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The lumbo-sacral transitional vertebra (LSTV) sacrum with negligible sacral kyphosis: a case report with an evolutionary review

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SUMMARY

Monkey and other hominids species have 5 sacral segments in 10% cases. The similar frequencies for each 6-segmented and 4-segmented sacra in human are known as lumbo-sacral transitional vertebra (LSTV). Achieving the erect posture in human has necessitated much skeletal modification, but these are more apparent in the lumbosacral region. Sacral kyphosis is a distinguishing feature of the human sacrum, which helps to differentiate them from the animal. The monkey has a sacral index near 80, and humans a sacral index is near 100.

The sacral index was 88 in six-segmented sacra with negligible sacral kyphosis, having sacralisation of the 5th lumbar vertebra. Therefore, SI is 88 and lack of sacral kyphosis challenge its human origin. On the contrary, gross morphology, actual sacral index, and comparison with apes gave sufficient evidence of human origin. Later excluding 5th Lumbar vertebra, the sacral index is 107.34 and might belong to a male which corresponds with bone bank record.

Key words: LSTV – Sacral curvature – Sacralisation – Sacral index

INTRODUCTION

The sacrum is the structural transition between proximal vertebral column and the caudal segments or the pelvis with the lower extremities. As a "keystone" in the pelvis, it performs a variety of functions like body weight transmission from the vertebral column to the lower limb, and propulsive force from vice-versa. The sacrum reflects significant taxonomic characters that are preserved by fossilization of intervertebral disc, and articulations and lateral processes fused with iliac blades (Schultz, 1961). The sacroiliac joints vary with locomotor stress and expand in humans. In man, it is larger than the monkey. The neural arches articulate with zygapophyses as in the lumbar region, but bony prominences are reduced and fused with each other from segment to segment. Succeeding vertebrae of the sacral region have neither arches nor processes and is appreciated as sacral hiatus. Sacral vertebrae number varies from two to nine in primates. Vesalius and Galen described that the sacrum is formed by the fusion of 5 segments in humans, but its number varies from 4 to 6 (Marani and Koch, 2014). The number of vertebrae in the sacrum may be increased by fusion of the last (fifth) lumbar vertebra (sacralisation), or addition of the first coccygeal (less often) or both (Tuttle, 2017). In order to achieve the erect posture, humans have necessitated much skeletal modification, but these are more apparent in the lumbosacral region. One of them is the addition of sacral segments, and another one is sacral kyphotic curvature. Monkeys and other hominid species have 6 or 7 sacral segments, and frequency of 5 sacral segments is 10% (Tubb et al., 2016). In humans were reported six-segmented and four-segmented sacrum at

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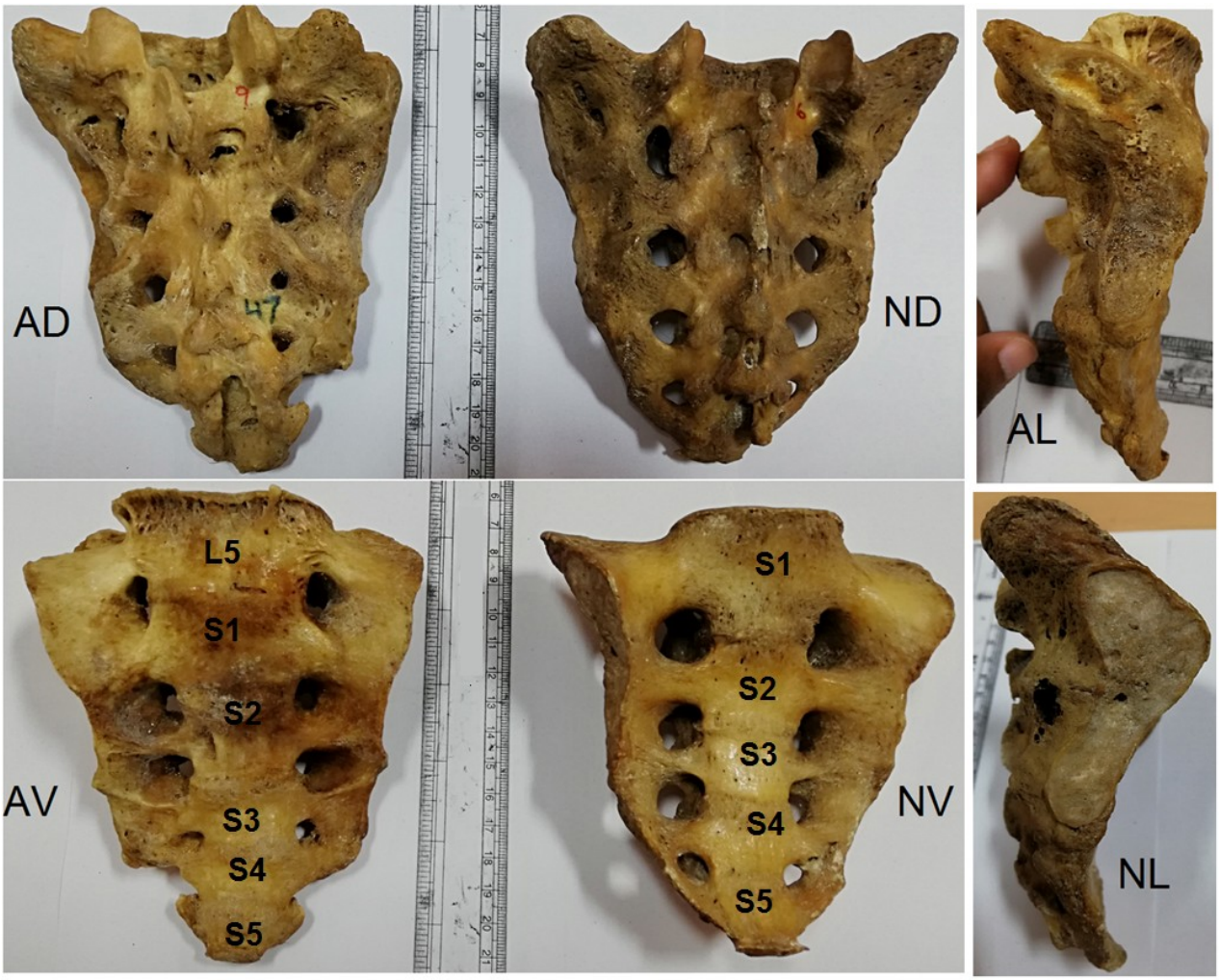

Fig 1. Comparisons of Abnormal (A) and Normal Sacrum (N) in dorsal view (AD & ND), Ventral view (AV & NV), and Lateral view (AL & NL).

lumbosacral transition, in one half of cases has characteristics of lumbar vertebra and in the other half matched with sacral vertebra called hemilumbarization-hemisacralisation, respectively. All these reported variations are called lumbosacral transitional vertebra (LSTV). The number of LSTV is very frequent in primates and hominids (Tuttle, 2017). The absence or minimal presence of the sacral curvature, is one of the most distinguishing features between human and near-human species. The sacral index in tailed primates varies from 20 to 50. The monkey has a sacral index near 80 and the human sacral index is near to 100 and even higher for female origin 120 (Ankel, 1965).

The human sacrum has 5 segments with concavity forward and side by side. The sacrum that has more than 5 segments and straight or negligible curvature creates doubts about its origin. Sacral kyphosis is a distinguishing feature of the human sacrum, which helps to differentiate it from the animal. The aim of this case report deals with a human sacrum with negligible curvature, of which human origin was debatable.

CASE REPORT

The sagittal and transverse curvatures of the sacrum were negligible (Fig. 1). The lower segment had slight lateral bend and rotated to the right side. The sacral length and breadth were 136 mm and 120 mm, respectively. The sacral index computed 88. These findings of sacrum were closer to the hominids' sacrum rather than a human sacrum. Sacralisation of the 5th lumbar vertebra is identifiable by the mammillary process in superior articular facet, the groove between transverse process and ala, and overriding of spinous process and lamina over the spine of first sacral vertebra. This sacrum was classified as Castellvi Type IIIB of LSTV along with negligible sacral kyphosis (Fig. 2). The digital X-ray is taken from 1-meter distance from the plate. The anteroposterior and lateral exposure taken by holding the sacrum with the help of toothed forceps in corresponding positions. Further evaluation was done with the help of DICOM Viewer (Able 3-d Doctor Version 5.0) after the acquisition of antero-posterior and lateral digital X-ray images from radiology. On anthropometric

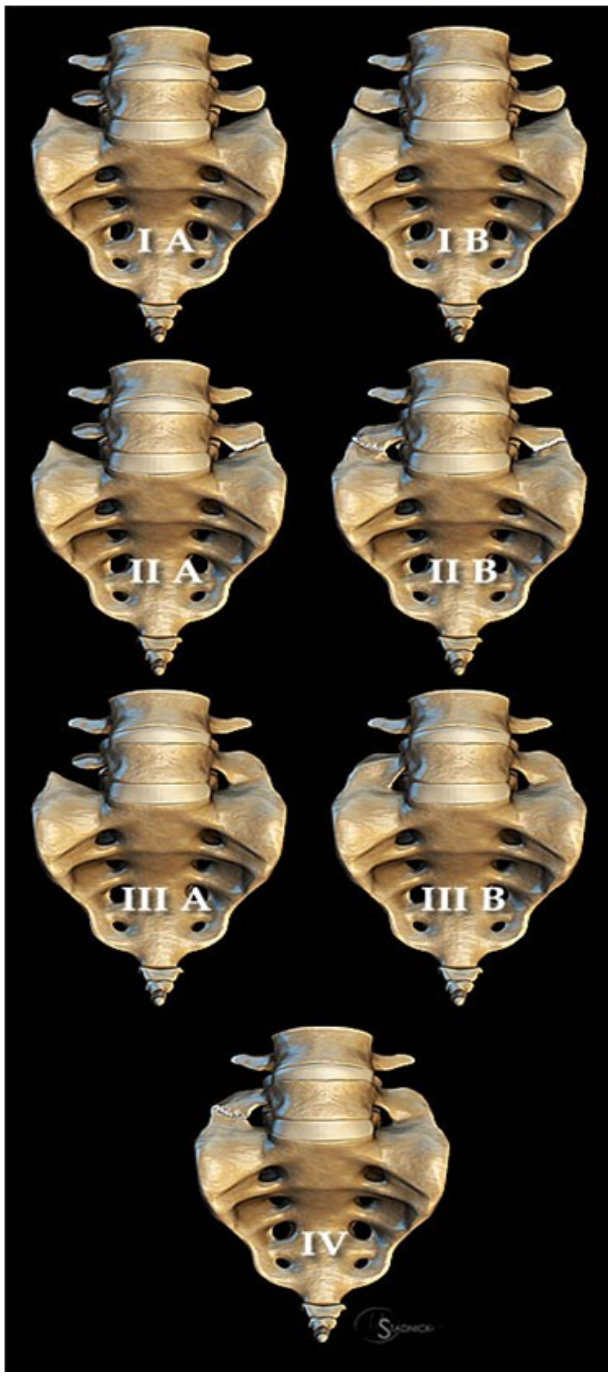

Fig 2. Castellvi Classification of LSTV (Castellvi et al., 1984

analysis, sacral slope, sacral kyphosis, and lumbosacral lordosis were 7.51º, 18.42º, and 11.60º, respectively. The Sacralisation was more apparent in X-ray (Fig. 3). Excluding fifth lumbar vertebra, sacral index was observed to be 107.34 (near to human male origin). The sacral curvature (SC) was 14.44º. Due to lack of facilities, the genetic analysis was not done. Taking into account the bone bank records, it was derived from male skeletal remain which was buried after complete dissection.

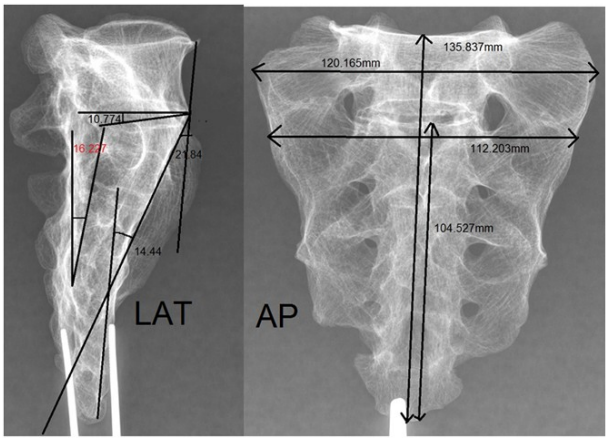

Fig 3. Digital X-ray of abnormal Sacrum: Lateral and AP view.

DISCUSSION

The sacrum not only supports the body in erect posture by transferring the body weight from the axial skeleton to the pelvic girdle and lower extremities, but also keeps the centre of gravity constant. As human achieved bipedalism, the sacrum and ilia underwent unique structural adaptation, such as pelvic tilt, sacral kyphosis, broadening of ala and vertical alignment of SI joints with acetabulae. In human beings the pelvic tilt is a key determinant of upright bipedal posture. In the course of evolution of bipedal hominins, the pelvic tilt was shown to undergo noticeable changes, in order to bring the body weight closer to the acetabulum (Snell et al., 1968). The sacralisation the 5th lumbar vertebra is a common congenital anomaly of Lumbo-sacral transitional vertebra (LSTV).

Vertebral Numeration

The human vertebral column develops from the 42nd to the 44th somite. The pre-sacral vertebrae develop from the 1st to the 30th somite, and the sacral and coccygeal vertebrae develop from the 31st to the 44th somite (Herkowitz et al., 2011). Thus, the lumbo-sacral region shows maximum ambiguity. 24 pre-sacral vertebrae are found in humans typically. Its numerical variation is considered LSTV, in which the last lumbar vertebra is either L4 or L6. At the same time, the sacral vertebrae will be 6 or 4 correspondingly (Thompson et al., 2017; Williams et al., 2015). The most prevalent vertebral formula in Homo sapiens is 7:12:5:5, the two most common appearing variations being 7:12:6:4 followed by 7:12:4:6. In 90% cases of Old and New world monkeys, the number of sacral vertebrae reported was three (Machnicki et al., 2016; Lovejoy et al., 2009). The number of sacral vertebrae in the apes varied between three and seven, with a predominance of five to seven sacral vertebrae (Lovejoy et al., 2009; Moorjani et al., 2016). The sacralisation of

Table 1. Prevalence of different number of lumbar and sacral segment in the human species.

Authors	Region	Subjects (Total)	No of Vertebrae		
			4	5	6
Paik et al. (2013)	Lumbar	8280	214 (2.6%)	7389 (89.2%)	682 (8.2%)
Apazidis et al.(2011)	Lumbar	211	NIL	197 (93.4%)	14 (6.6%)
Abitbol (1989)	Lumbar	157	5 (3.2%)	144 (91.7%)	8 (5.1%)
	Sacral	157	10 (6.4%)	130 (82.8%)	17 (10.8%)
Williams et al. (2016)	Sacral	631	8 (1.2%)	486 (77%)	137 (21.7%)

the 5th lumbar vertebra is a common congenital anomaly of the lumbo-sacral transitional vertebra (LSTV) (Wolpoff and Lee, 2001). The incidence of sacralisation varied from 10-17%. Of the 8280 consecutive patients, 214 (2.6%) had 4 lumbar vertebrae (L4), and 682 (8.2%) had 6 lumbar vertebrae (L6). Overall, 877 (10.6%) patients had LSTV of types II, III, or IV, including 439 (5.3%) with sacralized L5 vertebra and 438 (5.3%) with the lumbarized S1 vertebra (Table 1) (Paik et al., 2013; Apazidis et al., 2011; Abitbol MM, 1989; Williams et al., 2016).

Sacral Index

The sacral index is also variable and affected by the number of sacral segments. The early primates have less sacral segments (< 3 segments) and lower sacral indexes (Schultz, 1961; Tuttle, 2017). The addition of more segments in the sacrum causes an increase in sacral length along with the sacral index (Table 2). The human sacrum has a sacral index of near 100 (Snell et al., 1968). Patra el al. (2016) measured the sacral index in 44 normal sacra (5 segmented), and the mean was 97.76. They also computed sacral index in 6 LSTV sacrum (6 segmented) and 2 LSTV sacrum (4 segmented) and the means were 83.69 and 98.11 respectively.

Sacralisation

The human species and its last common ancestor undergo skeletal modifications like the expansion of the trunk medio-laterally. The shifting of the centre of gravity makes the buttock and the lower limb comparatively heavier in humans than in their near common ancestor. This sinks the last lumbar vertebra between the two iliac bones, because the sacrum itself is not enough for such an excessive load. This lumbosacral fusion is a biomechanical developmental demand, and it is appreciated as a different grade of fusion (Williams and Pilbeam, 2017). The need of large size of birth canal has a significant role for the lengthening of sacral segments. So, reduction of the lumbar segment and the reciprocal increase of sacral segment as compared to the last common ancestor of humans leads to further complex adaptation like sacral curvature, lumbosacral lordosis, and increase of angle of pelvic incidence in humans. So, the sacralisation seems more adaptive than evolutionary, although this but needs further investigations (Benlidayi et al., 2015).

Table 2. Sacral index recorded by Ankel (1965) in primates.

Species	Sacral Index
Early Primates	0-20
Primates with reduced tail	20-50
Prehensile monkey	50-80
Human	Near 100 (female has higher value)

Sacral Curvature

Sacral curvature (SC), represented by the angle between the first and the last sacral vertebrae, is a feature that differentiates the human pelvis from that of other animals. Monkeys have the least SC which is almost nil (mean 11.5º ± 6 SD degrees); apes have moderate curvature, but the human has the most evolved SC (64.7º ± 29 SD) (Thompson and Almecija, 2017). The SC is minimal in new-borns, increasing progressively till adolescence (Table 2). The human attains erect posture, which leads to dorsal tilt of the proximal segments of the sacrum and traction of levator ani pulls the lower part of the sacrum ventrally, which normally results in kyphosis. The minor variation in SC may result from differences in onset and postural habits. Sacral curvature in orthopaedic handicapped children varies from curved to flat –horizontal and flat –vertical (Abitbol, 1989). The sacral curvature observed was 14.44º, which was even less than monkeys or apes, and almost vertical. The sacral kyphosis has a positive correlation with pelvic incidence, which depends upon sacral slope and pelvic tilt (Benlidayi et al., 2015).

Lumbosacral Angle (LSA)

The angulation that forms between the lumbar spine and the sacrum is known as the sacral promontory or lumbosacral angle (LSA). The development of the LSA is related to the progressive acquisition of erect posture and the ontogeny of bipedal locomotion. In a study done

Table 3. Vertebral numeration of different near-human species.

Primates	Thoracic	Lumbar	Sacral	TLS complex	Vertebral formula C:T:L:S
Platyrrhines	14/13/15	7/6/5/4	3/4/2	22/21/23	
Cercopithecidae	12/13/14	7/6	3/2	22/21	7:12:6/7:3
Hylobatidae	13/12	4/5/6	5/4/6	22/23	7:13:5:4
Pongo	12/13	4/5/3	5/6/4/3	22/21	7:12:4:5
Pan	13/14	3/4/2/5	7/6/4/3/5	22/23	7:13:4:6
Gorilla	13/14	3/4/2/5	7/6/4/3/5	22/23/21	7:13:3:6
Homo sapiens	12/13/11	5/6/4	5/6/4	22/23	7:12:5:5

on 131 children, the LSA was 20º at birth and 70º at 5 years of age (Hellems and Keats, 1971). In another study done by Abitbol (1987), the LSA was observed to be 41.1º ± 7.7 in adult males (17-80 years). The lumbosacral angle calculated in this LSTV sacrum was 21.84º, which was far less than the human range.

This angle is almost nil in the non-primate mammals (who only infrequently stand erect). It is minimal in monkeys, who occasionally assume bipedal postures, and increases somewhat in living apes, who engage in the facultative bipedal positional behaviour. In the early Hominidae, the LSA is increased in apes, and it reaches its maximum in Homo sapiens (Abitbol, 1987; 1989).

Conclusion: Exact racial and sexual origin needs genetic analysis (not done due to lack of facility) of this bone, but the findings and correlations above point towards the adult human male sacrum of an orthopaedic handicap.

Table 4. Sacral curvature in human and near-human species.

Subjects	Mean	Range	Remarks
Tailed Primates	11.5º±6	10-22º	
Hylobatids	16º±10	6-27º	
Pongids	27.2º±16	9-46º	
Human	65º±29	29-107º	
Human (supine Posture)	83º±8	82-107º	
Human (Prone Posture)	32º±6	29-44º	P<0.0001 in relation to posture
Human (No preference posture)	65º±11	35-80º	
Before Bipedalism	--------	18-39º	Significant difference P<0.001 in relation to bipedalism
After Bipedalism	---------	33-69º	
This Sacrum	11.80º		

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