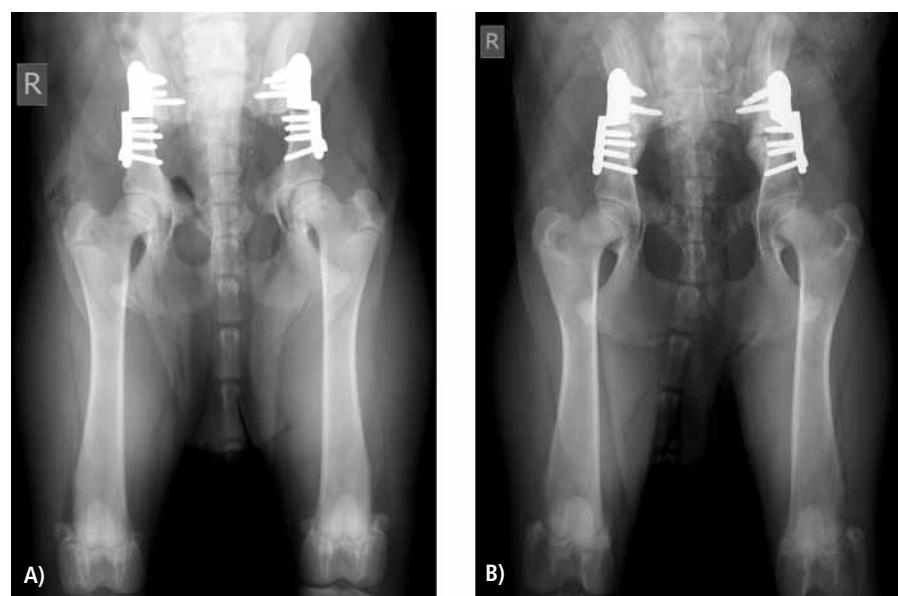


Fig. 3 Postoperative radiographs of the same patient shown in Figure 1. A) Standard ventrodorsal (VD) view taken immediately postoperatively; Ortolani values: right angle of reduction (AR) = 5° , right angle of subluxation (AS) = -10° , left AR = 10° , and left AS = 5° . B) Standard VD view taken two months postoperatively; right AR = 10° , right AS = 0° , left AR = 10° , and left AS = 0° .

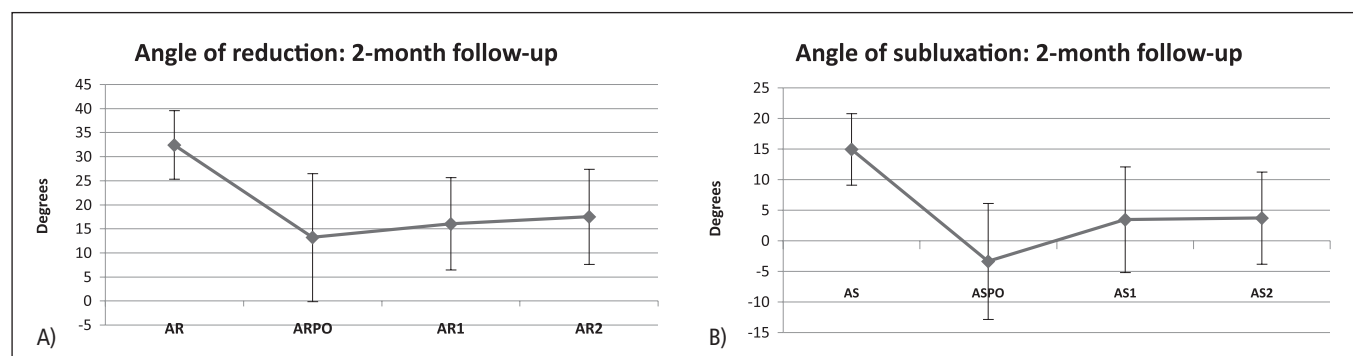


Fig. 4 Graphs showing the angle of reduction (AR) and angle of subluxation (AS) preoperatively (AR; AS), postoperatively (ARPO; ASPO), one month postoperatively (AR1; AS1), and two months postoperatively (AR2; AS2) in cases in which Ortolani's sign did not become negative.



Fig. 5 Standard ventrodorsal view of the same patient shown in Figure 1 and 3 taken seven months postoperatively; Ortolani values: right negative, left AR = 5° and AS = 0°.



Fig. 6 **A)** Six-month-old male Labrador Retriever weighing 28 kg with bilateral 25° New Generation Devices 'old' DPO plates. Follow-up radiograph one month after surgery showing partial pull-out of the distal plate on the left double pelvic osteotomy. **B)** 8.5-month-old female Labrador Retriever weighing 25 kg with a 25° Bioimpianti plate. Follow-up examination one month after surgery shows an incomplete, almost healed fracture of the ischial table as an incidental finding.

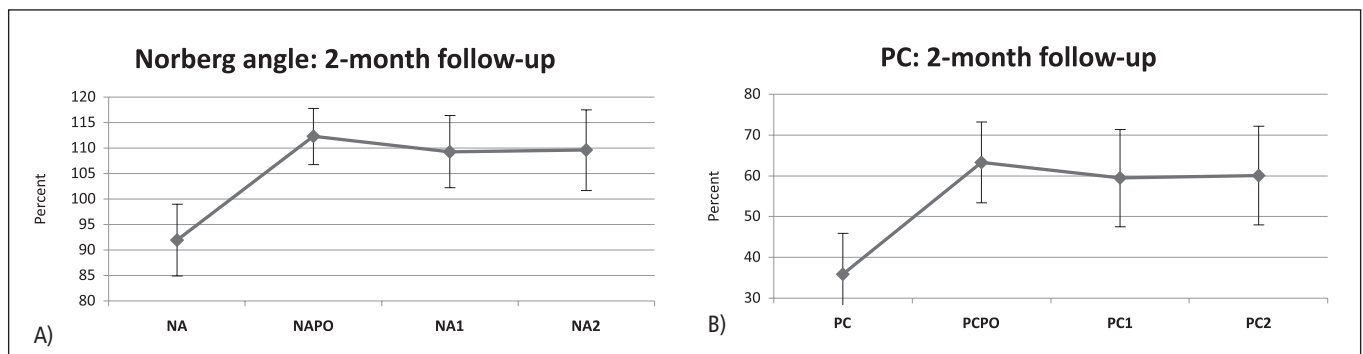


Fig. 7 Graphs showing the percent coverage of the femoral head (PC) and Norberg's angle (NA) preoperatively (PC; NA), postoperatively (PCPO; NAPO), one month postoperatively (PC1; NA1), and two months postoperatively (PC2; NA2). FU: follow-up.

There were a total of 19 complications in 11 (20.7%) of the 53 dogs. All the complications encountered were observed at the first re-evaluation one month after surgery. They included: implant failure with 12 loose screws and one broken screw (involving 13 plates) of 371 screws applied (3.5%); partial pull-out of the distal aspect of the plate in five cases (9.4%) (► Fig. 6A); 1 broken plate (1.8%); incomplete fracture of the ischial table with spontaneous healing in four cases (7.5%) (► Fig. 6B); and a fracture of the distal iliac segment just distal to the plate with spontaneous healing in one other case.

As a consequence of implant failure in four out of five cases with partial plate pull-

out, in the dog with an iliac fracture and in the dog with a broken plate, moderate narrowing of the pelvic canal was seen (11.3%). Most of the complications caused by implant failure did not require surgical revision because the achieved acetabular rotation was adequate. Only one dog required revision to remove a loose implant. Inadequate correction with persistent subluxation was seen in three cases (5.6%).

For the pelvic canal diameters, the C:B ($p = 0.104$) and A:C ($p = 0.051$) ratios did not change significantly between the preoperative and first and second re-evaluations, whereas the A:B ratio decreased throughout this time period ($p < 0.01$).

The mean NA was $91.9^\circ \pm 7.0^\circ$ preoperatively, $112.3^\circ \pm 5.5^\circ$ immediately postoperatively, $109.3^\circ \pm 7.1^\circ$ one month postoperatively, and $109.6^\circ \pm 7.9^\circ$ two months postoperatively. The average PC was $35.8\% \pm 10.1$ preoperatively, $63.2\% \pm 9.8$ immediately postoperatively, $59.4\% \pm 11.9\%$ one month postoperatively, and $60.1\% \pm 12.1$ two months postoperatively. ► Figure 7 shows the changes in PC and NA over the course of the study; values obtained immediately after surgery and at the first and second re-evaluations were significantly greater ($p < 0.01$ both) than values obtained before surgery.

The NA and PC were measured six months postoperatively in 30 cases; the

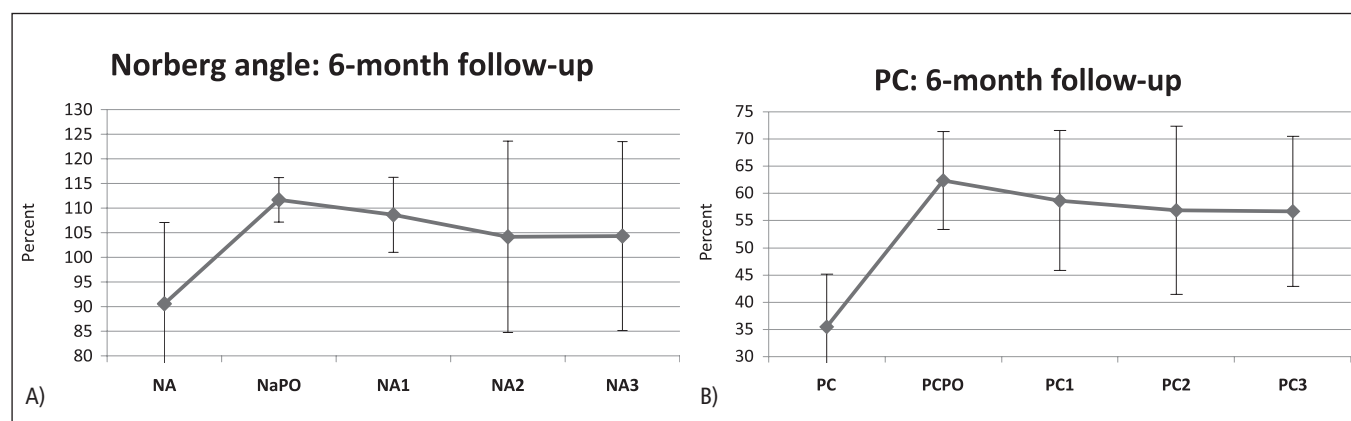


Fig. 8 Graphs showing the percent coverage of the femoral head (PC) and Norberg's angle (NA) preoperatively (PC; NA), postoperatively (PCPO; NAPO), one month postoperatively (PC1; NA1), two months postoperatively (PC2; NA2), and six months postoperatively (PC3; NA3). FU: follow-up.

mean NA was $104.32^\circ \pm 19.17^\circ$ and the mean PC was $56.71\% \pm 13.8$, with no significant change from the values obtained at the re-evaluation two months postoperatively (► Fig. 8).

Discussion

Encouraged by the *in vitro* results of Haudiquet and Guillon, we substituted DPO for TPO for the treatment of hip dysplasia in all young dogs suitable for pelvic osteotomy (16, 17). The surgical procedure, which involves rotating the acetabulum after osteotomy of the pubis and ilium, but not the ischium, appeared to be feasible and effective in achieving sufficient acetabular ventroversion to counteract joint subluxation. The average PC two months after surgery was $60.04\% \pm 12.1$ and the NA was $109.5^\circ \pm 7.9^\circ$, which reflected a significant improvement in joint congruity compared with preoperative data (PC: $35.8\% \pm 10.8\%$; NA: $91.9^\circ \pm 7.0^\circ$ [► Fig. 7]). Between two and six months (NA: $107^\circ \pm 7.6^\circ$ and PC: $58\% \pm 11$) after surgery these variables changed only minimally indicating that the achieved correction was stable and permanent (► Fig. 8). This was in contrast to TPO, in which an increased head coverage was described in the FU evaluations (3, 21, 22). Excessive femoral head coverage was not seen in any of our patients, even when a 30° plate (corresponding to 25° of rotation) was used. No gait abnormalities occurred, probably be-

cause a maximum of two-thirds of the femoral head was covered after DPO, which corresponds to the amount of coverage seen in normal hips. This is in contrast to TPO, which in our experience and according to reports in the literature often results in internal limb rotation during walking because of excessive femoral head coverage (3, 20–22).

The modification of the AR and AS in Ortolani's sign reflected the improvement of the dorsal acetabular coverage. While AR is predominantly correlated to the amount of joint laxity, the AS is mainly correlated to the DAR slope and integrity (1). Full correction of joint subluxation was achieved when Ortolani's sign became negative, although a small AS of up to five degrees appeared to be acceptable, as is often observed in dogs considered to have nearly normal joints. Higher AS values were indicative of a lack of efficacy of the surgical procedure, insufficient correction, or poor case selection when dogs with a damaged DAR and high AS were included; the latter are considered poor surgical candidates as evidenced by dogs with an $AS > 20^\circ$. Similar to case selection criteria used for TPO, stricter patient selection would likely reduce the risk of poor results after DPO (1–4, 21). The transient worsening of AR and AS from the immediate postoperative period to the one-month follow-up examination (► Fig. 4) could be explained by a loss of muscular strength in the early phase of healing of the osteotomies and the strict limitation of physical exercise in that time

period. The subsequent improvement of AR and AS at the two-month FU may have been related to restoration of muscular tone achieved by increased physical activity and advanced healing of the osteotomies in the second month after surgery.

Clinical observation of the treated patients showed that the morbidity after unilateral and bilateral DPO was lower than after TPO because elimination of the ischiatic osteotomy allowed for increased stability of the pelvis. The ability of the patient to stand and walk without assistance a few hours after surgery was the rule even after bilateral surgery. The ability to sit without discomfort after DPO was attributed to the stability of the ischium. In contrast, reluctance to sit postoperatively because of ischial pain after TPO has been observed by the authors and others (21).

In our experience, DPO was a more difficult technique than TPO because mobility of the distal iliac segment was limited and skilful rotation of this segment required a certain amount of training. After the iliac osteotomy, the distal iliac segment was gently elevated with a long osteotome to fix the caudal part of the plate. Fixation of the cranial part of the plate was done in conjunction with rotation of the distal iliac segment and took advantage of a bone-holding forceps applied to the distal iliac segment, and the screw traction in the first proximal hole of the plate close to the osteotomy. The combination of the two forces, that is, the rotational force created by the forceps and the traction force pro-

vided by the screw, made rotation of the distal iliac segment easier. In several of our early DPO operations, we released the sacrotuberous ligament at its insertion over the ischial tubercle to increase the rotational mobility of the ilium. However, with further surgical experience, we were able to reduce the frequency of this adjunctive procedure, and we currently no longer use it for DPO. Exclusion of this adjunctive procedure eliminates an additional incision and thus, a source of irritation and pain for the dog. Release of the sacrotuberous ligament did not appear to have any adverse consequences in our patients, but preservation of the ligament leaves the biomechanical tension-band function intact. Nevertheless, when rotation of the iliac segment in older puppies is too difficult, this adjunctive procedure may help in achieving the desired iliac rotation.

By leaving the ischium intact, the stability of the pelvic frame and that of the implant fixation appeared to be increased; nevertheless, healing time was similar to that reported by Whelan et al after TPO in all cases, and the osteotomies were almost completely healed two months postoperatively (7). Delayed union or non-union did not occur in any of our cases. Healing of the pubic osteotomy was considered proof of pelvic stability and maintenance of the pelvic frame. Morphometric measurements showed no narrowing of the pelvic cavity, except in a few cases with implant failure in which some pelvic narrowing occurred. This is in contrast to TPO, which usually results in narrowing of the pelvic canal (3, 4, 23).

Implant failure was the most frequent complication, although other than removing loose implants in one dog, revision surgery was never required because adequate acetabular orientation was preserved. The complications encountered were most often attributable to incomplete distal plate pull-out without a significant effect on the osteotomy healing process or stability. Plate pull-out occurred en bloc in three cases, in which locking NGD-TPO plates with seven and eight holes and parallel screws were used, but there was no screw loosening from the plate (► Fig. 6A). Two other cases occurred with Bioimpianti TPO plates in which regular screws became loose. Overall

screw loosening was minimal (3.2% of all screws). Screw purchase into the sacrum has been shown by Whelan et al in 2004 to reduce implant failure after TPO to 6% (7). Even though we did not insert the proximal screws deep into the sacral bone, the rate of screw loosening was low. We attributed this to the stability of the pelvic fixation, which resulted from leaving the ischium intact and consequently led to less stress on the implants. Double pelvic osteotomy may provide better stability because our frequency of screw loosening was less than that documented in studies of TPO; however a direct comparison with a control group was beyond the scope of this study (10–13). The fixation failures observed in our patients occurred in the first month after surgery. The lateral rotation exerted on the ilium with the intact ischium generates an opposite elastic force that pulls the screws medially until the process is halted by bone remodelling. Consequently, the cases of plate pull-out involved only the distal part of the plate and never the proximal, where the forces push the plate against the bone. This fact may explain the low incidence of screw loosening even though we did not insert the proximal screws into the sacral bone. The plates used in three cases in which plate pull-out occurred were locking plates with parallel screws. Parallel screws, even when locking, do not always withstand pull-out forces along the long axis. We have not encountered pull-out since we started using diverging screws with conventional plates and with locking plates. The sacro-tuberous ligament release was not associated with implant failure. For the DPO procedure, we started with conventional TPO plates, then changed to locking TPO plates with parallel screws, and finally to newly designed DPO plates^a with two divergent locking screws and two compression screws per side. The locking screws were intended to achieve a stronger fixation, particularly when bilateral DPO was carried out at the same time, while the compression screws were used to achieve the compression of the plate against the bone and the desired rotation of the ilium. Because the risk of iliac fixation failure was higher when we first started to perform DPO in very active or overweight dogs, we added a ventral plate to achieve maximum

stability instead of applying a cerclage wire in those cases (24). Cerclage wire appeared to be less reliable as it did not prevent plate pull-out in three of five cases. Further studies are in progress to evaluate the rate of implant loosening after DPO using different types of plates.

The four cases of incomplete ischiatic fracture were probably a reflection of the tension created by DPO on the ischiatic table in the first week postoperatively, when bone remodelling was incomplete (► Fig. 6B). In dogs undergoing bilateral DPO, rotation of the ilium on the second side was more difficult to achieve because torsion and deformation at the level of the ischium and pubic symphysis was already accomplished by the first DPO. In such circumstances it is advisable to operate on the side requiring more rotation first and then the side requiring less rotation whenever possible.

Conclusions

DPO is a surgical procedure that can reduce joint laxity and improve joint congruity by creating ventroversion of the acetabulum, similar to TPO but without osteotomy of the ischium. Restoration of normal joint congruity, in which 50 to 72% of the femoral head was covered by the acetabular roof, was the most interesting feature of DPO. Although a direct comparison with TPO was beyond the scope of this study, this feature was in contrast to TPO, which in our experience resulted in excessive (90% or more) femoral head coverage (21). DPO was associated with a low postoperative morbidity, which allowed bilateral procedures to be carried out during the same operation if necessary. Preservation of the pelvic geometry was an additional advantage of DPO compared with reported data on TPO, and when combined with restoration of normal joint congruity, it resulted in normal gait and joint function in operated dogs (3, 4, 13–15). The limited postoperative complications were an important feature of DPO, even though a more stable fixation of the iliac osteotomy was required. The surgical technique of DPO is a little more demanding than TPO because of the difficulty in handling and rotating the acet-

abular iliac segment, but this difficulty is offset by elimination of ischial osteotomy. Further studies are required to correlate plate angle to the preoperative values and the outcome in terms of improved NA and PC, and also to evaluate the long-term efficacy of DPO for the elimination of excessive joint laxity and for the prevention of osteoarthritis of the hip joint. For this purpose, long-term follow-up examinations showing low DI values without signs of osteoarthritis are required to objectively determine the outcome of DPO. Moreover, to further substantiate the value of this technique, comparison with a control group treated with TPO would be advisable. However, DPO appears to be an effective treatment option for hip dysplasia in growing dogs and has sparked renewed interest in therapies of this disorder in young dogs.

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