Original article

Trabecular architecture in human sacra: patterns observed in complete sacralisation and accessory articulation with the fifth lumbar vertebrae

Mahato, NK.*

Department of Anatomy, Sri Aurobindo Institute of Medical Sciences – SAIMS,
Indore-Ujjain Highway, Bhawrasala, Indore, Madhya Pradesh, India. Pin – 452 010

*E-mail: mahatonk@yahoo.co.in

Abstract

Trabecular and cortical bone architecture in the sacrum demonstrate the pattern of load-transmission through the bone. Transitional vertebrae at the lumbo-sacral junction present either with fusions between the L5 vertebrae and the first sacral segments or as accessory articulations between the transverse processes of L5 and the alae of the sacra. These morphological changes are associated with alterations in load-transmission patterns in the region and with low back pain situations. This study analyses the trabecular pattern in sacra bearing fused L5 vertebrae as well as those with unilateral articulation with L5 transverse element. The study reveals that: a) in complete sacralisation, the level of the auricular surfaces extend between the lower aspect of the L5 and the S2 segments with incorporation of the L5 into the load-bearing segments of the sacrum; b) The trabecular patterns are discrete and conspicuous in the L5, S1 and S2 segments and show prominent ventral and dorsal trabecular areas with an intervening area of reduced density; and c) The sacra with accessory L5 articulation demonstrate auricular surfaces situated at a relatively higher level with the upper two sacral segments bearing prominent trabecular as well as cortical bones on the side of the accessory articulation. The S3 segment bears less load and presents with rarified trabecular and cortical bone in transitional states with L5-S1 accessory articulation.

Keywords: auricular surface, trabeculae, transitional vertebrae, sacralisation.

1 Introduction

The sacrum forms the base of the vertebral column and acts as a terminal conduit for load transmission from the axial to the appendicular skeleton. The transmission of load contributes significantly to the design of the trabecular pattern as well as the cortical structure of a bone. The particular patterns of the trabecular (HAYES and SNYDER, 1981) and cortical (EVANS, BEHIRI, CURREY et al., 1990) architectures of a bone impart specific mechanical properties unique to the bone depending on its location and function (GOLDSTEIN, 1987). The trajectories of the forces applied to the bones also help to form the shape of the bone (LANYON, 1974). The sacrum receives enormous amount of load from above through the superior surface of the body of the first sacral vertebrae and its superior articulating facets. This weight is then dissipated bilaterally to the hip-bones across the two auricular surfaces of the sacrum through the sacro-iliac joint. The paradigm of load transfer through the sacrum (PAL, 1989) is instrumental in shaping up the morphology of the bone. The vertical extent of the auricular surfaces in the normal sacrum extends from the first sacral segment (S1) to the middle of third sacral segment (S3) and occupies two and half vertebral segments. The girth and robustness of these sacral segments at their costal and transverse elements are proportional to the degree of load bearing through-out this extent. The transverse and the costal elements along this span fuse to form the ala and the lateral mass of the sacrum. The passage of significant load through the upper three sacral segments not only gives rise to strong and compact cortical bone in the sacra as a whole (PERETZ, HIPP and HEGGENESS, 1998; EBRAHEIM, SABRY, NADIM et al., 2000), but also shows unique orientation of the internal trabecular pattern at the levels of the upper three sacral segments in normal sacra (EBRAHEIM, SABRY, NADIM et al., 2000). The orientations of these trabecular lamellae are same as the direction of load transfer in these segments towards the auricular surface (PAL, 1989). The shape of the sacrum narrows, its size diminishes and its trabecular patterns become indistinct abruptly below the level of the auricular surfaces, as these terminal segments of the sacrum do not transmit significant load. Accounting of trabecular structure in the sacrum is important from the view-point of several fixation procedures applied in surgical applications in the region. Studies of cortical and trabecular structural patterns in the normal sacra are available in literature. The present study focuses on the architecture of trabecular bone patterns in: a) sacra with complete and bilateral fusion (sacralisation) between the L5 and the S1 vertebrae and in b) sacra with unilateral accessory articulation between the ala of the sacrum and an extended transverse process of the L5 vertebrae. The present study is an attempt to understand the structural pattern of the trabecular and cortical bone in the light of load transmission through these types of sacra. Sacralisation or accessory articulation between elements of the L5 vertebrae and the sacral alae are believed to exhibit differential patterns of bone architecture as these situations are related to weight bearing in a manner different from the 'normal' sacra.

2 Material and methods

Twenty dried human sacra with complete bilaterally fused (sacralised) L5 vertebra, and twenty sacra with unilateral accessory articulation between an extended transverse process of L5 vertebrae and the ala of the sacrum were studied for: a) the trabecular structure and pattern at the different sacral segments, and b) cortical thickness at different levels. Data obtained from sacrum with unilateral accessory articulation was compared between both sides. High resolution X ray films were taken for all specimens to evaluate the trabecular pattern in them with the help of a GE Synergy SRI CT Scanner. Each sacrum was analysed for bone densities and specific cortical thickness across each of the sacral segments by taking 1 mm thick transverse slices through each segment (including through the fused L5 vertebrae) using the imager. 1mm thick longitudinal slices were also taken vertically through the sacral bodies and at vertical planes along the sacral foramina and the lateral mass of the sacra to determine the bone densities along the length of the sacrum at the different load-bearing areas.

3 Results

The X rays and computed tomography slices in the sacralised specimen revealed: a) prominent trabeculae extending from the L5, S1 and S2 vertebral bodies towards the auricular surface (Figure 1). The trabeculae were seen comparatively more prominent at the site of fusion of L5 with the first sacral segment. It was quite evident from the sacralised samples that sacralisation of the L5 vertebrae caused incorporation of the costal and transverse elements of the L5 vertebrae into the lateral mass of the sacrum. As a result of which, the auricular surfaces of such sacra 'shifted' up to stand by the side of the lower part of the L5 vertebrae. These auricular surfaces now extended between the levels of the L5 and the S2 vertebrae (in contrast to the 'normal' sacra where the auricular surfaces extend between S1 and mid-S3 segments). The transfer of weight through the sacralised specimen was found to be concentrated at a higher level due to this fusion. These segments revealed more prominent trabecular patterns i.e., at the L5, S1 and S2 levels of the bone; b) trabeculae extending from the vertebral bodies towards the auricular surfaces were found to be comparatively more condensed ventrally in the weight bearing (L5, S1 and S2) segments; c) a second set of prominent trabeculae extended from the facet joints towards the auricular surfaces. These trabeculae were situated dorsal to the ones mentioned earlier and formed an area of less dense trabecular bone, the 'alar void' (EBRAHEIM, SABRY, NADIM et al., 2000), between these two sets of trabeculae (Figure 2). This area of relatively lesser bone density was present in all the weight bearing segments of the sacralised specimens, extending vertically within the L5, S1 and S2 segments and situated between the vertebral bodies medially and the sacral foramina laterally. The two sets of trabeculae mentioned above eventually met each other within the transverse processes of the lumbar and sacral elements at the level of the sacral foramina; d) Beyond and lateral to this ventral-dorsal trabecular fusion, the lateral mass of the sacra was represented by a dense criss-crossing of trabecular elements; e) All the vertebral bodies exhibited a cruciate pattern of trabecular bone without definite direction of trabeculae within them; f) Prominence of trabecular patterns were observed to be abruptly lost in the non load-bearing, narrower segments (S3-S5) of the sacrum; and g) cortical thickenings were found to be accentuated around the load bearing segments and at the auricular surfaces in comparison to the rest of the sacrum (Figure 1).

Observation of trabecular patterns and bone densities in the sacra with unilateral accessory articulations exhibited: a) trabecular projections from the bodies of the weight bearing segments (S1 and S2) towards the two auricular surfaces (Figure 3) and b) similar arrangement of the ventral and dorsal sets ofdense trabeculae in the load bearing segments as discussed above (Figure 4). The trabeculae were distinctly prominent on the side bearing the accessory articulation. c) The accessory articulating surfaces on the sacra demonstrated a thick cortex. The auricular surface on the side of the additional articulation showed thickened cortical bone. Bone densities across the transverse slices were seen to be more compact on the side of the accessory articulation (Figure 3).

4 Discussion

Sacralisation (fusion) of the fifth lumbar vertebrae entails incorporation of the costal and transverse elements of the L5 vertebrae with the ala of the S1 segment. This fusion results in displacement of the vertical limits of the auricular surfaces. These surfaces subsequently lie at a level between the lower end of L5 and the body of the S2 sacral segment. Though the auricular surfaces shift upwards, the surfaces still consist of two and half vertebral segments (from mid-L5 to the lower part of S2). The S3 segment does not bear much

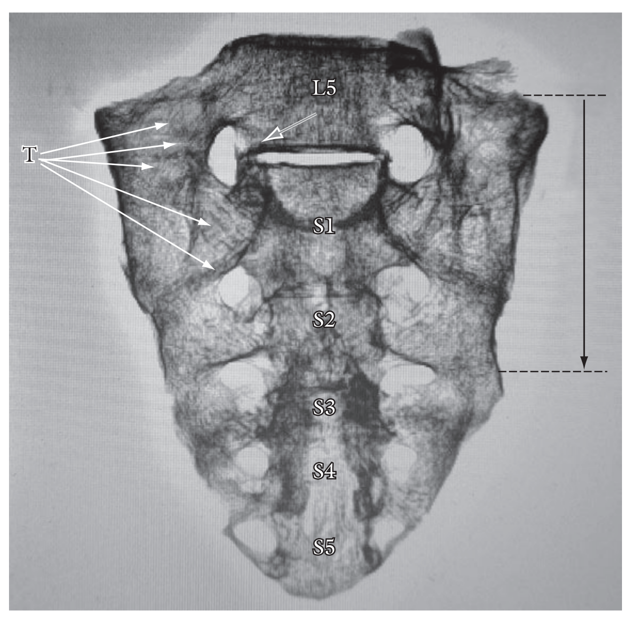

Figure 1. Complete, bilaterally sacralised L5 vertebra. Prominent trabecular patterns (T) visualized (in digital X ray film) extending bilaterally from the L5 vertebrae towards the auricular surfaces. Note that the vertical extent of the auricular surfaces span through the L5 up to S2 segments (shown only on the left by the arrow between the dashed lines). The gray arrow points to one of the bony unions at the L5-S1 bodies. These junctions transmit load and show emerging trabeculae extending laterally.

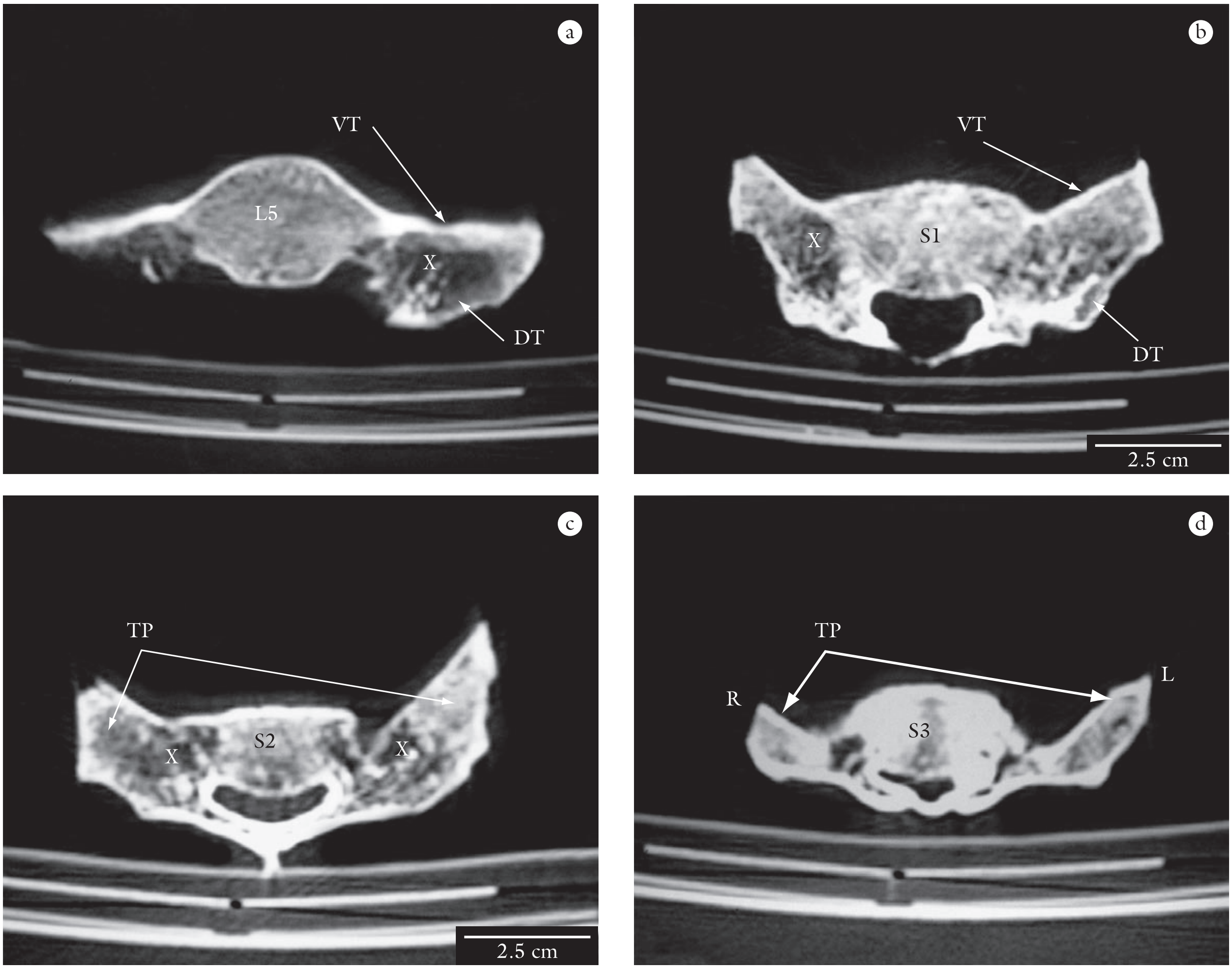

Figure 2. Tomographic scan slices through a) L5, b) S1, c) S2 and d) S3 levels showing the ventral (VT) and dorsal (DT) trabeculae with a relatively rarer area (X) between them. The trabeculae attenuate abruptly below this level (d).TP = Transverse Process.

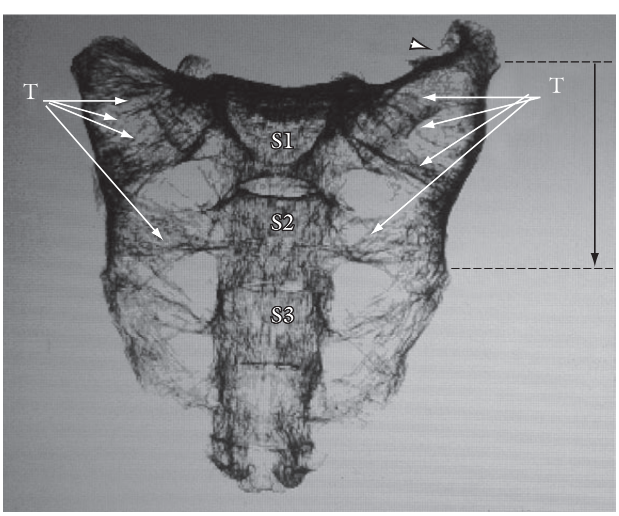

Figure 3. X ray of a sacrum with an accessory articulating facet (arrowhead) on the left side. 'T' represents prominent trabecular trajectories directed towards the auricular surfaces. The auricular surface (between the dashed lines on the left) can be seen extending beyond the upper S1 segment superiorly. Prominent trabeculae are confined predominantly at the upper two (S1 and S2) segments. Note the cruciform trabeculae within the sacral bodies.

load in these specimens. Trabecular bone is prominent on the ventral and dorsal aspects of the 'load-bearing' L5, S1 and S2 segments. Trabecular patterns are visibly attenuated below that level. The architecture of bone at the vertebral bodies exhibit compressional forces that result in a cruciate pattern of trabecular architecture with relative compactness at the transverse and longitudinal planes. The alar 'emptiness' is also seen at the plane of the L5 vertebrae between the ventral and dorsal sets of trabeculae.The situation presenting unilateral accessory articulation between extended L5 transverse process with the superior aspect of the alar surface exhibits prominent trabecular patterns on the side of additional load bearing. These sacra demonstrate distinctly thick cortices at the auricular surfaces on the same side as the accessory articulation as additional load is directed through these accessory articulations from L5 to S1, in addition to load normally transferred between the L5-S1 bodies and facet joints. Almost all sacra with these accessory articulations possess shorter than normal auricular surfaces projecting appreciably above the level of the superior surface of the S1 segment. These auricular surfaces extend superiorly just above S1 upwards and below to the lower limit of S2. Both the situations discussed in this study are transitional states of vertebrae at the lumbo-sacral junction (CASTELLVI,

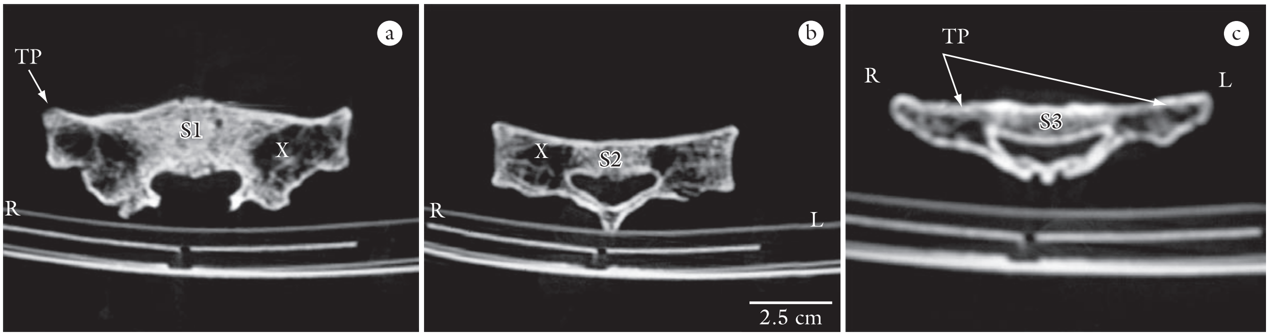

Figure 4. CT sections through the sacrum in Figure 3 at S1, S2 and S3 levels. Note the attenuation of trabeculae, cortical bone and the dimensions of the TP at S3 (c). TP = Transverse Process. X = the 'void' between ventral (VT) and dorsal (DT) array of trabeculae. R = Right and L = Left.

GOLDSTEIN and CHAN, 1984). These sacra are subject to asymmetric load-bearing and are thus predisposed to stress (BRON, VAN ROYEN and WUISMAN, 2007) and low back pain situations (LUOMA, VEHMAS, RAININKO et al., 2004) requiring surgical interventions. This study demonstrates that the trabecular patterns within the sacral bone in L5-S1 transitional situations are different from the 'normal' due to the altered dynamics of load transfer. It is crucial to understand the trabecular patterns in these sacra in the light of pathological load-bearing or intended surgical intervention at this junction.

References

BRON, JL., Van ROYEN, BJ. and WUISMAN, PI. The clinical significance of lumbosacral transitional anomalies. *Acta Orthopaedica Belgica*, 2007, vol. 73, no. 6, p. 687-695.

CASTELLVI, AE., GOLDSTEIN, LA. and CHAN, DPK. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. *Spine*, 1984, vol. 9, no. 5, p. 493-495.

EBRAHEIM, N., SABRY, FF., NADIM, Y., XU, R. and YEASTING, RA. Internal architecture of the sacrum in the elderly: an anatomic and radiographic study. *Spine*, 2000, vol. 25, no. 3, p. 292-297.

EVANS, GP., BEHIRI, JC., CURREY, JD. and BONFIELD, W. Microhardness and Young's modulus in cortical bone exhibiting a wide range of mineral volume fractions and in a bone analogue. *Journal of Materials Science: Materials in Medicine*, 1990, vol. 1, no. 1, p. 38-43.

GOLDSTEIN, SA. The mechanical properties of trabecular bone: dependence of anatomic location and function. *Journal of Biomechanics*, 1987, vol. 20, no. 11-12, p. 1055-1061.

HAYES, WC. and SNYDER, B. Towards a quantitative formulation of Wolff's law in trabecular bone. In COWIN, SC. (Ed.). *Mechanical Properties of Bone*. New York: McGraw-Hill, 1981. p. 43-68.

LANYON, LE. Experimental support for the trajectoral theory of bone structure. *Journal of Bone & Joint Surgery*, 1974, vol. 56B, no. 1, p. 160-166.

LUOMA, K., VEHMAS, T., RAININKO, R., LUUKKONEN, R. and RIIHIMÄKI, H. Lumbosacral transitional vertebra: relation to disc degeneration and low back pain. *Spine*, 2004, vol. 29, no. 2, p. 200-205.

PAL, GP. Weight transmission through the sacrum in man. *Journal of Anatomy,* 1989, vol. 162, p. 9-17.

PERETZ, AM., HIPP, JA. and HEGGENESS, MH. The internal bony architecture of the sacrum. *Spine*, 1998, vol. 23, no. 9, p. 971-974.

Received October 3, 2010
Accepted June 22, 2010