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Brief communication

Developmental dysplasia of the hip in female adult individual: Site Tres Cruces I, Salta, Argentina (Superior formative period, 400–1000 AD)

Marcos Plischuk[a,*], María Eugenia De Feo[b], Bárbara Desántolo[c]

[a] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Cátedra de Citología, Histología y Embriología "A", Facultad de Ciencias Médicas, Universidad Nacional de La Plata, Calle 60 y 120, Cátedra, La Plata, Argentina

[b] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), División Arqueología, Museo de La Plata, Universidad Nacional de La Plata, Paseo del Bosque s/n, La Plata, Argentina

[c] Cátedra de Citología, Histología y Embriología "A", Facultad de Ciencias Médicas, Universidad Nacional de La Plata, Calle 60 y 120 Cátedra, La Plata, Argentina

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ABSTRACT

Developmental dysplasia of the hip (DDH) is a developmental defect that prevents normal articulation between the acetabulum and the femoral head. This is an unusual condition, with a prevalence of 1–2 per thousand, and with only two poorly described skeletons documented in South American paleopathological literature. In this work we report an individual with such a condition, from the archeological site Tres Cruces I (Quebrada del Toro, Salta, Argentina). Several radiocarbon dates and associated materials date it to the Superior Formative (400–1000 AD). The remains are of an adult female, who also has tabular oblique cranial modification. Through detection of abnormalities in the morphology of the femora and *ossa coxae,* a differential diagnosis was carried out. On the left hip joint the formation of a well-defined false acetabulum, without connection with the true one, was observed. The latter was shallow, triangular, with an irregular base. The left *os coxae* showed a wider greater sciatic notch angle. The right *os coxae* exhibited a false acetabulum connected with the true one. Both femora presented a small femoral head, flat and mushroom-shaped, with shortening of the neck. These features were more pronounced on the right-side elements. On the basis of the aforementioned, a presumptive diagnosis of bilateral developmental dysplasia of the hip with complete dislocation on both sides was established.

1. Introduction

Developmental dysplasia of the hip (DDH) is a developmental defect that prevents normal articulation between the acetabulum and the femoral head. This is an unusual condition, with an estimated prevalence of 1–2 per thousand birth (Dezateux and Rosendahl, 2007).

Etiology of DDH is multifactorial, including endogenous (genetic disorders of collagen or collagen-related enzymes, transmembrane G-protein) and exogenous factors (intrauterine biomechanics, swaddling technique) (Spasovski et al., 2017). The strongest risk factors are female sex, positive family history of DDH, breech position, vaginal delivery, and first gestation (Zamir et al., 2008; Spasovski et al., 2017). Paleophatological literature is dominated by cases from Europe and North America. Most of the European ones are from France (Arnaud and Arnaud, 1975; Blondiaux and Millot, 1991; Mafart et al., 2007) and England (Dawes and Magilton, 1980; Wakely, 1993; Mitchell and Redfern, 2007; 2008; 2011), with some cases in Poland (Agnew and Justus, 2013), Slovakia (Masnicová and Beňuš, 2003), Romania (Eng et al., 2009), Italy (Petrella et al., 2016), and the Netherlands (Katzmarzyk and Schats, 2011). In North America there have been several studies with different chronologies between 6th century AD (Blatt, 2015) and 12–15th centuries AD (Clabeaux, 1977; Ausel, 2016), many of them in relation to the high prevalence of the condition in contemporary Native Americans (see Blatt, 2015). On the contrary, the condition in South American bioarchaeology is poorly documented, with only two possible examples. Moodie (1923) mentions the effects of luxation and the formation of a neoacetabulum in a Peruvian skeleton, but without clear images or a detailed description (Brothwell, 1967). The other likely individual with this condition is reported by Costa and Llagostera (1994), from site Coyo Occidente 3, San Pedro de Atacama, Chile, and dated to the end of the Middle period (10th century AD). The authors describe a female skeleton exhibiting "a bilateral luxation of the hip, with high probability of being congenital" (Costa and Llagostera, 1994:96) (Table 1).

In this article we present and discuss an individual with such condition, from the archeological site Tres Cruces I (Quebrada del Toro, Salta, Argentina).

* Corresponding author.
E-mail addresses: marcosplischuk@yahoo.com.ar (M. Plischuk), eugeniadefeo@yahoo.com.ar (M.E. De Feo), barbaradesantolo@hotmail.com (B. Desántolo).

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Table 1
Paleopathological published cases of DDH.

Country	Region	Chronology (centuries AD)	n	Sex	References
Europe					
France	Notre-Dame du Brusc, Châteauneuf-Grasse	1–6th	1	Female	Arnaud and Arnaud (1975)
	Notre-Dame-du-Bourg, Digne	11–17th	9	Females (9)	Mafart et al. (2007)
	Northern and Eastern France	4–8th	11	Females (5) Males (5) Undetermined (1)	Blondiaux and Millot (1991)
England	Spitalfields	11–16th	9	Females (5) Males (4)	Mitchell and Redfern (2007, 2008)
	St Helen-on-the-Walls, Aldwark	14–15th	1	Female	Dawes and Magilton (1980)
	St. Mary Spital, London	12–16th	10	Females (4) Males (4) Undetermined (2)	Mitchell and Redfern (2011)
	Abingdon, Berks	11–16th	1	Female	Wakely (1993)
Italy	Roccapelago, Italian Apennines	16th	1	Female	Petrella et al. (2016)
Poland	Giecz Collection	11–12th	1	Unknown	Agnew and Justus (2013)
Neatherlands	Alkmaar	15–16th	1	Male	Katzmarzyk and Schats (2011)
Romania	Bobald	16–18th	2	Females (2)	Eng et al. (2009)
Slovakia	Devín	11–12th	1	Male	Masnicová and Beňuš (2003)
North America					
USA	Buffalo site, West Virginia	6th	18	Females (13) Males (5)	Blatt (2015)
USA	Angel, Ohio	12–15th	1	Male	Ausel (2016)
USA	New Jersey State Museum, Trenton	12–15th	2	Unknown (2)	Clabeaux (1977)
Canada	Orchid Site, Fort Erie	12–15th	1	Unknown	Clabeaux (1977)
South America					
Peru[a]	Unknown	Unknown	1	Unknown	Moodie (1923)
Chile[a]	Coyo Occidente 3, San Pedro de Atacama	10th	1	Female	Costa and Llagostera (1994)

[a] Probable DDH.

2. Materials and methods

2.1. The archeological site and the burial TC1-G

The archeological site Tres Cruces I, located in Salta province, northern Argentina (Fig. 1) represents an agropastoral village and its occupation is estimated to around the second half of the first millennium of the era, according to a series of radiocarbon datings (Superior Formative Period: 408–556 cal AD at 95,4% − CSIC 125; 636–801 cal AD at 95,4% − LP-2038; 668–861 cal AD at 95,4% − LP-2066). This is composed of several household units and crop-growing structures. TCI-E3, a domestic structure, was excavated during 2005 and 2006. This circular unit included residential domestic activities such as cooking, storage, sleeping, tool manufacture, and trash disposal (De Feo, 2014). Underneath the floor of the living area 27 individuals (Fig. 2), of both sexes and different age ranges (non-adults and adults) had been buried in a wide variety of burial modalities (De Feo, 2012). A previous study showed that all the individuals from this site have modified skulls (De Feo et al., 2016). The individual whose pathology is analyzed in this study comes from this group, specifically from TCI-G burial. A sample of the individual TCI-G's ribs gave a radiocarbon date of 1500 ± 60 years BP (LP- 3389: 463–676 cal AD at 95,4%, date modeled in Calib Radiocarbon Calibration Program 7.04 (used in conjunction with Stuiver and Reimer, 1993), using SHCal13 calibration curve (Hogg et al., 2013). This date confirms that the individual belonged to the Superior Formative Period.

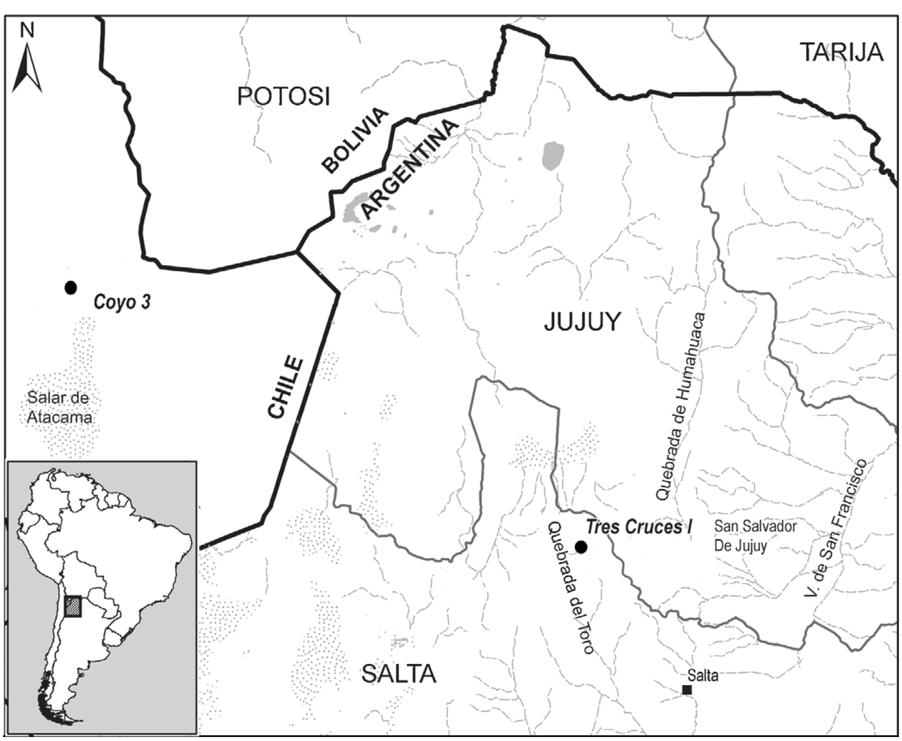

Fig. 1. Geographic location of Tres Cruces I archeological site.

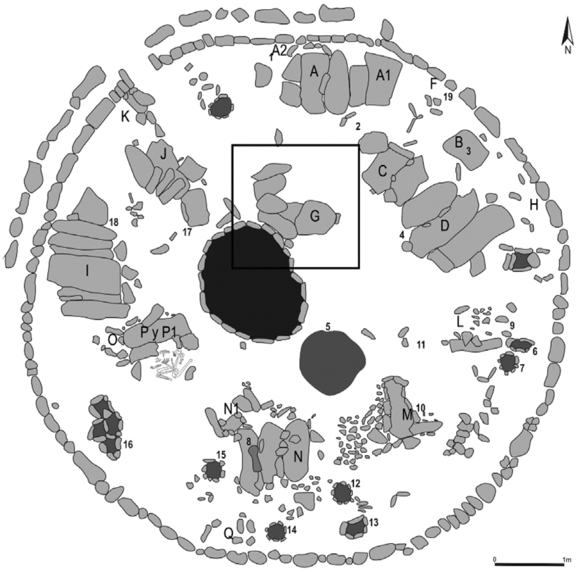

Fig. 2. Excavation plan of the TCI-E3 structure with the location of burial TCI-G (square).

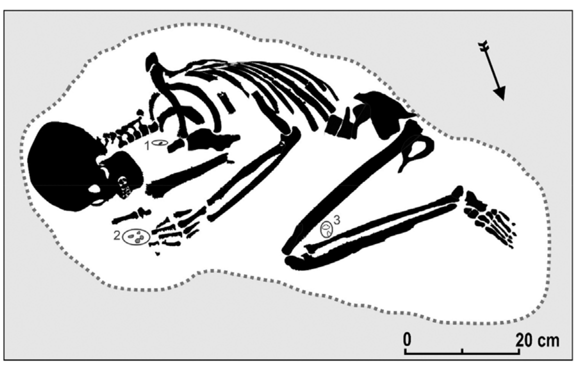

Fig. 3. In situ burial TCI-G graphic. 1) Cylindrical beads of lapis lazuli; 2) Red granules of ocher; 3) Yellow granules of ocher. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

This individual was found inside a chamber of 1.07 m long (E-W) and 0.60 m wide (N-S). It was found at 1.55 m deep, on the edge of the structure central fireplace. Above ground, the chamber was delimited by slabs whose longest sides were transversely arranged along the length of the burial. The burial pit had been dug in the gravel; there were no stones delimiting the chamber interior walls. Immediately below the upper slabs a burial was found: the body was articulated and had been placed in a genuflected position on its right side, and with orientation SE-NW (Fig. 3). The individual was in a good state of preservation, except for the long bones of the right side, on which the body lay. Taphonomic factors had caused cortical bone loss in the right femoral diaphysis and a subtrochanteric breakage. Besides, the right ilium and pubis also appeared incomplete due to postmortem breakage. The body was accompanied by two cylindrical beads of lapis lazuli located near the left scapula, granules of yellow ocher in the angle formed by the left femur and the fibula, and red ocher on the hands.

2.2. Age, sex, skeletal biology and paleopathological criteria

Sex was determined using seven pelvic features and seven skull characters (Ferembach et al., 1980; Buikstra and Ubelaker, 1994). The sciatic notch was not considered to determine sex because of the presence of the dislocation (Singh and Potturi, 1978; Takahashi, 2006). Determination of age-at-death was estimated using degenerative changes of the pubic symphysis and auricular surface (Lovejoy et al., 1985; Brooks and Suchey, 1990).

Through detection of abnormalities in the morphology of both femora, *ossa coxae*, tibiae and spine, a differential diagnosis was carried out considering the aspects proposed by Mitchell and Redfern (2008) (Table 2).

Computed tomography scans were performed in the coronal plane (General Electric Bright Speed Multislicer). Contiguous scans were performed using a slice thickness of 2 mm every 1.25 mm. Scanning parameters were 247 mAs, 120 kVp, DFOV 51.8 cm.

Table 2
Summary of palaeopathological changes resulting from developmental dislocation of the hip (adapted from Mitchell and Redfern, 2008):.

Anatomical structure	Pathological anatomy	Right	Left
True acetabulum	Oval, shallow, irregular floor, little roof	x	x
False acetabulum	Type 1–smooth shallow depression	–	–
	Type 2–fine patchy layer of bone on cortex	–	–
	Type 3–raised bony plaque	–	–
	Type 4–deep rounded cup	x	x
Rest of pelvis	Wider greater sciatic notch angle	x	x
	Triangular obturator foramen	x	x
	Shorter, broader ilium	–	–
Femoral head	Small, flat or mushroom-shaped in type 1–3 acetabula	–	–
	Good size but oval in AP plane in type 4 acetabula	x	x
Femoral neck	Usually short and thin–may have nodules	x	x
	Anteverted in vast majority of cases	–	–
	Valgus, varus or normal in AP plane	x	x
Lesser trochanter	Position may be superior, inferior or lateralised	x	x
	Mushroom-shaped, elongated or normal	–	–
Greater trochanter	Small size, reduced intertrochanteric distance	–	–
Femoral shaft	Reduced femoral shaft circumference	–	–
Distal femur	Smaller articular surface	–	–
	Valgus knee if femur adducted	–	–
Tibia	Smaller articular surface on tibial plateau	–	–
	Reduced length and shaft circumference	–	–
	May have compensatory external tibial torsion	–	–
Spine	Asymmetric facets, transverse process, body	–	–
	Osteophytes at apex of scoliosis curves	–	–
	Evidence of syndromes–fusion, hemivertebrae	–	–

Note: x = feature observed in this individual; – = feature not observed in this individual.

3. Results

3.1. Age, sex, skeletal biology and pathological observations

The skeleton belongs to a middle adult woman with a cranial modification classified as tabular oblique.

The most relevant morphological changes of the pelvis were observed in the acetabulum (Table 2). The true acetabulum was triangular in shape, with an irregular base (Table 2), and lay toward the obturator foramen, while its apex was directed posterosuperiorly (Fig. 4). The right true acetabulum was shallower than the left one (Fig. 4) (Table 3). None of them showed smooth surfaces, which are characteristic of articular development, but both presented marked vascular porosity. In both *ossa coxae* the formation of a false acetabulum or neoacetabulum was detected, posterosuperiorly to the true acetabulum, on the ilium. In the left *os coxae* the false acetabulum had no connection with the true one, whereas in the right they were partially connected.

The false acetabulum was a deep rounded cup more reminiscent of a normal acetabulum (Table 2), with well-defined limits that could be classified as type 4 *sensu* Mitchell and Redfern (2008) (Table 2). The mean distance between the centers of the true and false acetabula was

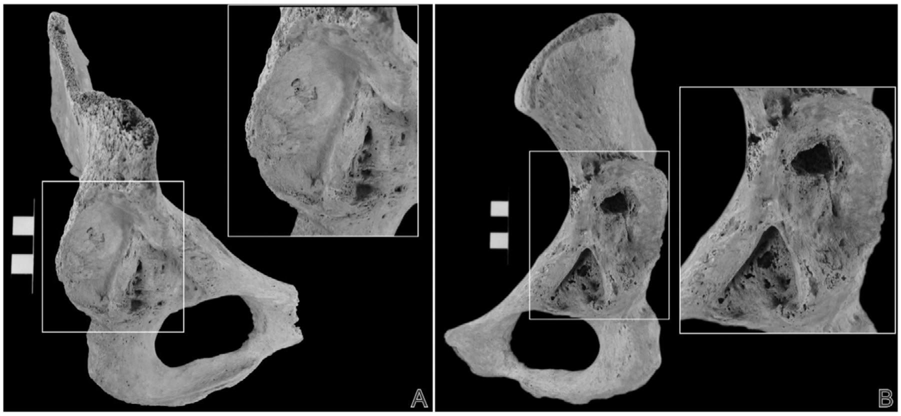

Fig. 4. Coxae in anterior view. A- Right coxae with false acetabulum connected with the true one. B-Left coxae with false acetabulum without connection with the true one.

Table 3
Comparative osteometric analysis of *ossa coxae* and femora:.

Bone	Measurement (mm)	Right	Left
Os coxae	Diameter false acetabulum	57.98	51.15
	Deep false acetabulum	18.56	19.9
	Base true acetabulum	34.7	32.4
	Height true acetabulum	37.8	32.15
	Deep true acetabulum	10.04	17.97
Femora	Vertical head diameter	43.26	44.69
	Horizontal head diameter	46.76	42.75
	Medial-lateral midshaft diameter	–	21.8
	Anterior-posterior midshaft diameter	–	79.8
	Maximum length	–	398
	Physiological length	–	396
	Neck-shaft angle	122°	105°
	Anteversion angle	–	10°

Note: − = not measurable.

29.16 mm (right) and 37.38 mm (left). Both *ossa coxae* exhibited bone spurs around the joint margins of both neoacetabula, which indicate articular activity. At the bottom of the left neoacetabulum multiple vascular channels were observed (Figs. 4A and B). The left pelvis also showed a wider greater sciatic notch with an angle of 108° (96° for the right one). The obturator foramen of both *ossa coxae* was triangular in shape (Figs. 4). There was no evidence of new bone formation in neither acetabula, therefore, unlikely to have been produced by an infectious or inflammatory disease mechanism.

Both femora had oval heads in the anteroposterior plane, with a slightly marked fovea capitis. In the lateral view, a mushroom-shaped head and shortening of the neck was observed, especially in the left one, which presented marginal lipping on the posterior surface. The angle of anteversion of the left femur was 10°, and the shaft-neck angle were 122° for the right one and 105° for the left one (Table 3). Muscle attachments were observed on both distal femora (Fig. 5).

There were no abnormal features in related bones. The tibiae presented a normal articular plateaus, as well as normal length and shaft circumferences. With respect to the spine, there were no asymmetric facets, hemivertebrae or scoliosis. There were no other pathologies detected on TC1-G individual.

CT scan slices showed the joint between femora and neoacetabula, without participation of the true acetabula (Fig. 6). The left femur also evidenced marked thinning of its neck (Fig. 6).

A 3D reconstruction showed the left coxofemoral joint in detail, in which a reduction of the shaft-neck angle could be appreciated, with consequent coxa vara formation (Fig. 7).

4. Discussion

Coxofemoral joint abnormalities can be ascribed to several pathological conditions. Traumatic events, even minor ones, can cause slipped capital femoral epiphysis with consequent luxation (Bullough, 2010; Solomon et al., 2010). However, the true acetabulum analyzed did not present any visible signs of functionality, while there was no distinctive trace of fracture, neither using gross pathology or CT. Therefore, that diagnostic hypothesis was discarded. The other condition likely to produce a similar morphology of the femoral proximal epiphysis is Legg-Calvé-Perthes disease, causing, due to a vascular disruption on the proximal epiphysis, a mushroom-shaped femoral head with shortening of the neck (Solomon et al., 2010). The acetabulum changes its appearance, becoming longer and losing depth, but without neoacetabulum development (Solomon et al., 2010). On the basis of the neoacetabulum formation, the true acetabulum morphology, and the femoral proximal epiphysis, the diagnosis of developmental dysplasia of the hip was established. Maximum severity of dysplasia was considered: a bilateral dislocation, given the total separation of the femur and the true acetabulum, with complete dislocation on both sides. The angle of anteversion of the left femur was normal, and the shaft-neck angle

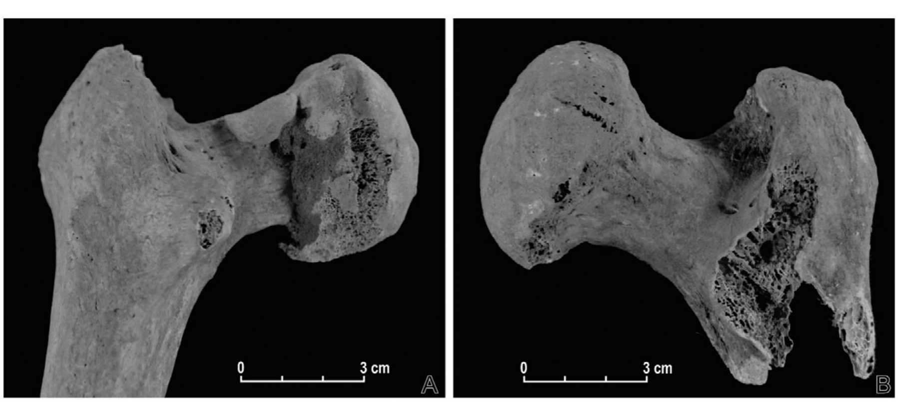

Fig. 5. Femoral epiphysis in posterior view. A- Left. B- Right showing postmortem breakage.

Fig. 6. Frontal pelvic plane CT image in anterior view.

Fig. 7. CT 3D reconstruction of left femoral joint with false acetabulum in anterior view.

indicated a normal range for the right one and varus for the left one (Anderson and Trinkaus, 1998; Mitchell and Redfern, 2008). The differences in size of the horizontal head diameter could be due to the different morphology of right and left neoacetabula.

That a female individual should have the condition observed in our study is consistent with contemporary epidemiological data (Stein-Zamir et al., 2008; Loder and Skopelja, 2011; Blatt, 2015) and bioarchaeological literature on DDH (Arnaud and Arnaud, 1975; Wakely, 1993; Mafart et al., 2007; Mitchell and Redfern, 2007; 2011; Eng et al., 2009; Agnew and Justus, 2013; Petrella et al., 2016).

The absence of lower limb asymmetry, of scoliosis, as well as the normal size of their long bones suggest that this woman would not have particular difficulties during her life. The lack of a large femoral neck anteversion and hip adduction did not seem to generate anomalies in the rotational movements of the legs (Mitchell and Redfern, 2008). Moreover, several studies have shown that complete bilateral dysplasia causes less functional limitations since leg shortening is similar on both sides, avoiding the development of compensatory scoliosis (Weinstein, 2001; Ortner, 2003; Storer and Skaggs, 2006).

In the first decade of life there seems to be no pain or degenerative changes (Blatt, 2015), while this starts to be a problem when secondary osteoarthritis develops at the compromised bones (Mitchell and Redfern, 2008). Nowadays, for instance, the need for hip replacement appears after the fourth decade of life (Blatt, 2015). Besides, individuals with subluxation are more likely to be affected by pain than those with complete dislocation (Shapiro, 2001), because of the lack of secondary degenerative changes, as we have seen in this individual.

Considering the inferred lifestyle of the formative-period village communities of the region, characterized by a stable residence associated with an agricultural and pastoral economy, an activity in which only a portion of the population must have involved, the condition observed in this individual must have allowed her participation in the daily household chores of the group. However, according with the Index of Care (Tilley and Cameron, 2014), this individual could have needed assistance to move over longer distances. Apart from DDH, their skeletal condition was similar to other females from this site, and adults of both sexes also had some dental pathologies (caries, abscess, periodontitis), mild vertebral osteoarthritis, and one male individual had evidence for interpersonal violence (De Feo, 2012).

An individual with DDH reported by Costa and Llagostera (1994) also comes from a context contemporary to our sample, from site Coyo Occidente 3, San Pedro de Atacama, Chile. Besides, the presence of ceramic pieces that are stylistically assignable to the black-burnished San Pedro Negro type characteristic of the oases of the Atacama region in the burials of Tres Cruces I, has served as support in order to propose interactions between both populations during the second half of the first millennium of the era (De Feo, 2014; De Feo et al., 2016). This is backed up by petrographic analyzes of ceramic pastes that suggest a cross-Andean origin for the burnished pottery pieces found at Tres Cruces area (De Feo and Pereyra Domingorena, 2015). Unfortunately, the authors did not provide more precise diagnosis or images of the skeleton that might allow comparison.

5. Conclusions

This analysis is the first to describe a developmental dysplasia of the hip from South America using modern paleopathological criteria. According to clinical evidence and Index of Care model this pathological condition would have allowed her participation in the daily activities in Tres Cruces I society.

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