Year: 2013

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Abstract: Study Design: An analysis and differential diagnosis of bony alterations in the lower lumbar vertebrae of a Homo erectus boy skeleton. Objective: To analyze low back problems during early human evolution. Summary of Background Data: Back problems in modern humans are often attributed to our upright, bipedal locomotion that is thought to place huge mechanical stresses on the vertebral column. However, little is known of this situation during the course of human evolution. Methods: We analyzed the lower lumbar spine of the most complete early hominid skeleton, the 1.5 million year old Homo erectus boy KNM-WT 15000 from Nariokotome, Kenya, who died at an age of approximately 8 years. We use bony alterations as indirect evidence for disc disease in the absence of soft tissue. Results: We describe an extensive osteophytic anterior curved remodeling of the left superior articular process of L5 and formation of a new joint at the underside of the left pedicle of L4. This indicates collisional facet joint subluxation, most likely as the result of juvenile traumatic disc herniation. Conclusions: This indirect evidence of juvenile disc herniation in a Homo erectus boy skeleton represents the earliest known case of this typical human ailment that is intricately linked to upright bipedalism. The extensive bony remodeling of the articular processes of L4 and L5 suggests that the disc herniation occurred several months before his death. Disabling backache and recurrent sciatica might have at least temporarily restricted his daily activities, which indicates advanced social care and nursing in early Homo. We hypothesize that the early Homo intervertebral discs were more vulnerable to injury compared to modern humans due to a relatively small vertebral cross-sectional area.

DOI: https://doi.org/10.1097/BRS.0b013e31827cd245

Originally published at:
Häusler, Martin; Schiess, Regula; Böni, Thomas (2013). Evidence for juvenile disc herniation in a Homo erectus boy skeleton. Spine, 38:123-128.
DOI: https://doi.org/10.1097/BRS.0b013e31827cd245

Evidence for juvenile disc herniation in *Homo erectus* boy skeleton

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Conflicts of Interest: none

ACKNOWLEDGEMENTS

We thank Emma Mbua, Meave Leakey, and the staff of the National Museums of Kenya, Nairobi, as well as the Kenyan Ministry of Education, Science and Technology for access to the Nariokotome boy skeleton. Traveling expenses have been supported by the A.H. Schultz Foundation.

ABSTRACT

Study Design: An analysis and differential diagnosis of bony alterations in the lower lumbar vertebrae of a *Homo erectus* boy skeleton.

Objective: To analyze low back problems during early human evolution.

Summary of Background Data: Back problems in modern humans are often attributed to our upright, bipedal locomotion that is thought to place huge mechanical stresses on the vertebral column. However, little is known of this situation during the course of human evolution.

Methods: We analyzed the lower lumbar spine of the most complete early hominid skeleton, the 1.5 million year old *Homo erectus* boy KNM-WT 15000 from Nariokotome, Kenya, who died at an age of approximately 8 years. We use bony alterations as indirect evidence for disc disease in the absence of soft tissue.

Results: We describe an extensive osteophytic anterior curved remodeling of the left superior articular process of L5 and formation of a new joint at the underside of the left pedicle of L4. This indicates collisional facet joint subluxation, most likely as the result of juvenile traumatic disc herniation.

Conclusions: This indirect evidence of possible juvenile disc herniation in a *Homo erectus* boy skeleton represents the earliest known case of this typical human ailment that is intricately linked to upright bipedalism. The extensive bony remodeling of the articular processes of L4 and L5 suggests that the disc herniation occurred several months before his death. Disabling backache and recurrent sciatica might have at least temporarily restricted his daily activities, which indicates advanced social care and nursing in early *Homo.* We hypothesize that the early *Homo* intervertebral discs were more vulnerable to injury compared to modern humans due to a relatively small vertebral cross-sectional area.

KEY POINTS

- Facet joint subluxation and formation of a new joint between the tip of the superior articular facet of L5 and the underside of the pedicle of L4 probably indicates juvenile disc herniation in a 1.5 million year old *Homo erectus* boy skeleton.

- Disc herniation therefore seems to be a very ancient disease in human prehistory and probably intimately linked to the evolution of bipedal locomotion.

- The extensive bony alterations in the L4-5 facet joint indicates that this *Homo erectus* boy survived a substantial period of time with this potentially disabling condition, which implies some form of advanced social care and nursing at that time.

- The evolution of an increased vertebral cross-sectional area in modern humans might have made our intervertebral discs less vulnerable to injury than in our ancestors.

INTRODUCTION

Disorders of the lower back are the foremost musculoskeletal problem of modern humans. Thus, 60 to 80% of all people are affected by low back pain at some point in their life.[1] They constitute an increasing public health issue in Western societies with immense socioeconomic costs.[2] However, despite enormous advances in medicine there is no compelling evidence that the prevalence of musculoskeletal disorders of the lower back has changed in the last decades nor is significantly different throughout the world.[3,4] Nevertheless, a few risk factors have been causally linked to spinal degeneration and low back pain, including genetic predisposition[5-9], age and repetitive heavy physical activities, particularly activities that involve bending and twisting.[7,10-12]

Presumably the most important origin of mechanical strain on our vertebral column stems from our upright, bipedal posture and locomotion, which led some authors to suggest that the true origin of back problems is to be sought in our evolutionary history.[13,14] In fact, spinal pathologies are remarkably uncommon in our closest relatives, the quadrupedal great apes.[15] On the other hand, a study of bipedal rats suggests that prolonged upright posture induces degenerative changes in intervertebral discs of the rat lumbar spine.[16] Furthermore, a study of monozygotic twins showed that heredity just explains 32% of the variance in disc degeneration at the L4-S1 levels, age an additional 7%, and physical loading exposure an additional 2%.[17] The 59% of the variance that remained unexplained might be attributed to lifetime exposure associated with everyday activity and upright posture and locomotion.[18]

However, little is known of the adaptations and failures of the spinal column during the course of human evolution, as vertebrae have rarely survive in the fossil record. Only a handful of fossils preserve more than a few vertebrae. The most complete fossil spinal column belongs to a juvenile male *Homo erectus* skeleton from Nariokotome, Kenya.[19,20] His lower lumbar spine presents an unusual pathology[21,22] that we will analyse here.

MATERIAL AND METHODS

The KNM-WT 15000 *Homo erectus* skeleton was found in 1.53 million year old lake sediments at Nariokotome at the western shore of Lake Turkana, Kenya.[19,23] It is the best preserved early hominid skeleton discovered to date and most of our knowledge about the anatomy and biology of early *Homo* is based on this exceptionally complete skeleton. It only lacks the first six cervical and two thoracic vertebrae, both radii, and the majority of the hand and foot bones. Pelvis and skull robusticity suggest that it is from a male individual. The long bones imply a stature of 157 cm,[24] and an analysis of tooth microanatomy indicates an age at death of approximately eight years.[25,26] Epiphyseal closure pattern and skeletal development are, however, comparable to 13.5 – 15-year-old modern humans, which entails an ape-like, rapid growth velocity in *H. erectus*.[27,28] Nevertheless, body shape and proportion of the Nariokotome boy were already very human-like, and the lumbar lordosis was well developed.[29-31] Recently discovered additional vertebral and rib material shows that his lumbar region was composed of five rather than six vertebrae as previously thought.[20,32-34] His spinal biomechanics, posture and mode of locomotion were therefore probably very similar to modern humans.

RESULTS

A visual analysis of the spinal column of Nariokotome boy discloses striking asymmetries in shape and length of the articular processes of the last two lumbar vertebrae as the only obvious pathology of the axial skeleton (Fig. 1). The left superior facet of L5 is markedly shortened. Its tip is bent anteriorly and articulates with a nearthrosis at the inferior side of the left pedicle of L4 (Fig. 2). This extra joint is discernable in the form of a prominent eburnated knob, suggesting intra vitam bone remodeling rather than post-mortem deformation as interpreted previously.[19]

DIFFERENTIAL DIAGNOSIS

An equivalent condition with a nearthrosis between the superior articular process and the underside of the superjacent pedicle is typical of advanced stages of disc space narrowing.[35-37] Here, the facet joints of the affected vertebrae may sub-luxate and finally collide, resulting in anterior curved osteophytic remodeling of the tips of the superior articular facets.[36] The affliction is often unilateral as in the Nariokotome boy. We attribute the marked asymmetry in length of the other facet joints of the last two lumbar vertebrae to the juvenile age of the Nariokotome boy and the remaining potential for growth, which allowed for a compensative lengthening of the articular processes to offset the obliquity of the vertebral bodies of L4 and L5.

The differential diagnosis of narrowed intervertebral disc space in adolescents includes trauma, degeneration, congenital anomalies and infection. There is no evidence for the latter in the vertebral column of KNM-WT 15000 because in discitis, irregularities of the vertebral bodies would be expected rather than an exclusive involvement of the posterior elements of the vertebrae. However, in accordance to the juvenile age of the specimen, the cartilaginous superior and inferior vertebral growth plates are not preserved.

Several congenital anomalies are associated with juvenile disc herniation, including block and hemivertebrae, spondylolisthesis, asymmetrical sacralisation and lumbalisation, a six-element long lumbar vertebral column, spina bifida and scoliosis.[38-40] None of these anomalies are present in the spine of the Nariokotome boy save for a spina bifida occulta affecting the last three sacral vertebrae, which can be considered a normal variation without clinical relevance, or it might be solely attributable to his juvenile age.[22] A previous report on the axial skeleton of Nariokotome boy described distortions of the vertebrae and ribs and interpreted them as indicating severe congenital scoliosis.[41] However, a rearrangements of his ribs based on the new vertebral and rib material reveiled a perfectly symmetric rib cage that challenges the diagnosis of a structural scoliosis.[20,42]

Degeneration and trauma are more likely factors contributing to disc space narrowing. Incipient degenerative processes are often already detectable in intervertebral discs of adolescents.[6-9,17,18,38,39,43-47] A sudden impact or a fall, particularly with torsion of the flexed spine, could also cause an annulus tear or an endplate fracture. These injuries may induce accelerated disc degeneration, although this has only been shown experimentally.[48-50] The massive unilateral osteophytic bone remodeling of the L4–5 facet joint of the *Homo erectus* youth might, however, also suggest a traumatic disc herniation, perhaps with a concomitant traumatic disruption of the left facet joint capsule. In fact, in contrast to adults between 40 and 75% of juvenile disc herniations are traumatic in origin or related to sports injury, rather than degenerative.[38,39,51-55] The level of the presumed disc herniation of the Nariokotome boy at L4–5 also perfectly fits the frequency distribution of disc herniations in modern human children with 97% occurring at L4–5 and L5–S1.[55]

Facet joint tropism of 16°, which can be observed at the L4–5 level of the Nariokotome boy vertebral column, might be another possible morphological risk factor for disc lesions (Fig. 3). Particularly in adolescent patients this asymmetric sagittal angulation of the facet joints has been related to increased intervertebral shear forces, although its role is controversially discussed.[56-58]

DISCUSSION

If our interpretation of the telescoping subluxation and formation of a new joint between the two last lumbar vertebrae of the 1.5 million year old Nariokotome *Homo erectus* boy is correct, it provides evidence for the earliest disc lesion in human prehistory. Although there are reports of naturally occurring disc extrusions in certain dog breeds[59,60] and cats,[61,62] traumatic disc rupture in a penguin,[63] and of disc degeneration in baboons,[64] macaques[65] and sand rats,[66,67] lumbar disc disease is otherwise restricted to humans. This emphasizes the importance of biomechanical factors in its etiology as well as its relation to the evolution of upright bipedalism and lumbar lordosis. *Homo erectus* is the earliest human ancestor with a truly modern body shape and spinal curvature.[20,29-31] Thus, it would not be unexpected if he already suffered from this typical human disease.

On the other hand, this is, to our knowledge, the first study that deduces traumatic disc lesion from skeletal remains without preserved soft tissue. This is owed to a number of unique circumstances. The nearthrosis between the tip of the superior articular process of L5 and the underside of the pedicle of L4 suggests that concurrent to the disc lesion the Nariokotome boy probably experienced a substantial trauma that may also have disrupted the facet joint capsula. Further, the immature age of the Nariokotome boy and the remaining potential for growth facilitated bony remodeling of the contiguous articular processes secondary to asymmetrical disc space narrowing and a compensatory scoliosis. Moreover, the extensive curved bony remodeling of the left facet joint L4/5 indicates that the Nariokotome boy survived a considerable period of time with this potentially disabling condition. Patients with similar findings of bony impingement are reported to have a history of between at least six months and several years of recurrent low back pain and sciatica.[35,68,69]

Although back symptoms only weakly correlate with the amount of pathologic changes it can be hypothesized that the Nariokotome boy was temporarily restricted in walking, bending and other daily activities. In addition, pediatric patients with lumbar disk hernias tend to be more disabled than adults.[39,52,54] This contributes to evidence for advanced social care in other early *Homo* fossils.[70,71]

Lumbar disc herniation is common in modern humans with a prevalence of about 2-5% and a peak incidence at age 40 to 45.[72-74] However, in adolescents disc herniation is rare and exceptional in children before puberty.[75] In fact, so far only ten cases have been reported in the worldwide literature in children younger than ten years.[52,75] Yet, skeletal rather than chronological age seems to be critical. Although the age at death of the Nariokotome boy is estimated to approximately eight years based on dental microanatomy, epiphyseal fusion pattern rather is comparable to 13 – 15-year-old modern humans.[25-28] This is in good agreement with the known vulnerable phase for disc lesions during the period of accelerated growth.[54]

An important characteristic of the *Homo erectus* spinal column is a relatively small cross-sectional area of the vertebral bodies compared to those of average modern humans.[29] Because stress is directly proportional to the force over the loaded area, a small cross-section makes vertebrae and discs more susceptible to injury. This might not only account for the disc herniation in the Nariokotome boy, but also for surprisingly frequent Scheuermann's disease in earlier australopithecines.[76,77] We might therefore speculate that our spinal column has been shaped by a long process of natural selection to become less vulnerable than that of our ancestors. Increased vertebral cross-sectional area might indeed be considered one of the most important vertebral adaptations to habitual bipedal locomotion. The evolutionary history of modern humans should therefore not be blamed for the widespread back problems. Rather, our results corroborate the hypothesis that the vertebral column of modern humans is an optimized compromise between mobility and stability.[78]

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FIGURES

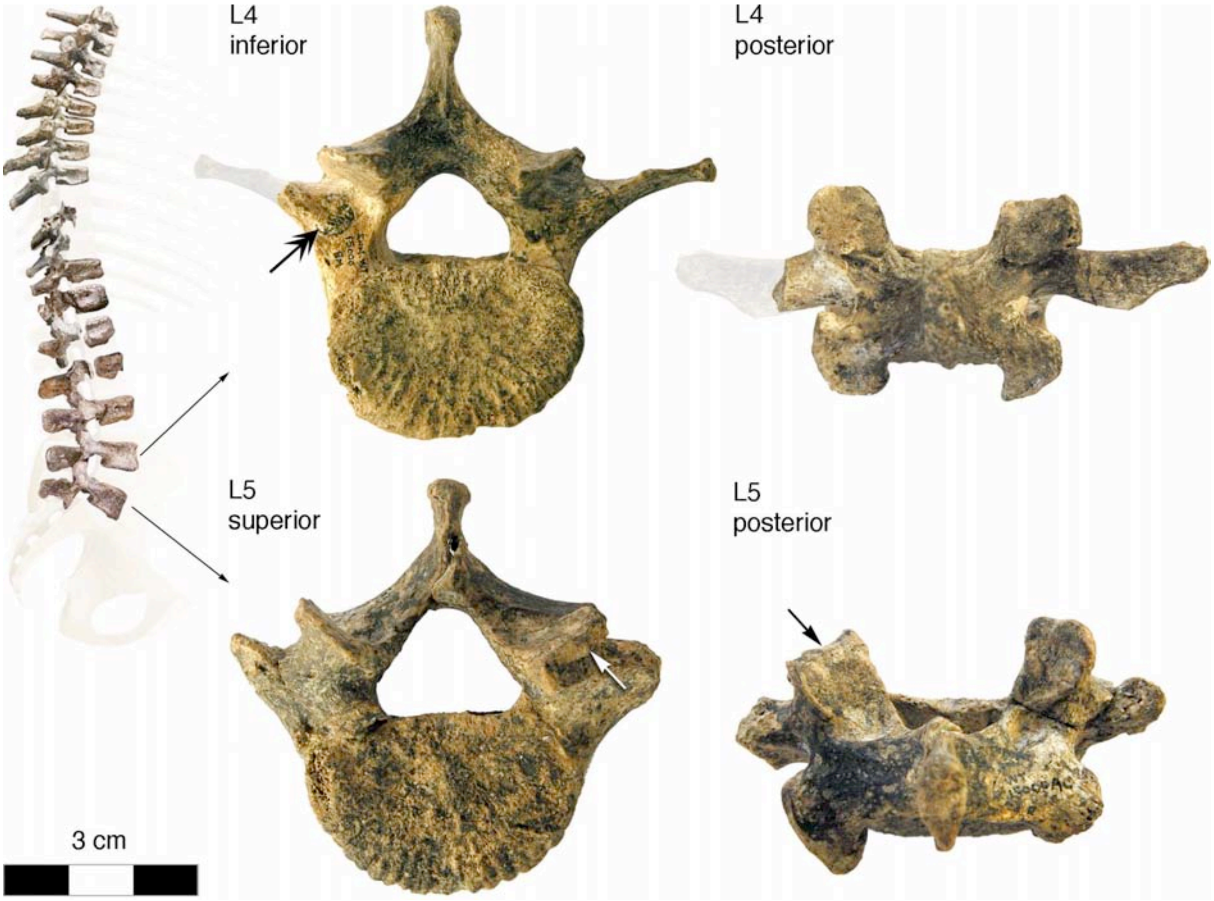

Figure 1. Facet joint subluxation of the two last lumbar vertebrae of the *Homo erectus* boy KNM-WT 15000. A schematic representation of the preserved vertebrae is shown on the left, photographs of the original fossil vertebrae L4 and L5 in inferior and superior view, respectively (middle), and in dorsal view (right). The broken off left lateral process of L4 is graphically reconstructed in semitransparent colours. Note the collisional curved remodelling of the left superior articular facet of L5 (simple arrows) and the nearthrosis it has built at the underside of L4 (double arrow).

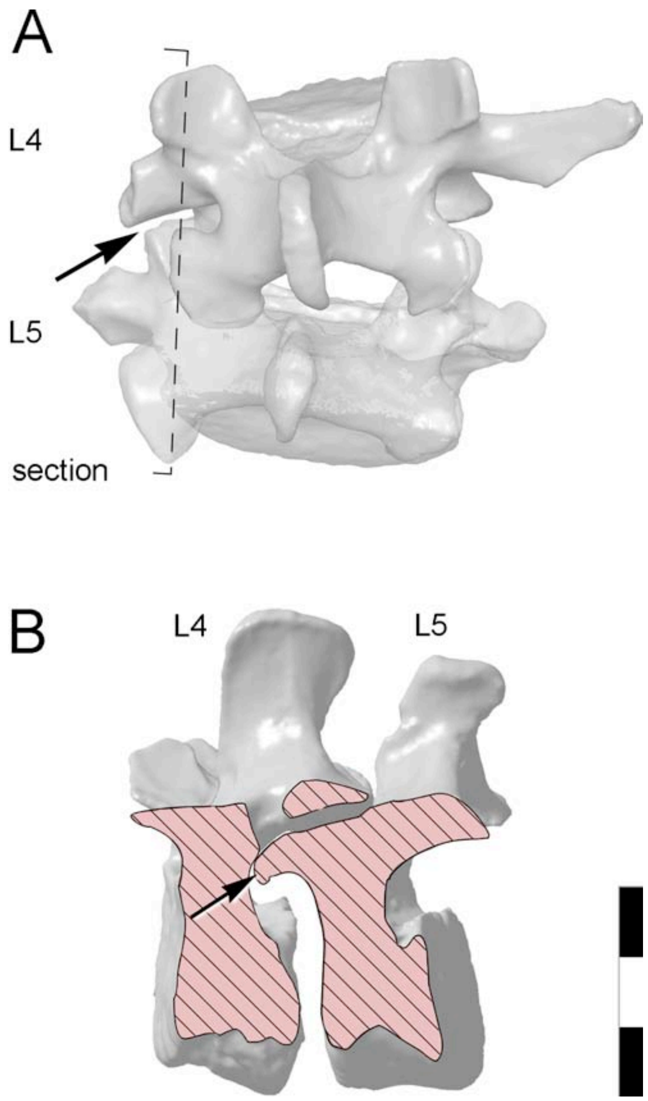

Figure 2. A, Digital models of articulated vertebrae L4 and L5 of KNM-WT 15000, in dorsal view. The models have been generated from high-resolution 3D surface scans of casts of the original vertebrae (Polygon Technology, Darmstadt, Germany). The extra joint (nearthrosis, arrow) and the asymmetric articular processes imply an oblique position of the vertebrae relative to each other. B, Section through the nearthrosis (see A), left lateral view. Cropped parts of the vertebrae are hatched. Compare the remodelled superior articular facet of L5 (arrow) to the normal shape of a superior articular facet in L4. Scale bar 3 cm.

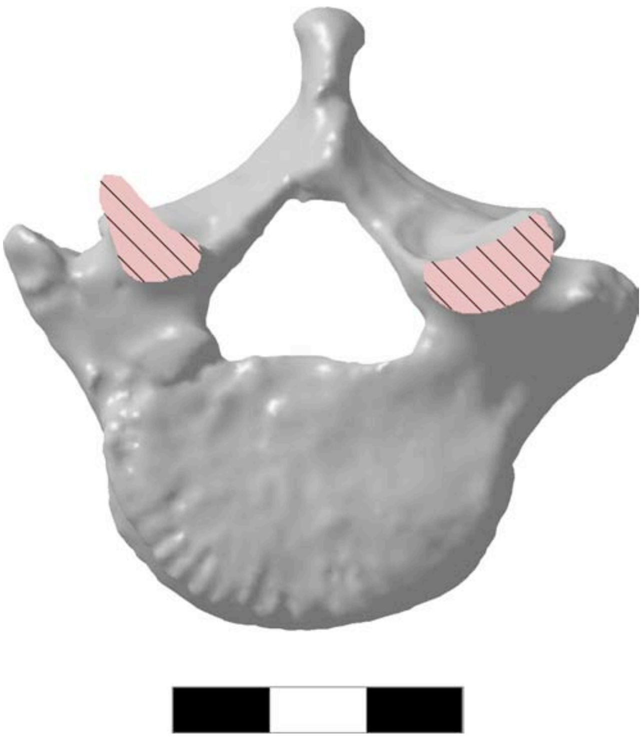

Figure 3. Section through the superior articular processes of a digital model of vertebra L5. Cropped parts are hatched. The model has been generated from high-resolution 3D surface scans of a cast of the original vertebra (Polygon Technology, Darmstadt, Germany). Scale bar 3 cm.