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Original article

Morphometric Evaluation of Coccyx with Microcomputed Tomography (Micro CT) and Computed Tomography (CT) Technology

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Abstract

Aim: We investigated the coccyx anatomy accurately in detail by microcomputed tomography (micro CT) and computed tomography (CT) to contribute to the data related to the coccyx anatomy and the potential clinical contribution of these datas in the treatment of coccyx's pathologies.

Material and Methods: Twenty coccyges from embalmed cadavers were examined with a micro CT device. The inferior part of the sacrum and coccyx together with the surrounding soft tissue was removed safely. The tissue was scanned with a micro CT device, and all parameters were measured with micro CT image viewer programs. CT images of 29 patients without coccyx pathology were measured with OsiriX programs. Measured morphometric parameters with micro CT and CT were evaluated using statistical methods.

Results: Generally, the morphometric parameters as mean values were larger in males than in females. Mean values for vertical length and coccyx width were higher for CT compared with micro CT images. Coccyx was more flat in the frontal plane in females. There were statistically significant differences between the micro CT and CT images regarding mean vertical length, width, lateral deviation angle, and sacrococcygeal angle and length of the vertebrae ($p < 0.05$). There were no statistically significant differences in number and width of the vertebrae ($p > 0.05$).

Conclusion: We suggest that examining the normal coccyx morphology will help to better understand and treat the pathologic conditions of the coccyx. We believe our findings will contribute to the data related to the coccyx anatomy.

Keywords: Coccyx - Anatomy - Microcomputed tomography – Computed tomography - Cadaver.

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INTRODUCTION

The coccyx is a triangular bone consisting of a varying number of (usually) 3–5 vertebrae and joints in the lower part of the sacrum (1,2). It is predominantly inclined anteriorly and inferiorly (3). Rarely, it may be inclined backwards in the sagittal plane (4). Clinically, pathologies associated with the coccyx are seen in many tumors, fractures, dislocations, and infections (5-8). In addition, coccygodynia, first described by Simpson in 1859, is an important pathology of this region, causing pain at the lower end of the spine that is severe when sitting, standing, and walking. Trauma, infection, tumor, disc degeneration, and birth are causative factors for coccygodynia (5-7,9-11). Radiologic images taken *in situ* and in standing position and clinical findings are important for diagnosis. In these radiologic images, the angle and shape of the coccyx are evaluated (3,12-14).

Tomography systems enable display of three-dimensional (3D) structures of anatomic formations and performance of required measurements on these formations without using sample preparation steps. Spatial resolution of medical computed tomography (CT) is 1–2 mm and corresponds to the size of 1–10 mm^3 voxel (3D pixel). Computerized microtomographs (micro CT) allow a spatial resolution of <10 µm, reaching a voxel size of 1×10^{-6} mm^3. As the object to be displayed rotates in a table, the system receives multiple X-ray shadow transition images from different angles. Using these shadow images, the obtuse section images are reconstructed, and a 3D model of the internal microstructure and density in the selected height range is created in the transition images. Internal morphologic parameters can be calculated by reconstruction (7-17). There are a few studies on the coccyx anatomy or morphometry and very few on micro CT. Knowing the anatomy and variations of coccyx will facilitate understanding of the coccyx's clinical pathology such as coccygodynia, chordoma and also provide the effective surgical treatment of these pathologies. In this study we examined the coccyx anatomy using micro CT and CT devices in detail and reconstructed the 2-dimensional images to 3-dimensional real-like digital images to evaluate the complete radiological morphology of coccyx. Thus, we examined the usefulness of preoperative radiological evaluation in understanding and treatment of the coccygs pathologies.

MATERIALS and METHODS

This study was approved by the ethics committees of XXX University Medical School (GO 16/339-28) and YYY University Medical School (2018-414). The study was performed in accordance with the principles outlined in the Declaration of Helsinki. Twenty adult cadavers (13 males, 7 females) stored in 7% formaldehyde solution and CT images of 29 patients (11 males, 18 females) without coccyx pathology from the Turkish population were used. The cadavers were dissected in the dissection laboratory. The inferior sacrum and coccyx together with the surrounding soft tissue were removed safely. Extracted tissues were taken in sample containers containing freshly prepared 7% formaldehyde solution. The tissue was scanned using a micro CT device (Bruker X-ray) at a low isotropic resolution (33 µm) with the following parameters: 800 mA, 50 kV, within 360° rotation, and 3500 msec scanning time for each specimen. The scanned data were reconstructed with the NRecon program (SkyScan, version 1.6.4.8), and transverse sections were taken. Then 3D modeling was performed using CTAn (SkyScan, version 1.11.10.0) and CTvox (SkyScan, version 2.3) programs, and both 3D and 2D analyses were evaluated (Fig.1). Measurements on CT images of patients without coccyx pathology were performed using the OsiriX program (Pixmeo SARL, Geneva, Swiss) (Fig. 2). The following seven parameters at CT and Micro CT images were measured as shown in Fig. 1: (1) width of coccyx, (2) straight length of coccyx, (3) lenght of processus transversus, (4) width of vertebra, (5) length of vertebra, (6) angle of lateral deviation of the coccyx, (7) sacrococcygeal angle of the coccyx. IBM SPSS Statistics 23.0 (IBM Corporation, Armonk, NY, USA) package program was used for statistical evaluations. All values were compared using the $\chi 2$ test, and statistical significance was defined as $p < 0.05$.

RESULTS

Table 1 shows the mean coccygeal length and width. All mean measured parameters were larger in males than in females; however, statistically, they did not differ according to sex ($p > 0.05$).

Mean coccygeal length and width were higher on CT compared with micro CT images (Table 1). The maximum/minimum coccygeal lengths and widths were 39.58 mm (male)/10.58 mm (female) and 35.00 mm (male)/12.23 mm (female), respectively, for micro CT and 43.60 mm (male)/20.09 mm (male) and 41.00 mm (male)/15.30 mm (female) for CT images.

The number of vertebrae forming the coccyx ranged from 1 to 5 in micro CT and 2 to 5 in CT images (Table 2). On micro CT images, 1, 1, 11, 5, and 2 coccyges were formed by 1, 2, 3, 4, and 5 vertebrae, respectively. On CT images, 5, 16, 7, and 1 coccyx were formed by 2, 3, 4, and 5 vertebrae, respectively (Table 2).

Generally, the vertebral width and length decreased gradually from the first to the last vertebra, and the vertebrae in CT images were longer and wider. Also, the vertebrae were generally longer and wider in men. Mean and standard deviation for all vertebrae were presented in Table 3.

On micro CT images, there was no fusion between the vertebrae in five coccyges. Fusion was found between two, three, four, and five vertebrae in seven, six, one, and one coccyges, respectively (Fig. 3). On CT images, there was no fusion between the vertebrae of 5 coccyges, whereas fusion was noted between 2, 3, and 4 vertebrae in 16, 6, and 2 coccyges, respectively (Table 2). With micro CT, 41 (62%) of the 66 total vertebrae were fused, compared with 58 of 91 (64%) with CT.

On micro CT images, 8 coccyges (four females, four males) had no transverse processes, whereas the remaining 12 had 1 to 9 transverse processes (mean 3.30 for all coccyges). Mean transverse process length was 3.53 ± 1.42 mm in males and 4.44 ± 0.12 mm in females ($p > 0.05$). On CT images, 4 coccyges (3 females, 1 male) had no transverse processes, whereas 25 had 1–6 transverse processes (mean 2.55 for all coccyges). Mean transverse process length was 2.78 ± 0.12 mm in males and 2.23 ± 0.13 mm in females ($p > 0.05$).

Lateral coccygeal deviation (frontal plane) and sacrococcygeal (sagittal plane) angles were measured on micro CT images with the CTAn program. The midlines of the coccyx and sacrum were considered to be zero in the same plane. There were no left or right deviations in four coccyges (20%), whereas 10 (50%) and 6 (30%) showed right and left deviations, respectively ($p > 0.05$, Table 4). Mean sacrococcygeal angle was 14.24° ± 8.55° overall, 13.55° ± 7.97° in males, and 15.53° ± 9.34° in females ($p > 0.05$, Table 4). On CT images, these angles were measured with OsiriX. There were no left or right deviations in 14 coccyges (48%), whereas 7 (24%) and 8 (28%) showed right and left deviations, respectively ($p > 0.05$, Table 4). Mean sacrococcygeal angle was 23.59° ± 16.50° overall, 26.84° ± 19.66° in males, and 21.61° ± 4.49° in females ($p > 0.05$, Table 5).

Mean coccygeal length, width, lateral deviation angle, sacrococcygeal angle, and vertebral length showed statistically significant differences between the micro CT and CT images ($P < 0.05$). For the number of vertebrae and vertebral width, there were no statistically significant differences between micro CT and CT images ($p > 0.05$).

Discussion

The data obtained from studies on coccygeal length vary. Oh et al. (18) studied 50 Korean cadavers in 2004 and found mean coccygeal length to be 33 mm (range, 18–48). In 2009, Aggarwal et al. (19) reported a mean coccygeal length of 58 mm (range, 38–82). In general, values were measured close to these in our study. Ethnicity is thought to be one of the reasons why the average length of the coccyx is different. Ethnicity can affect the average height of the person and accordingly the average of the coccyx. Furthermore, even within the same ethnic background, the morphologic structure of coccyx varied. We also found, as reported in some studies, that the length, width, and thickness of the coccyx were generally greater in males than in females (20,21). We consider that the main reason for this is the difference in average height between men and women.

Postacchini et al. compared the idiopathic coccygodynia patients and healthy individuals without clinical symptoms. As a result of the study, sacrococcygeal joint fusion was observed at a higher rate in the coccyx of idiopathic coccygodynia patients than the healthy individuals. In addition, the angle of the coccyx in the sagittal plane was also different in both of the groups. In 69% of healthy individuals, the coccyx was slightly curved forward, while 68% of idiopathic coccygodynia patients had a much greater angle than the healthy group (3). Maigne et al. reported that straight, short and vertical coccyxes were more prone to subluxation, whereas curved and longer coccyxes were prone to hypermobility (22). In addition, Kaneki et al. reported that the forward-curving coccyx caused an ulcer in the rectum in a woman who had a normal delivery, due to the pressure of the rectum towards the coccyx during childbirth (23). In 2008, Richard reported that the sacrum is shorter, wider, and straighter in females than in males, and this makes it easier for females to give birth (24). In 2013, Woon et al. found that the female coccyx would tend toward a straight shape (21). In accordance with the data of these studies, in our micro CT and CT groups, the coccyges were flatter in the frontal plane in females than in males. Fusion between the vertebrae was found more frequently among males than females. In the coccyges examined using micro CT, fusion was present in 10 of 21 vertebrae in females (48%), but in 31 of 45 vertebrae in males (69%), whereas in the coccyges examined using CT, fusion was present in 29 of 50 (58%) and 29 of 41 (71%) vertebrae, respectively. This difference between men and women is generally compatible with the studies mentioned, and we think that this may be related to birth. A coccyx with fused vertebrae, as in men, is probably a disadvantage at birth, as it will not have the ability to stretch. On the other hand, we consider that a less angled coccyx in the frontal plane, which is more common in women, may be an advantage since it will not obstruct the birth canal.

Many studies indicates that tumors can lead to the pain in some patients with typical coccydynia. Krasin et al. detected a mass adhering to the coccyx and extending to the rectum in a patient who has the diagnosis of coccygodynia. As a result of the analyses, it was determined that the mass was cloacogenic carcinoma. Sacral and coccygeal tumors are often overlooked. Krasin et al. reported that patients with sacral and coccygeal chronic pain were suspected of having a tumor (25). Sacrococcygeal teratoma (SCT) is a germ cell tumor with a rate of 1 in 35,000 to 40,000 newborns. Complete removal of coccyx is the best solution for its treatment. If the coccyx is not completely removed, the probability of recurrence is very high. Graves et al. reported a Sacrococcygeal teratoma case that recurred 17 years later because the coccyx was not completely removed. However, recurrent cases have been reported after 43 years. Recurrences are usually malignant. The variability of coccyx anatomy makes it difficult to fully resected (26). Glomus coccygeum is an encapsulated arterovenous vascular network located below the coccyx. Kim et al. determined a patient with typical coccydynia symptoms with glomus tumor of the coccyx. They removed the glomus coccygeus without resection of the coccyx, and the patient got rid of clinical symptoms. In their study, they drew attention to the glomus tumor factor of the coccyx, which was overlooked in coccydynia cases (27). There are studies indicating a relationship between coccygodynia and coccyx morphology. There are also studies demonstrating that the main cause of coccygodynia cases is overlooked tumors. We think that studies that will examine the links between tumors and coccyx morphology. In most of the coccygeal pathologies, MRI (Mangnetic Rezonance Imaging) or CT are commonly preferred together to evaulate the extension of the pathology and the changings of the bony structure. However, there is no question of knowing the previous, unaffected normal anatomy in these patients before the surgical procedure. For bone tumors, such as chordoma, in which gross total resection is essential to avoid local recurrence and the increase the tumor free period and the long-term survival, knowing that there may be non-fusion part of the coccygs and searching and resection of these separate coccygs parts are important for these purposes (28,29).

Since micro ct has a higher resolution, we conducted the study with micro ct. However, coccyx-related diagnoses are made using CT in the clinic and micro ct don't has clinical use. For this reason, we used the CT and compared the imaging, analysis and reconstruction possibilities of the two imaging systems.

CT is used for coccyx related diagnoses in the clinic. However, there are some difficulties in imaging the coccyx with CT such as intrinsic sacral tilt, dorsal angle of the coccyx, fecal material in front of the coccyx, obesity, low resolution images. Between 25% and 70% of the sacral and coccygeal fractures are not noticed at the first examination, missed and diagnosed later. 25% of these missed fractures may present with neurological symptoms such as ipsilateral leg weakness, bladder dysfunction or bowel dysfunction (30). When we look at the literature, it is seen that the academic studies on coccyx are generally carried out using CT. In our studie at cadavers, micro CT was very effective in obtaining the visuals as well as in providing good measurement results of the morphometric parameters and angles. Therefore, we suggest that all values that can be measured by CT can also be measured using micro CT. The high spatial resolution of micro CT allowed for a more detailed examination of the structures. Similar to this study, in 2018, Kulahoğlu et al. (31) reported significant agreement between cone-beam CT (CBCT) and micro CT images when the smallest voxel size was used. We think that micro ct has a very wide usage potential for bone and cadaver tissue studies.

Conclusion

In conclusion, evaluation of normal coccygeal morphology helps to better understand the pathologic conditions of the coccyx. We believe our findings will contribute to the data related to the coccyx anatomy and thence novel clinical techniques and treatment strategies in the management of coccygeal pathologies.

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TABLES

Table 1. Morphometric characteristics of the coccyx

	Micro CT		CT	
	Male	Female	Male	Female
Straight coccygeal length	26.82 ± 6.19	23.22 ± 6.90	33.79 ± 7.35	30.10 ± 0.51
Width of the coccyx	25.32 ± 6.26	20.17 ± 6.66	30.23 ± 7.24	25.61 ± 7.46

Mean ± SD.
Unit: mm
p > 0.05 between males and females.

Table 2. Fusion status between the coccygeal vertebrae

Micro CT			CT		
Sex	Number of vertebrae	Vertebrae with fusion among them	Sex	Number of vertebrae	Vertebrae with fusion among them
Female	4	2-3-4	Female	3	1-2-3
Female	3	2-3	Female	3	2-3
Male	3	2-3	Male	3	1-2-3
Male	3	1-2-3	Male	4	1-2-3-4
Male	3	1-2	Male	3	2-3
Female	3	-	Female	3	2-3
Male	4	3-4	Male	2	1-2
Male	3	2-3	Female	2	1-2
Male	3	-	Female	3	1-2-3
Male	2	-	Male	2	1-2
Male	4	2-3-4	Female	2	1-2
Female	3	-	Female	3	-
Female	4	1-2	Male	2	1-2
Female	3	1-2-3	Male	3	2-3
Male	3	1-2-3	Female	3	2-3
Male	3	2-3	Female	4	-
Male	4	2-3-4	Male	3	-
Male	5	2-3-4-5	Female	4	2-3
Male	5	1-2-3-4-5	Female	4	3-4
Female	1	-	Male	3	2-3
			Female	4	1-2-3-4
			Female	3	-
			Female	3	2-3
			Female	3	-
			Female	4	2-3-4
			Male	4	2-3-4
			Male	5	3-4-5
			Female	3	2-3
			Female	3	2-3

Table 3. Morphometric characteristics of the vertebrae

	Micro CT		CT	
	Male	Female	Male	Female
Straight length of the first vertebra	9.07 ± 3.26	7.31 ± 1.78	13.89 ± 3.98	11.68 ± 4.21
Width of the first vertebra	25.32 ± 6.26	20.17 ± 6.66	29.07 ± 8.52	24.62 ± 8.74
Straight length of the second vertebra	7.39 ± 1.47	6.14 ± 1.41	9.56 ± 3.04	8.57 ± 4.24
Width of the second vertebra	14.85 ± 2.41	11.7 ± 2.99	16.25 ± 7.67	13.19 ± 3.66
Straight length of the third vertebra	6.19 ± 1.16	5.73 ± 1.50	6.62 ± 2.29	19.63 ± 19.78
Width of the third vertebra	11.01 ± 2.23	8.53 ± 3.13	10.45 ± 2.64	8.88 ± 2.76
Straight length of the fourth vertebra	4.71 ± 1.10	5.66 ± 1.03	6.03 ± 2.20	4.80 ± 0.99
Width of the fourth vertebra	9.46 ± 1.67	8.38 ± 3.25	9.43 ± 3.0	7.46 ± 2.29
Straight length of the fifth vertebra	4.27 ± 1.33	-	3.80	-
Width of the fifth vertebra	8.70 ± 1.53	-	5.10	-

Mean ± SD.

Unit: mm

$p > 0.05$ between males and females.

Table 4. Incidence and angle of lateral deviation of the coccyx (in the frontal plane)

	Micro CT				CT			
	Male		Female		Male		Female	
	Incidence	Angle	Incidence	Angle	Incidence	Angle	Incidence	Angle
Straight	1 (%8)		3 (%43)		4 (%36)		10 (%56)	
Right deviated	6 (%46)	6.20 ± 4.62	4 (%57)	7.29 ± 4.30	3 (%28)	9.59 ± 5.78	4 (%22)	6.09 ± 4.07
Left deviated	6 (%46)	9.64 ± 5.03	0		4 (%36)	14.26 ± 8.98	4 (%22)	4.46 ± 2.22

Mean ± SD.

Unit: degree (angles)

$p > 0.05$ between males and females.

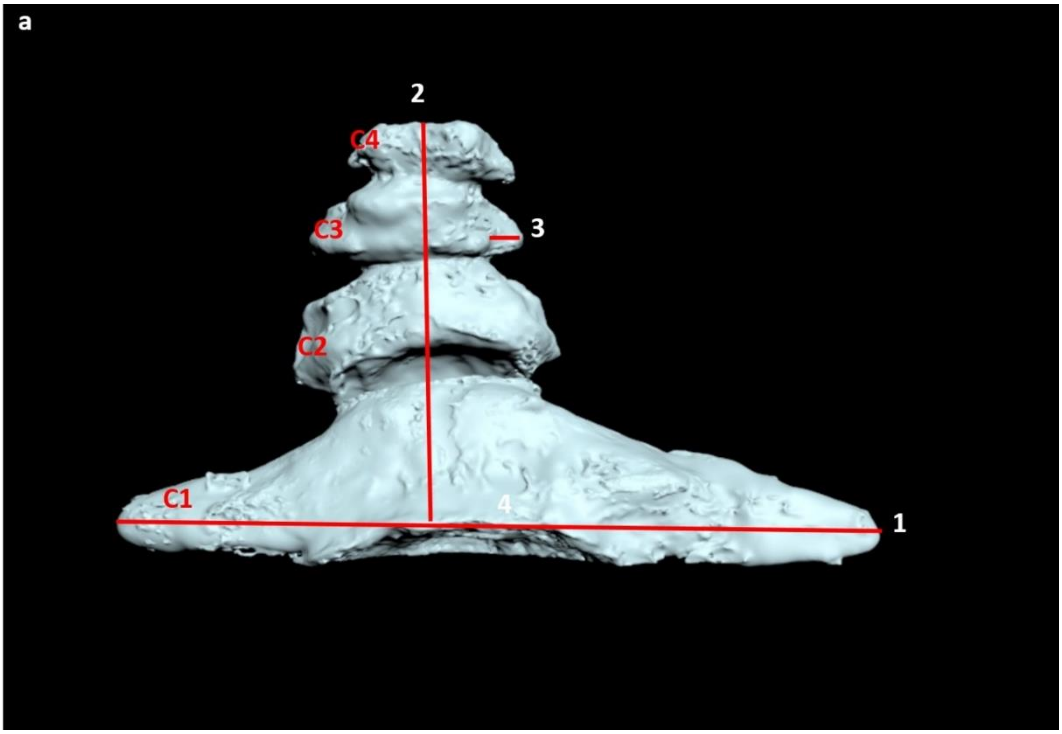
Table 5. Difference of sacrococcygeal angle of the coccyx (in the sagittal plane) and angle of the first coccygeal vertebrae with the sacrum

	Micro CT		CT	
	Male	Female	Male	Female
Sacrococcygeal angle of coccyx	13.55 ± 7.97	15.53 ± 9.34	26.84 ± 19.66	21.61 ± 4.49
Angle of the first coccygeal vertebrae with sacrum	4.70 ± 5.79	3.13 ± 4.28	16.20 ± 15.95	7.34 ± 9.77

Mean ± SD.

Unit: degree (angles)

$p > 0.05$ between males and females.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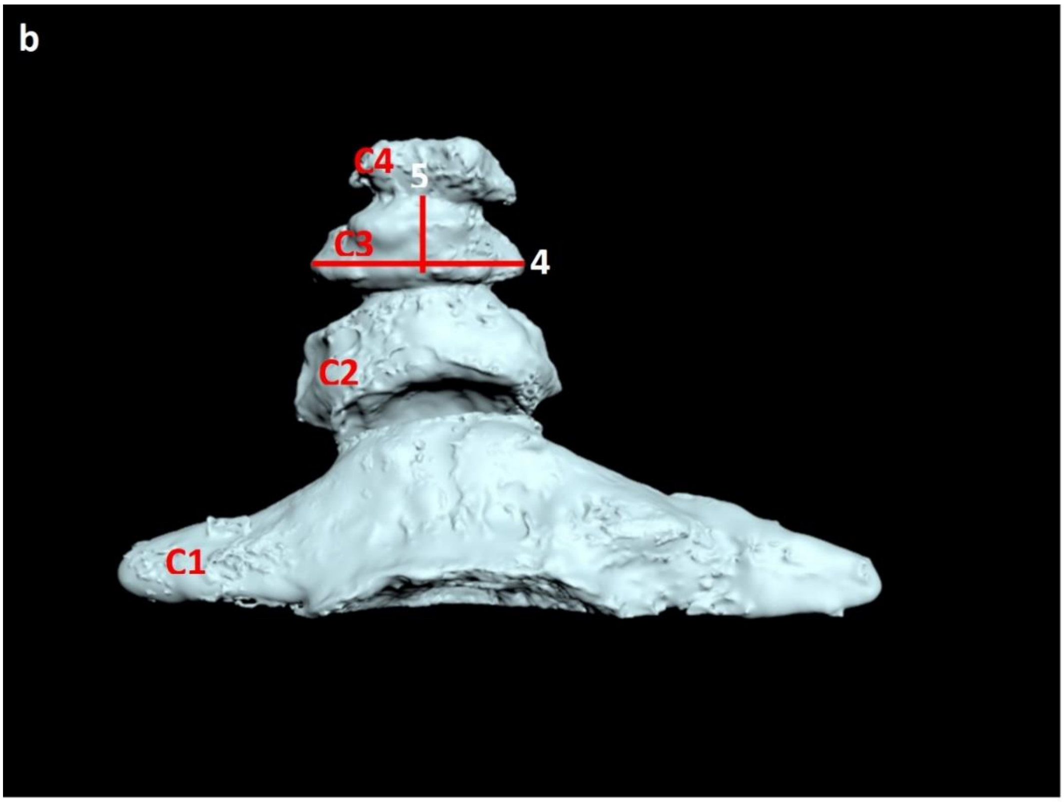
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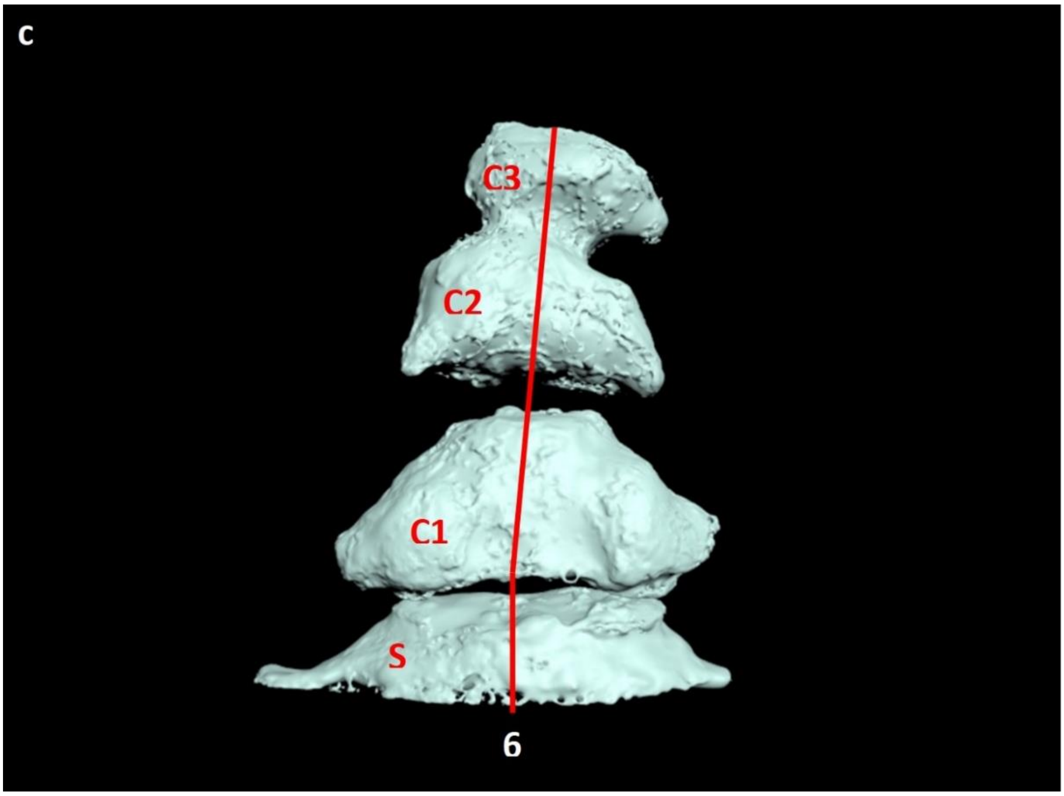


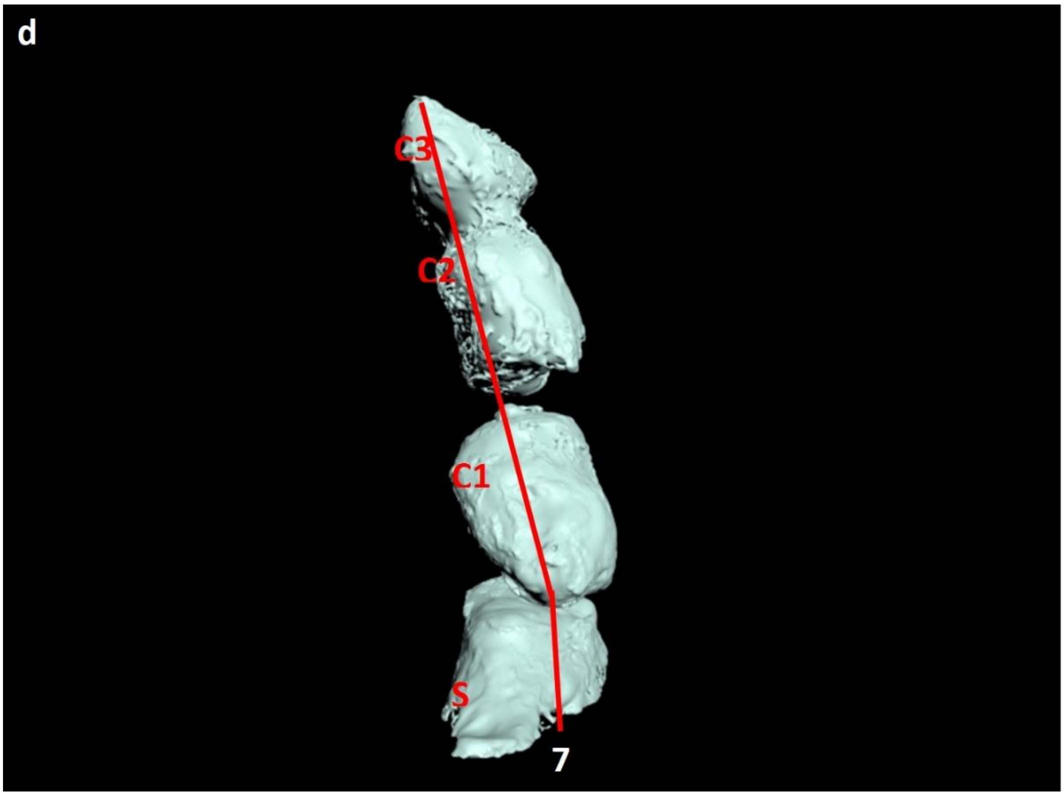
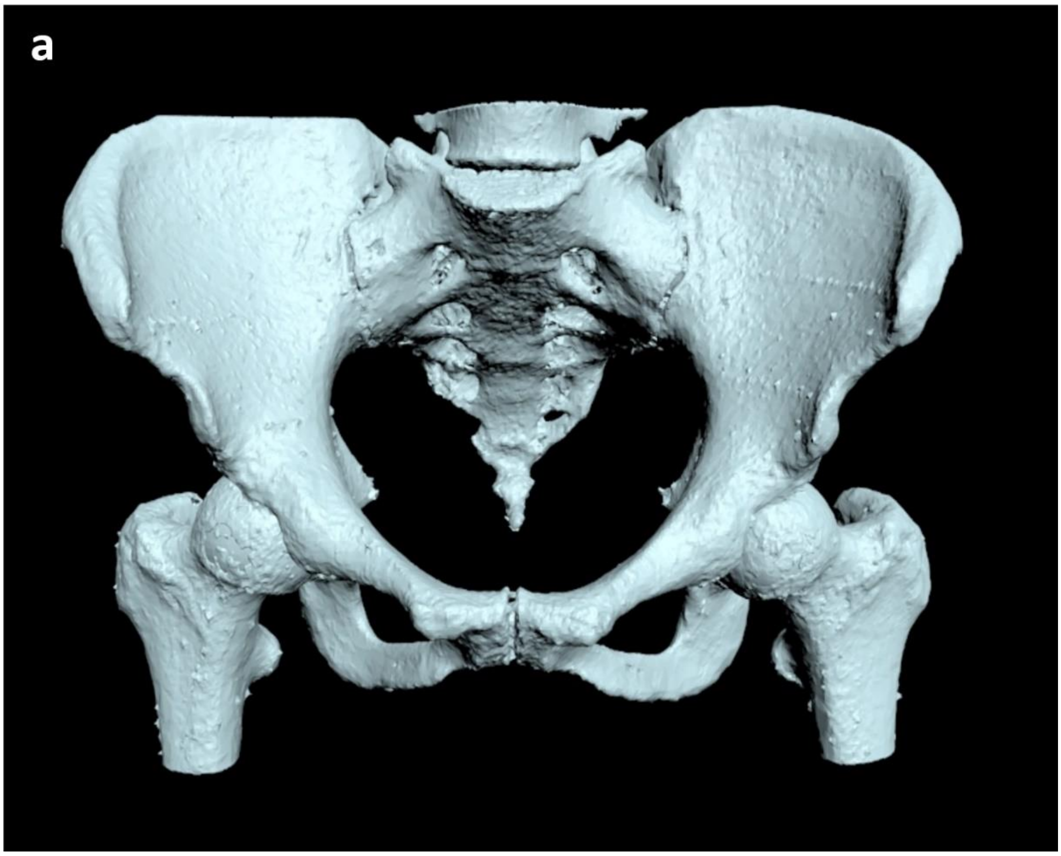


Figure 1. a-d. Parameters measured in this study: (a) anterior view: (1) width of coccyx, (2) straight length of coccyx, (3) lenght of processus transversus (b) anterior view: (4) width of vertebra, (5) length of vertebra, (c) posterior view: (6) angle of lateral deviation of the coccyx (d) lateral view: (7) sacrococcygeal angle. S: Sacrum, C1: 1. Coccygeal vertebrae, C2: 2. Coccygeal vertebrae, C3: 3. Coccygeal vertebrae


a


b

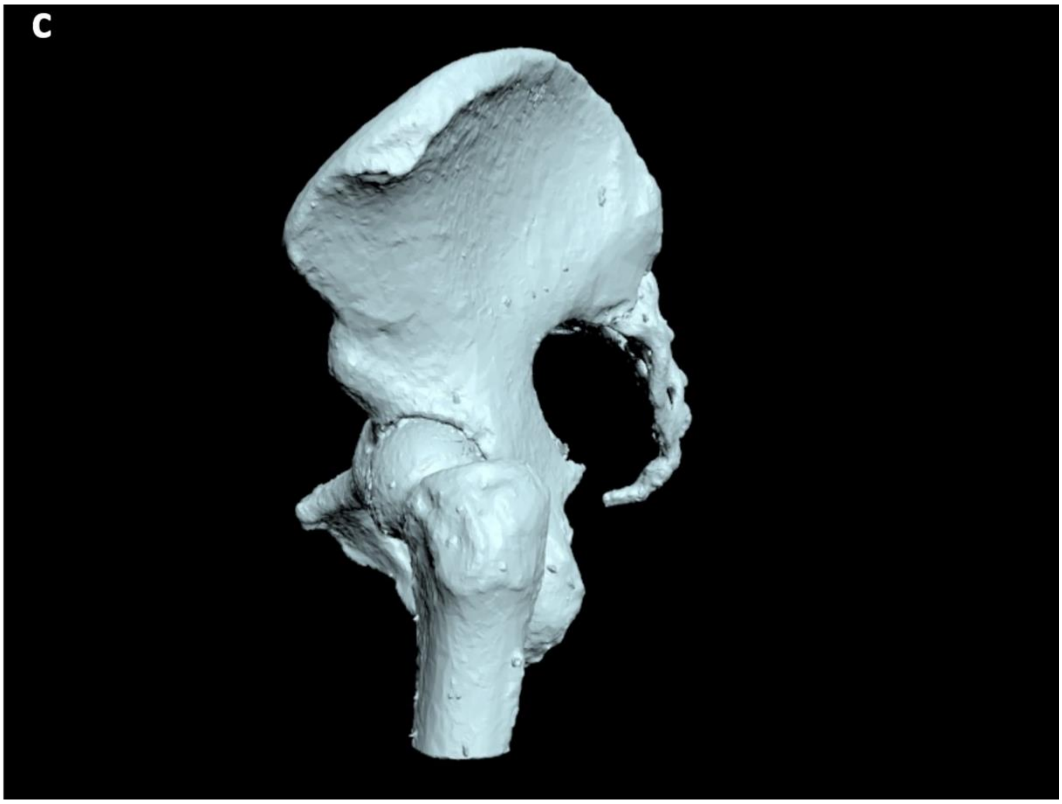


Figure 2. a-c. CT images of patients without coccyx pathology: (a) anterior view, (b) posterior view, (c) lateral view.

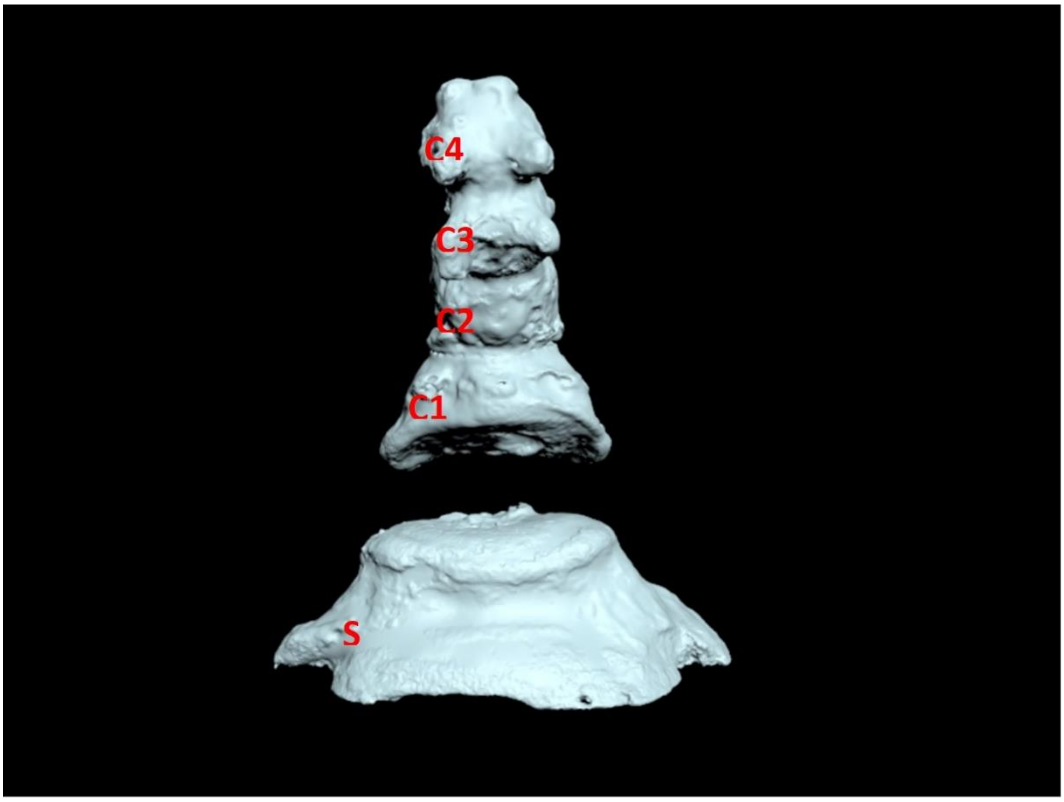


Figure 3. Fusion between four vertebrae. S: Sacrum, C1: 1. Coccygeal vertebrae, C2: 2. Coccygeal vertebrae, C3: 3. Coccygeal vertebrae, C4: 4. Coccygeal vertebrae