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Case Study

Two cases of neurogenic paralysis in medieval skeletal samples from Croatia

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ABSTRACT

Osteological changes consistent with neurogenic paralysis were observed in one male and one female skeleton recovered from two Croatian medieval sites – Virje and Zadar. Both skeletons display limb asymmetry typical of neurogenic paralysis that occurs during the childhood. The male skeleton displays atrophy and shortening of the right arm and the right femur, while the female skeleton exhibits identical changes on the right arm and both legs. Additionally, both skeletons exhibit scoliotic changes of the spine, and the female skeleton also displays bilateral hip dysplasia. Differential diagnosis included disorders such as cerebral palsy, poliomyelitis, cerebrovascular accident, and Rasmussen's encephalitis. These are the first cases of neurogenic paralysis (cerebral palsy and/or paralytic poliomyelitis) identified in Croatian archeological series. The Virje skeleton is only the third case of hemiplegia identified from archeological contexts (first with spinal scoliosis), while the Zadar skeleton represents the first case of triplegia reported in the paleopathological literature.

1. Introduction

Identifying the specific cause of neurogenic paralysis in human skeletal remains from archeological contexts is problematic. Numerous hereditary and acquired disorders can result in similar limb atrophy and shortening, although the number of limbs affected may provide clues to the etiology. Reliable osteological evidence of neurogenic paralysis found within archeological contexts has been rare, and only a few cases of limb asymmetry associated with neurogenic paralysis have been published. In most cases, these changes were associated with paralytic poliomyelitis, while upon two occasions cerebral palsy was suggested as a possible cause.

Table 1 provides a brief overview of probable poliomyelitis and cerebral palsy cases from archeological contexts published in the paleopathological literature. The earliest known polio case is dated to the Neolithic (Wells, 1964), while the most recent is dated to the mid-late 19th century (Thompson, 2014). Of the 13 published cases of polio only four were females (Table 1); the youngest individual was between 18 and 25 years at the time of death (Thompson, 2014), while the oldest one was over 60 years of age (Umbelino et al., 1996).

Probably the most well-known case attributed to cerebral palsy is that of a young adult male from medieval parish cemetery in Norwich, England who suffered from atrophy and shortening of both legs (paraplegia) as well as spinal scoliosis (Stirland, 1997). Furthermore, Sansone (1999) examined postcranial remains of an individual from a New York 19th century almshouse and suggested that the observed changes could be attributed to cerebral palsy.

A review of the paleopathological literature suggests that in most of the reported cases only one extremity was affected, while impairment of two limbs was reported in five cases. Of those, two individuals suffered from paraplegia, two individuals were affected by hemiplegia, and in one case the opposite limbs were affected. No cases of triplegia have been reported.

As already stated, it is hard to determine the exact cause of skeletal changes such as limb atrophy and shortening in individuals who passed away several hundreds or even thousands of years ago. In this paper we describe two probable cases of neurogenic paralysis from two Croatian medieval sites, Virje and Zadar, and compare them with those previously reported. The skeletal material recovered from these sites is part of the Osteological Collection of the Croatian Academy of Sciences and Arts in Zagreb, and the cases

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Table 1
Probable cases of poliomyelitis and cerebral palsy published in the paleopathological literature.

Site	Chronological period	Sex and age	Affected extremities	Reference
Cissbury, England	Neolithic	Adult male	Left arm	Wells (1964)
Cerro de la Cabeza, Spain	Chalcolitic	Male, 30–35 years	Left arm, left leg	Jori et al. (2003)
Barton Bendish, England	Bronze Age	Adult male?	Left arm	Wells (1964)
Deshasheh, Egypt	Early Egyptian Period	??	Left leg	Mitchell (1900)
Marseille, France	5th c. AD	Female, 20 years	Right leg	Perrot and Arnaud (1975)
Linz, Austria	Late Antiquity	Adult male	Both legs	Wiltschke-Schrotta and Teschler-Nicola (1991)
Georgenberg, Austria	Early Middle Ages	Young female	Right arm, left leg	Winkler and Großschmidt (1988)
Raunds, England	8th–10th c. AD	Male, 20–30 years	Right leg	Roberts and Manchester (2005)
Gruczno, Poland	12th–14th c. AD	Male, 35–50 years	Right leg	Kozlowski and Piontek (2000)
Norwich, England	13th–15th c. AD	Young male	Both legs	Stirland (1997)
Corroios, Portugal	15th c. AD	Male, over 60 years	Right leg	Umbelino et al. (1996)
Zienki, Poland	17th/18th c. AD	Female, 25–30 years	Right leg	Gładykowska-Rzeczycka and Śmiszkiewicz-Skwarska (1998)
Radziejów Kujawski, Poland	14th–18th c. AD	Male, 35–50 years	Right leg	Kozlowski and Kowalski (1996)
New York, USA	19th c. AD	??	??	Sansone (1999)
Southwestern Mississippi, USA	19th c. AD	Female, 18–25 years	Right arm, right leg	Thompson (2014)

described in this paper represent the only examples of neurogenic paralysis recorded in these samples.

2. Materials and methods

The municipality of Virje is located in the continental Croatia, about 50 km north-eastern of Zagreb, while the city of Zadar is located in southern Croatia on the eastern Adriatic coast (Fig. 1). The first case was recovered from grave number 89 in Virje – St. Martin's parish church (Fig. 2A). This cemetery was in use between the end of the 14th and the end of the 17th centuries, while grave 89 is dated to the first half of the 16th century, based on vertical stratigraphy and its position in relationship to the church (Čimin, personal communication). The second skeleton was recovered from grave number 22 in Zadar, Petar Zoranić square; the skeleton was found in the south-western part of the grave, disturbed, due to the subsequent inhumation of another skeleton (Fig. 2B). The graveyard was in use during the medieval period, and grave 22, based on vertical stratigraphy and the recovered material remains (pottery, metal objects), is dated between the 12th and the 15th century (Vučić, personal communication).

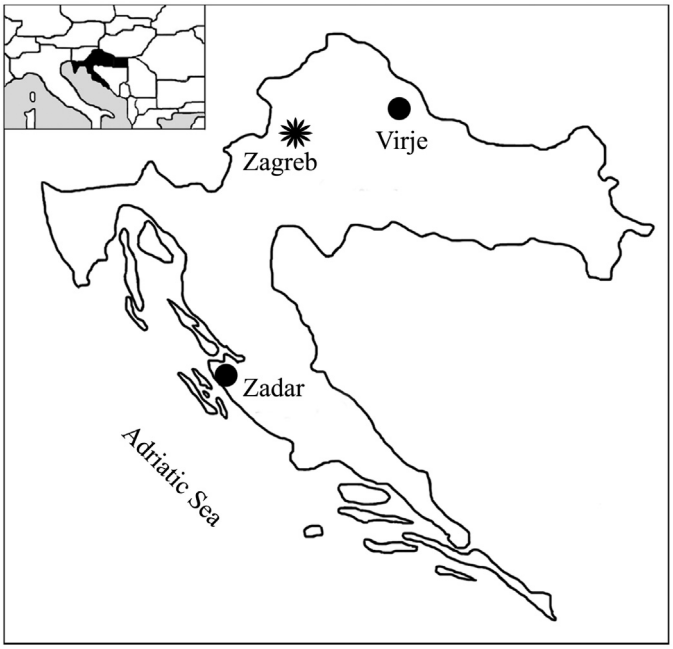

Fig. 1. Map of Croatia showing the geographical locations of the analyzed sites.

Sex and the age at death were estimated using standard anthropological methods described in Buikstra and Ubelaker (1994). Sex was additionally confirmed using discriminant functions for the femur specifically developed for medieval Croatian populations (Šlaus, 1997). The maximum femoral lengths in both skeletons were reconstructed using the method proposed by Gidna and Domínguez-Rodrigo (2013). Cases of spinal scoliosis reported in this study were diagnosed according to criteria presented by Aufderheide and Rodríguez-Martín (1998).

3. Paleopathological analysis

3.1. Case 1

This was a well-preserved skeleton of a 25–35 year old male. The cranium, right innominate, tibia and fibula were missing postmortem. This individual suffered from considerable pronounced atrophy and limb shortening in the right upper limb (humerus, radius, ulna, and metacarpals) (Fig. 3A) and the right femur (Fig. 3B; Table 2), suggesting he was hemiplegic. Both clavicles display very well developed costal tuberosities for the attachment of the costoclavicular ligament and well developed deltoid tuberosities for the attachment of the deltoid muscle. As a result of abnormal biomechanical stress, some of the bones exhibit abnormal curvature. This is pronounced in both femora where the distal portions are bent laterally. This skeleton also exhibits C-shaped spinal scoliosis, convex to the left side in the thoraco-lumbar region. Scoliotic changes are most pronounced in T12, L1, and L2, with the apex of the curve being at T12 (Fig. 4). In these three vertebrae, body height is considerably less on the right side than on the left: T12 – right 20 mm, left 26 mm; L1 – right 22 mm, left 26 mm; L2 – right 26 mm, left 28 mm. Some other changes associated with scoliosis are also present: (a) the right articular surfaces appear larger than the left; (b) osteoarthritis is present on the right inferior articular surface of T12. Other paleopathological findings include the presence of dental enamel hypoplasia, a non-specific indicator of subadult stress, on the mandibular canines.

In order to determine the extent of atrophy and shortening of the right femur, a comparison with the average dimensions of femora from the male Virje sample was conducted (Table 3). The comparison showed that all analyzed dimensions of the right femur of this individual are considerably smaller in relation to the average femora dimensions of the Virje males.

3.2. Case 2

The skeleton from Zadar is excellently preserved, with only several ribs and some of the small bones from the hands and feet

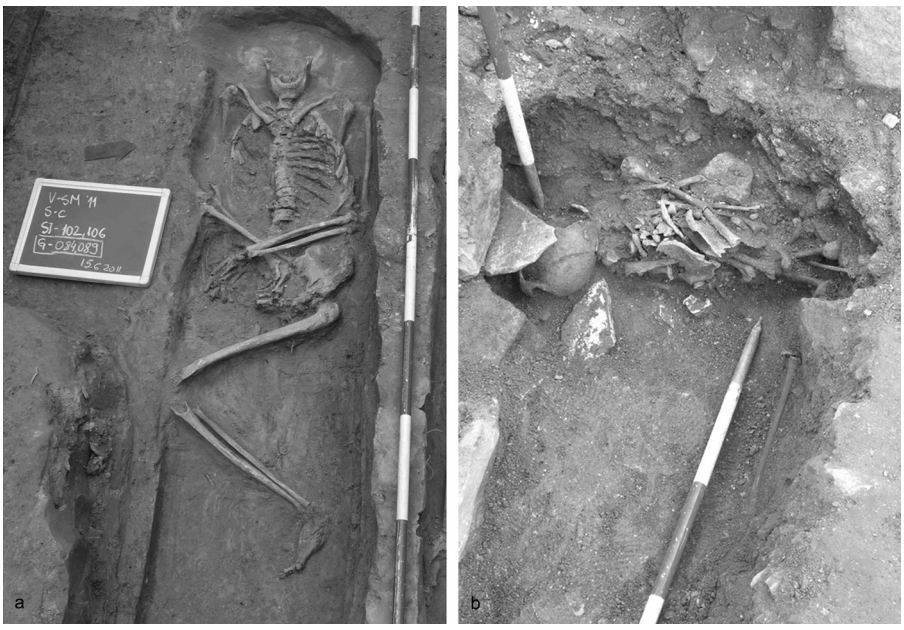

Fig. 2. Skeleton of the adult male from Virje (A) and the adult female from Zadar (B) during the excavation.

missing. This skeleton belongs to an adult female aged between 25 and 35 years at the time of death. In all likelihood this individual suffered from triplegia as all long bones except those of the left arm display considerable atrophy (Figs. 5 and 6; Table 2). The right humerus displays considerable concave (anterior) bowing of the distal half of the diaphyseal shaft. On the left side there is 90° internal tibial torsion, while the anterior crest of the right tibia is rotated laterally. Both femora display significant anterior bowing of the proximal portions with an increased femoral neck anteversion of 45°. Both acetabula are exceptionally shallow – 6 mm measuring from the acetabular margin to the deepest point within the acetabular fossa (Fig. 7A, 7B). Due to postmortem damage, the

Table 2
Measurements (in mm) of all preserved long bones belonging to the studied skeletons.

Bone	Virje		Difference	Zadar		Difference
	Left	Right	%	Left	Right	%
Clavicle						
Maximum length	–[a]	–		145	140	3.4
Sagittal diameter at midshaft	–	–		10	8	20.0
Vertical diameter at midshaft	–	–		7	6	14.3
Humerus						
Maximum length	–	–		301	273	9.3
Epicondylar breadth	–	–		52	45	13.5
Maximum vertical diameter of head	–	–		43	32	25.6
Maximum diameter at midshaft	20	18	10	21	11	47.6
Minimum diameter at midshaft	15	13	13.3	15	9	40.0
Radius						
Maximum length	280	–		227	197	13.2
Sagittal diameter at midshaft	12	11	8.3	12	8	33.3
Transverse diameter at midshaft	15	10	33.3	16	10	37.5
Ulna						
Maximum length	–	–		244	–	
Dorso–volar diameter	13	11	15.4	13	10	23.1
Transverse diameter	15	13	13.3	10	7	30.0
Physiological length	–	–		216	190	12.0
Minimum circumference	39	33	15.4	33	20	39.4
Femur						
Maximum length[b]	437	367	17.4	352	341	3.2
Bicondylar breadth	–	–		350	–	
Epicondylar breadth	–	–		–	–	
Maximum diameter of head	–	–		41	–	
A/P subtrochanteric diameter	21	15	28.6	17	13	23.5
Transverse subtrochanteric diameter	28	14	50.0	20	12	40.0
Sagittal diameter at midshaft	19	16	15.8	14	14	0.0
Transverse diameter at midshaft	22	14	36.4	16	12	25.0
Circumference at midshaft	–	–		46	43	6.5

[a] Measurement could not be taken.
[b] Maximum femoral lengths were reconstructed.

Table 3
Comparison of the right femur measurements belonging to the individuals from Virje and Zadar with average dimensions of the right femur for males in the Virje series and females in the Zadar series.

Measurement	Virje male	Average values in Virje males ($N = 17$)	Zadar female	Average values in Zadar females ($N = 32$)
Maximum length	367	453.2	341	419.9
A/P subtrochanteric diameter	15	26.4	13	24.2
Transverse subtrochanteric diameter	14	29.7	12	27.3
Sagittal diameter at midshaft	16	30.4	14	28.1
Transverse diameter at midshaft	14	27.6	12	26.4
Circumference at midshaft	–	89.8	43	85.6

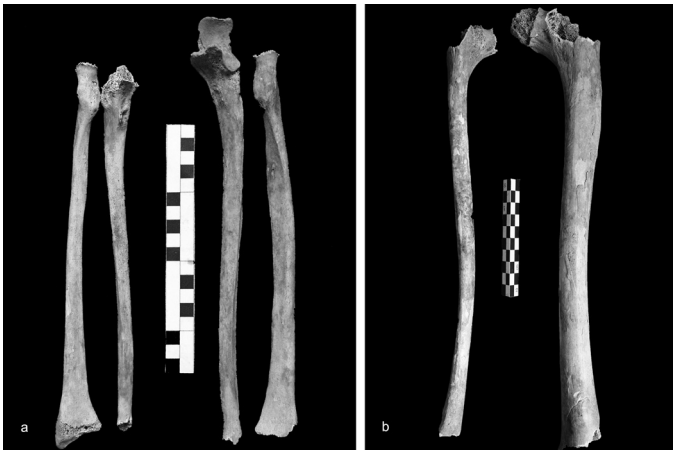

Fig. 3. Side comparison of forearm bones (A) and femora (B) in the male from Virje. Note considerable atrophy and limb shortening on the right side.

acetabular index could only be estimated for the left side; it is between 38 and 40°. The changes in the pelvic region are probably the result of bilateral hip dysplasia. Severe C-shaped scoliosis, convex to the right side with the apex of the curve on T4, is present in the thoracic region; the most notable differences in vertebral body height are present in T3 (left aspect 16 mm, right aspect 21 mm), T4 (left 12 mm, right 23 mm), T5 (left 13 mm, right 23 mm), and T6 (left 17 mm, right 22 mm) (Fig. 8A and B). Other changes besides the wedging of the vertebral bodies associated with scoliosis are present in the spine: (a) the left articular surfaces of C3–C7 and T2–T7 are visibly larger than those on the right side (Fig. 8C); (b) the presence of osteoarthritis on the inferior articular surfaces of L3 and L5; (c) the spinous processes of T2–T6 are rotated toward the concave (left) side. All of the preserved ribs are abnormally rotated and curved as a result of scoliosis. This individual also displays dental enamel hypoplasia on the maxillary and mandibular molars.

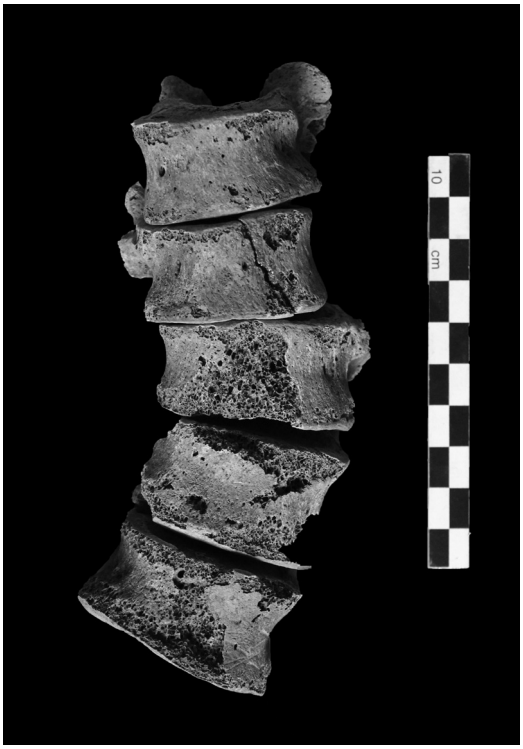

Fig. 4. Spinal scoliosis in the thoraco-lumbar region (T10-L2) of the Virje skeleton, anterior view.

Similar to Case 1, a comparison of the dimensions of the right femur belonging to the Zadar female with the average dimensions of femora from the female Zadar series was conducted (Table 3). Again, the study showed that all analyzed dimensions of the right femur of this individual are considerably smaller, compared to the average femora dimensions of the Zadar females.

4. Differential diagnosis

Several disorders may result in skeletal changes that include limb shortening and bone atrophy. The fact that both skeletons exhibit shortened long bones shows that the disuse must have started during growth. Accordingly, in terms of differential diagnosis we included only disorders with childhood onset: cerebral palsy, poliomyelitis, cerebrovascular accident, and Rasmussen's encephalitis. Neurological disorders that only start to affect people in adulthood such as Kennedy's disease, multiple sclerosis, and amyotrophic lateral sclerosis were excluded.

Cerebral palsy (CP) is an umbrella term for several permanent, non-progressive disorders that occur during the development of fetal brain (Samilson, 1981). It can be caused by a number of factors such as infection during pregnancy, insufficient oxygen to the fetus, premature birth, or traumatic injury (Krigger, 2006). The most characteristic clinical signs are muscular impairment, skeletal abnormalities, and changes in skeletal maturation (Fawcitt, 1964; Ihkkan and Yalçin, 2001). CP is defined by spasticity rather than the paralysis, and the most common type of cerebral palsy is spastic CP, which occurs in 80% of all cases (Stanley et al., 2000). A study conducted by Odding et al. (2006) suggests that it is more common to have spasticity in multiple limbs (60% of cases) than in a single limb (40% of cases). In cases when paralysis occurs, hemiplegia is most frequent (50%), followed by quadriplegia (25%), then paraplegia (21%). Triplegia is rare and occurs in only 3.1% of the cases (Ebnezar, 2003). It seems that CP affects more males then females, and in Europe this ratio is 1.3 to 1 (Johnson, 2002). Scoliosis is common in children with CP, and the incidence of scoliosis and scoliotic curve patterns depend on the degree of neurologic involvement (McCarthy et al., 2006). Other skeletal changes associated with CP include hip dysplasia, femoral neck anteversion, and various foot deformities (Ebnezar, 2003).

Poliomyelitis is a viral infectious disease caused by the poliovirus (genus *Enterovirus*), which is transmitted by the fecal-oral route. The poliovirus may invade anterior horn cells of the

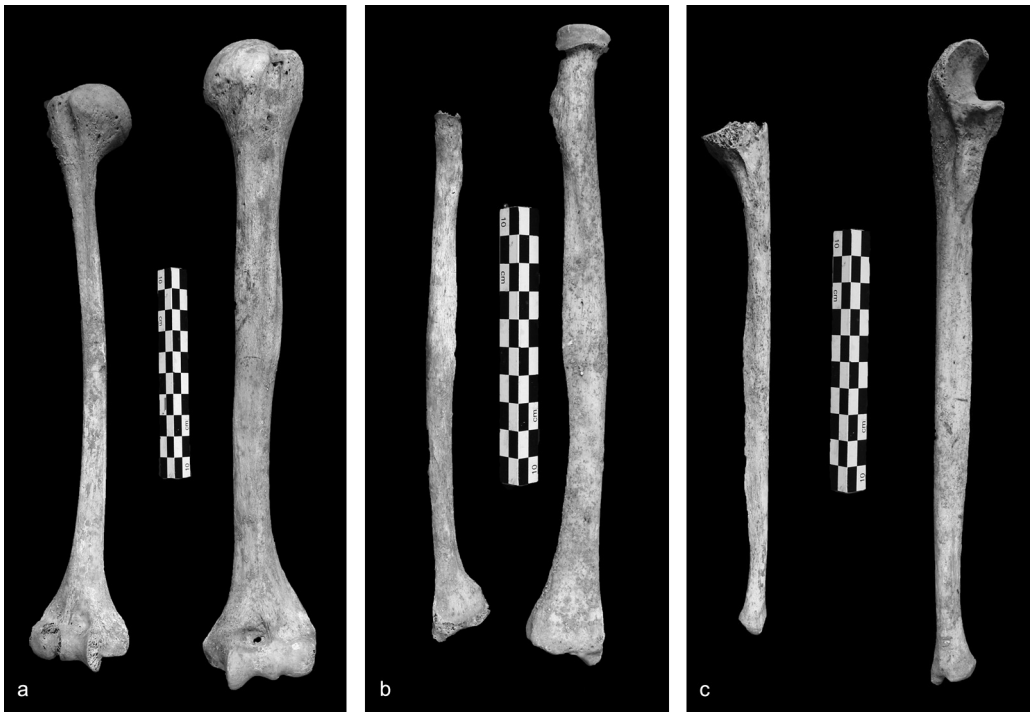

Fig. 5. Comparison of the upper limb bones of the female from Zadar: humeri (A), radii (B) and ulnae (C). Note considerable atrophy and limb shortening on the right side.

spinal cord, and it may cause temporary or permanent damage of the nerve cells due to the inflammation process (Shibuya and Murray, 2004). According to Marx et al. (2000) as many as 1% of infected individuals develop paralytic disease. Polio usually affects children under 12 months of age (Ebnezar, 2003), but the probability of developing paralytic polio increases with age since paralysis in children occurs in 1/1000 cases, while in adults 1/75 may develop paralysis (Gawne and Halstead, 1995). Some epidemiological studies have reported a male-to-female ratio in the prevalence of paralytic poliomyelitis of 1.4 to 1 (Jamison et al., 1993). Young (1989) proposed that in very young children (under 5 years of age) paralysis of one leg is most common, while in adults extensive paralysis of trunk and all four limbs is more probable. On the other hand, the study conducted by Dias-Tosta and Kückelhaus (2004) suggests that the occurrence of triplegia in individuals affected by paralytic polio is rare. The skeletal change most frequently associated with paralytic polio is spinal scoliosis, and the frequency of scoliosis in post-polio survivors has been estimated at 30% (Colonna and Vom Saal, 1941). Other frequent changes associated with polio are hip dysplasia, femoral neck anteversion, and deformities of foot bones (Ebnezar, 2003).

Rassmusens's encephalitis (RE) is a rare, but severe, inflammatory neurological disorder. Usually it is associated with intractable focal epilepsy, cognitive decline, hemiparesis and hemiplegia (Sheybania et al., 2011). Although unilateral neurologic deficit is most common in patients suffering from RE, occasional cases of bilateral involvement have also been reported (Bien et al., 2002). For now, there is no conclusive evidence why and how RE starts, although infection by a virus has been suggested by Rasmussen et al. (1958), and more recently cytotoxic T cells were presumed to directly account for neurodegeneration in patients with RE (Bien et al., 2002). The age at onset is during childhood, most frequently between 6 and 8 years (Mastrangelo et al., 2010), but in around 10% of cases the disease may start after the age of 12 (Sheybania et al., 2011). A study conducted by Bien et al. (2013) estimates that the incidence rate for this disorder is 2.4 cases per 10^7 in people under the age of 18 years.

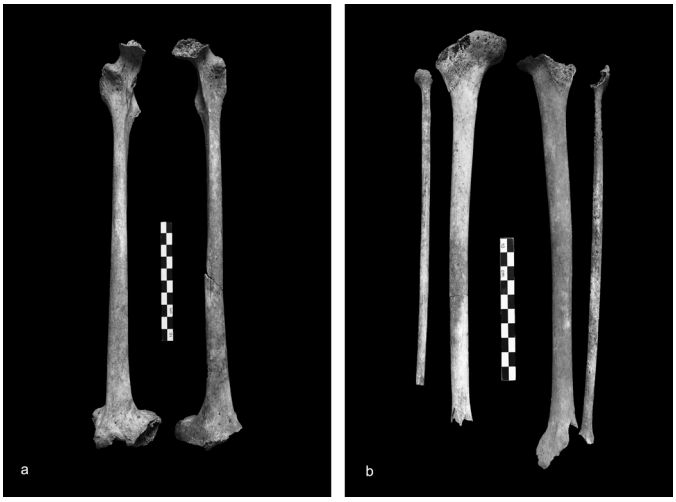

Fig. 6. Comparison of the lower limb bones of the female from Zadar: femora (A), tibiae and fibulae (B). Note considerable atrophy and limb shortening on both sides.

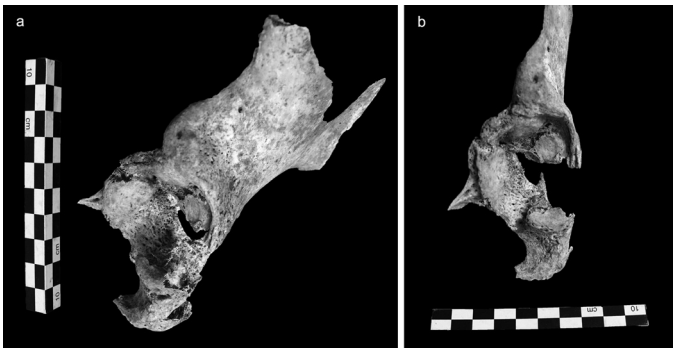

Fig. 7. Left acetabulum belonging to Zadar skeleton: latero-posterior view (A), lateral view (B).

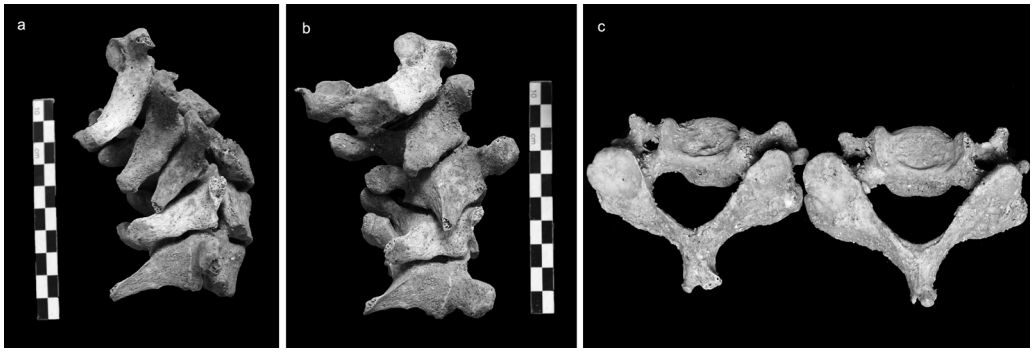

Fig. 8. Spinal scoliosis in the thoracic region (T2–T6) of the Zadar skeleton: lateral view (A), posterior view (B). Difference in size between the left and the right articular surfaces of C4 and C5, posterior view (C).

Cerebrovascular accident (CVA) or stroke is caused by occlusion of a major artery in the brain that results in death of all cells within the affected tissue (Sims and Muyderman, 2009). CVA may be divided into ischemic (about 80%) and hemorrhagic stroke categories (Donnan et al., 2008). Advanced age seems to be one of the most significant CVA risk factors. Today it primarily affects people older than 65 years of age (Towfighi et al., 2008), but clinical studies suggest that CVA in children occurs more frequently than was initially thought. The incidence varies between 2 and 3 per 100 000 (e.g. Schoenberg et al., 1978; Broderick et al., 1993; Fullerton et al., 2003). Individuals afflicted by stroke usually show signs of depression and anxiety, and they also suffer from neurological disorders such as reduced functional capacity as well as muscle atrophy and partial paralysis (hemiplegia) (Gordon et al., 2004).

5. Discussion

The main characteristic of the skeletons analyzed here, atrophy and shortening of long bones, indicates a childhood onset of impairment. The presence of triplegia in the Zadar skeleton rules out the possibility of RE and stroke because triplegia is not found in these disorders. Triplegia could be a possible indicator of CP, but it also occurs as a result of polio, although in both disorders it is very rare. The presence of spinal scoliosis in the Zadar female also indicates that RE and stroke are not plausible causes. The observed increased femoral neck anteversion can be associated with clinical conditions such as polio and cerebral palsy (Srimathi et al., 2012). Bilateral hip dysplasia recorded in the same skeleton could be caused by cerebral palsy, especially since the study conducted by Scrutton et al. (2001) indicated that bilateral hip dysplasia occurs in approximately one third of children under 5 years of age suffering from CP. However, it might also result from polio as some studies reported the occurrence of hip dislocations in individuals suffering from polio (e.g. Laguna and Barrientos, 2008; Yoon et al., 2014). The Virje male may have suffered from either RE or stroke, but scoliotic changes in the thoraco-lumbar region again rule out these alternatives. Rassmusen's encephalitis is not probable for either skeleton due to the fact that this disease is extremely rare, appearing in only 2.4 cases per ten million individuals under the age of 18 (Bien et al., 2013). The occurrence of cerebrovascular accident in both cases is also highly unlikely since 95% of strokes occur in people over 45 years of age (Carroll et al., 2001). Spinal scoliosis in both individuals was probably caused by polio or/and CP, since neuropathic forms of neuromuscular scoliosis are caused by several diseases such as CP and polio, which may result in long C-shaped curves extending from the lower cervical region to the sacrum (Netter, 1987). In conclusion, both the differential diagnosis and the data presented in this section strongly indicate that the changes observed in individuals from Virje and Zadar were caused by neurogenic paralysis, most probably cerebral palsy and/or paralytic poliomyelitis.

Several cases of poliomyelitis and cerebral palsy have been reported (Table 1), and they all share one common trait – all are adults ranging between 18 and 65 years of age at the time of death. Regarding the sex distribution, it seems that the majority of afflicted individuals are males, but this information has to be viewed with caution since in some cases data on sex are missing (e.g. Mitchell, 1900; Sansone, 1999). In most examples only one limb was affected, predominantly the right leg (see Table 1). In other unilateral cases either the left leg or the left arm were involved. Impairment of two extremities was reported in five cases: two individuals probably suffered from paraplegia, two were probably hemiplegic, while one individual suffered from atrophy and shortening of the right arm and the left leg. Spinal scoliosis was observed in six cases (Winkler and Großschmidt, 1988; Wiltschke-Schrotta and Teschler-Nicola, 1991; Umbelino et al., 1996; Stirland, 1997; Gładykowska-Rzeczycka and Śmiszkiewicz-Skwarska, 1998; Kozlowski and Piontek, 2000) while bilateral hip dysplasia was recorded only in one case (Wiltschke-Schrotta and Teschler-Nicola, 1991).

When these two examples from Croatia are compared to other cases of polio/CP from archeological contexts, it is obvious that they share similarities, including atrophy and shortening of the limbs and scoliotic changes in the spine. Some features, however, are unique. Of the known five cases of shortening and atrophy of two limbs, the Virje male is most similar to a young female from southwest Mississippi as both were probably hemiplegic on the right side, but the Virje skeleton also exhibits spinal scoliosis. On the other hand, it seems that the Zadar female represents the first case of triplegia reported in the paleopathological literature, and uniqueness of this individual is further reflected in the fact that she also suffered from bilateral hip dysplasia.

Both individuals under study suffered from multiple pathological changes that severely and negatively affected their quality of life, as they suffered impaired function caused by hemiplegia and triplegia. It is likely that their physical impairment separated them from the rest of the community in which they lived, but we cannot tell how they were treated by the people surrounding them. Were they regarded as members of the community or were they treated differently from the rest of the population? The only indication of their social status, however weak, might be derived from the fact that both were buried in the middle of established parochial cemeteries, and not on the edges. This might suggest they were considered full community members, who were given necessary care to survive. A similar assumption was proposed by Stirland (1997) in case of the male from Norwich who suffered from paraplegia caused by CP.

The prevalence of cerebral palsy today is estimated as above 2.0 per 1000 live births (Odding et al., 2006), while the prevalence of paralytic poliomyelitis before the start of the global eradication program in the 1980s ranged between fewer than 1 per 1000 to more than 20 per 1000 (Shibuya and Murray, 2004). Assuming that the skeletal changes described in this paper are the result of polio and/or CP, the overall prevalence of these diseases combined in the medieval Croatian skeletal sample curated in the Osteological Collection of the Croatian Academy of Sciences and Arts in Zagreb would be 2/4226 or 0.47 cases per 1000 (subadult and adult skeletons combined). These data are, however, at best provisional since some skeletons from this collection are partially preserved, resulting in possibly serious underestimation.

6. Conclusion

The skeletons belonging to the individuals described in this study exhibit osteological changes (atrophy and shortening of long bones, scoliotic changes of the spine) consistent with a neurogenic paralysis that occurred during the early childhood. Differential diagnosis included disorders such as cerebral palsy, poliomyelitis, cerebrovascular accident, and Rasmussen's encephalitis, while detailed macroscopic analysis of skeletal remains strongly indicates cerebral palsy and/or paralytic poliomyelitis as probable diagnoses. Although skeletal changes associated with neurogenic paralysis recovered from archeological sites have already been published, the importance of cases reported in this paper lies in the fact that the Virje skeleton is only the third case of hemiplegia known so far (first with spinal scoliosis), while the Zadar skeleton represents the first case of triplegia ever reported in the paleopathological literature.

Acknowledgments

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