Leonardo Da Vinci unveiled degenerative diseases of the spine through his novel, exquisite anatomical drawings

Francesco Tonelli [1,4], Matteo Barbagli [2], Harry Genant [3†], Maria Luisa Brandi [2, 4]

[1] University of Florence, Florence, Italy; [2] Donatello Bone Clinic, Florence, Italy; [3] Departments of Radiology, Medicine and Orthopaedic Surgery, University of California, San Francisco, California, USA; [4] FIRMO Foundation, Florence, Italy; † *Deceased*

ABSTRACT

Leonardo da Vinci set out to produce a true treatise of anatomy, since in his time no such work existed. His drawing of the spine is a formidable example of his genius. Since artworks by Leonardo are appreciated for their accuracy and careful adherence to the subject represented, we examined Leonardo's spine as one would a radiograph, looking for evidence of osteoporotic fractures or signs of osteoarthritis. The dorsal and lumbar vertebrae show a slightly wedge-shaped deformity without "radiological" signs of fracture. Instead, signs of osteoarthritis can be noted at the lumbar vertebrae. With his extraordinary eye for detail, Leonardo produced an image that foreshadows those that radiology would later make available to clinicians for the diagnosis of problems linked to vertebral degeneration.

Introduction

Artworks by Leonardo da Vinci are appreciated for their careful adherence to the subject represented and for their accuracy. The light used was the most suitable and the proportions and perspective were correct. These characteristics of his work, developed under the guidance of his master Andrea Verrocchio, accompanied Leonardo throughout his life, as his interest, over time, became predominantly scientific. The same accuracy and mastery were applied to his anatomical designs, allowing him to reach unprecedented levels of perfection and beauty, which in the centuries since have proved difficult to replicate. His interest in anatomy arose early during his apprenticeship as an artist and gradually became more profound as he started performing dissections of corpses. In those early times opening a corpse was not only particularly unpleasant, but also required resources, time and commitment. Through sheer will and passion for knowledge, Leonardo overcame all these difficulties. In fact, in the notes that accompany his drawings, he states: *"And if you love such a thing (anatomy), you will perhaps be prevented by fear of living nocturnal hours in the company of the quartered and flayed, and frightening to see, dead. And if this does not prevent you, perhaps you do not have a good hand for drawing, which is needed for such figuration. And if you have a good hand, it may not be accompanied by perspective. And if it is, you may not know the order of geometric demonstrations and the order of the calculations of the forces and of the muscles. And you may lack patience or diligence. If all these things were or were not in me, one hundred and twenty books composed by me in which I have not been hindered by avarice or negligence, but by time alone, will give judgment*." (RL 19070v).

Article history
Received 12 Oct 2021 – Accepted 29 Oct 2021

Contact
Maria Luisa Brandi; marialuisa.brandi@unifi.it; marialuisa@marialuisabrandi.it
F.I.R.M.O. Italian Foundation for the Research on Bone Diseases,
Via Reginaldo Giuliani 195/A, 50141 Florence, Italy
Tel: +39 055 2336663, Mobile phone: +39 337 685511

Leonardo studied more than 30 corpses with the intention of producing a true treatise of anatomy, since no such work existed among the manuscripts and books printed and in circulation in his time. The methodological systematization of his anatomical research appeared abruptly during his stay in Milan, perhaps due to his meetings with Marcantonio della Torre, a professor of anatomy in Pavia [1,2].

In the winter of 1510-1511, Leonardo created an incredible work: in 240 drawings he depicted all the bones and muscles of the human body, shown from various angles and in varying detail, in such a way as to provide an accurate and perfect record of each element. These drawings are collected in his so-called Manuscript A, and are part of the Royal Library of Windsor, property of the Queen of the United Kingdom. In addition to showing the morphology, he would often provide a diagram or a detail to explain functional aspects, for example evaluating the distribution of muscular forces during movement. The structural aspect was not neglected, either, as he furnished details on the structure of bones (some compact, others trabecular or spongy) and muscles (for example, through transverse and progressive sections of the limbs, foreshadowing the current tomographic slices of CT or MRI scans), describing atrophy, and highlighting the intimate relationship between bone and muscle trophism [3].

Int J Bone Frag. 2021; 1(3):128-134
https:doi.org/10.57582/IJBF.210103.128

Leonardo's drawings of the spine are a formidable example of his genius. In previously available manuscripts, the spine had been shown as a rectilinear set of vertebral bodies, visualized only in the anteroposterior projection, without articular and muscle-tendon connections, and with a number of vertebrae that varied from author to author [4,5].

Suddenly, after centuries of darkness, a faithful image had been created: a complete representation of the vertebral column seen in anterior, posterior and lateral projections, executed on paper using charcoal and pen and brown ink (RL 19007v) (Fig.1). The vertebral bodies with their spinous and transverse processes are shown with great accuracy as are the intervertebral joints with well depicted discs.

For the first time, normal thoracic kyphosis and lumbar

Figure 1 Windsor RL 19007v, pen and ink with wash, over black chalk. Drawing of the spine by Leonardo. Circa 1510–1511.
This image is credited as: Royal Collection Trust/© Her Majesty Queen Elizabeth II 2020.

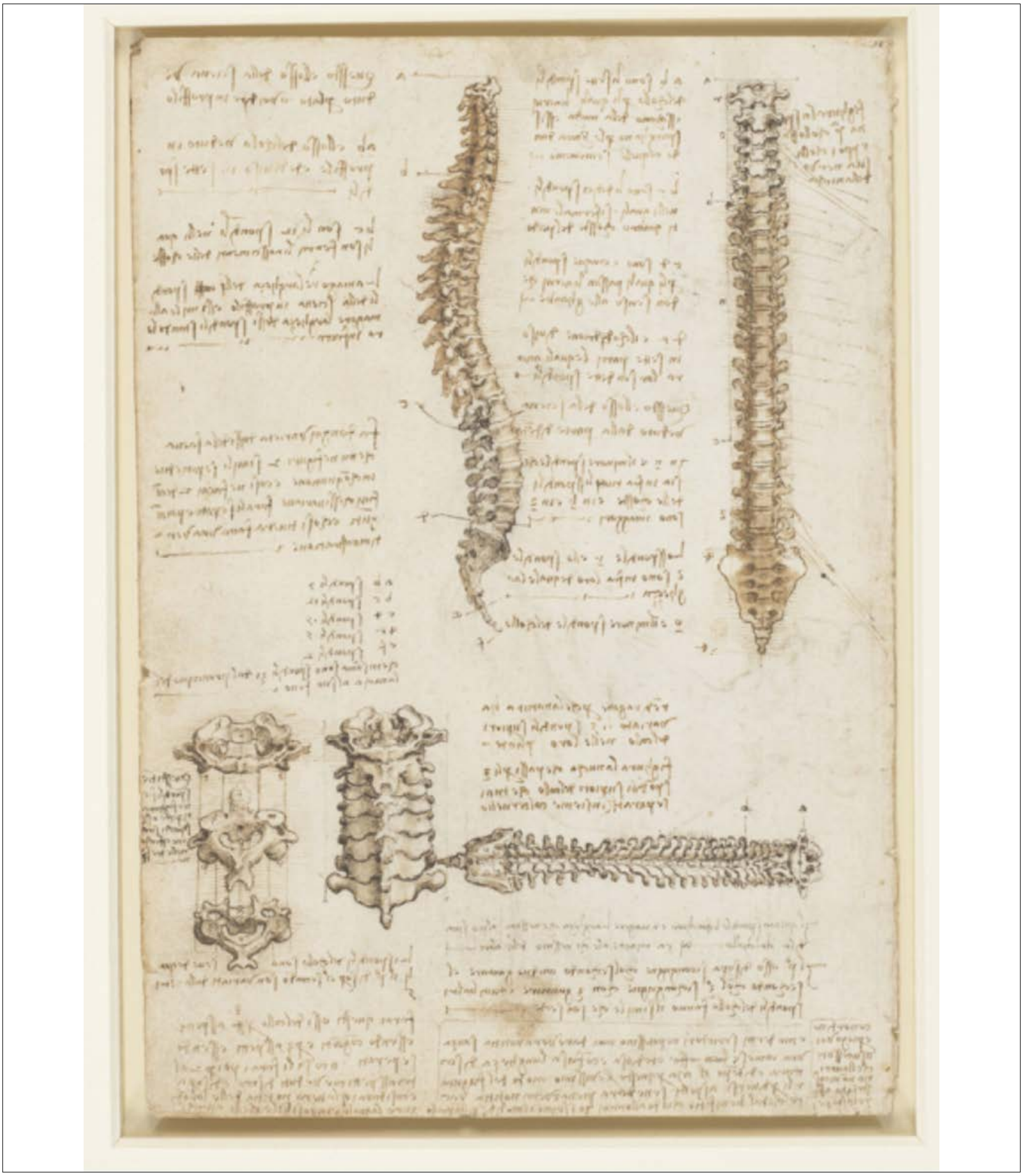
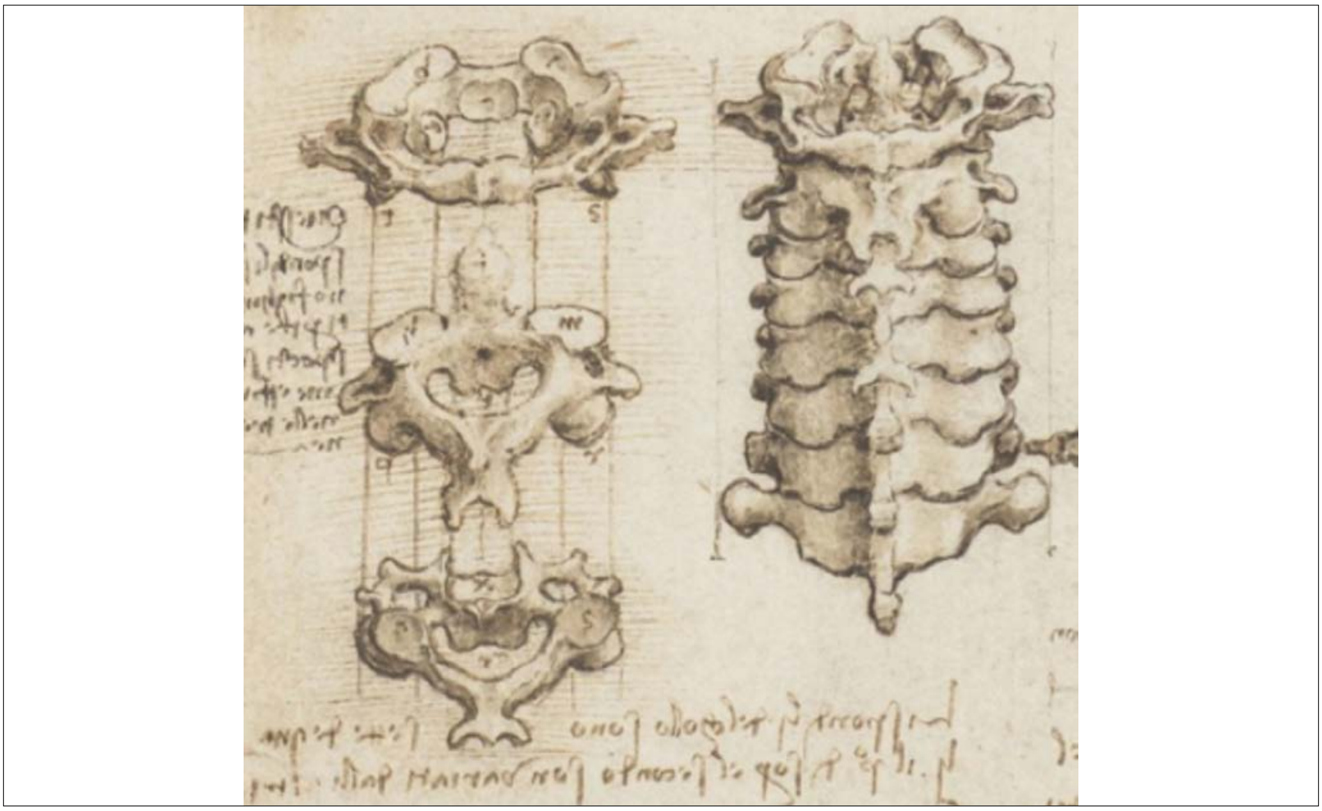


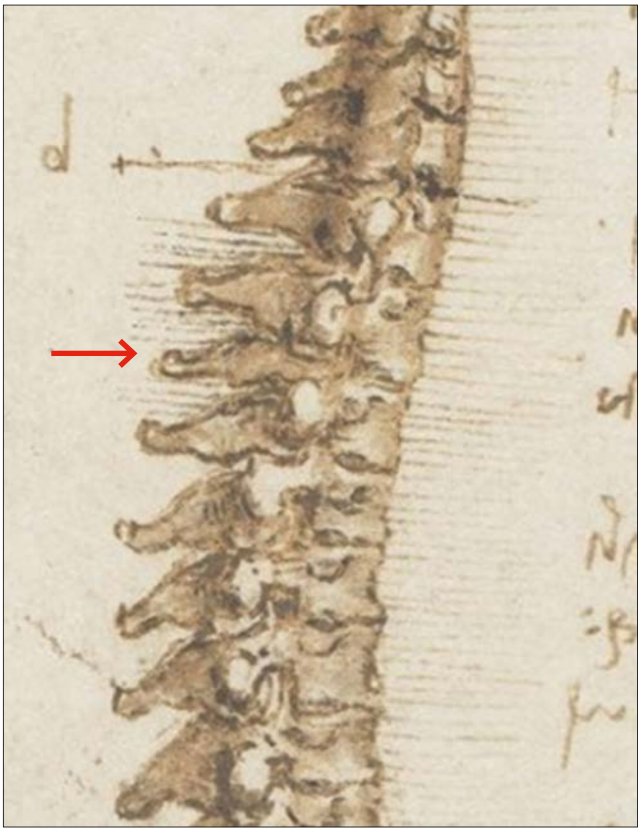
Figure 2 Windsor RL 19007v. Close up of the image of the cervical vertebrae. This image is credited as: Royal Collection Trust/© Her Majesty Queen Elizabeth II 2020.



lordosis could be observed. The vertebrae are classified, as in the modern way, into cervical, dorsal, lumbar, sacral, and coccygeal segments. Leonardo was the first to describe how the dimensions vary according to the site, that the width of the vertebral bodies seen in profile is the same as that seen from the front, that the width of the 7th cervical vertebra and the 4th dorsal vertebra are similar, and that the spinous process of the 7th cervical vertebra protrudes as much as that of the 5th lumbar one. The first cervical vertebra is drawn separately and with innovative vision, probably honed by Leonardo's engineering studies. To make the spatial and functional relationships of the cervical vertebrae clear, Leonardo in an exploded drawing (*disegno scoppiato*), "dismantled" the assembled parts, making it possible to appreciate their articular and ligamentous relationships (Fig.2). To quote Kemp [6], *"This the first accurate depiction of the spine in history, and in the 500 years following, no artist or anatomical illustrator has surpassed Leonardo's accomplishment"*.

However, even the great Leonardo sometimes made mistakes, and it takes an eye for detail to see the error: an extra spinous process, with no accompanying vertebral body, at the level of the 4th dorsal vertebra (Fig.3). This was not noticed at first sight, but only by counting the spinal apophyses, as reported by Kleyton and Philo [1]. We might consider a bone abnormality as a possible explanation for this, however it should be noted that bone dysplasias at the level of the spinous processes are very rare (they may be congenital due to a malformation, or acquired, for example due to post-traumatic ossifying myositis) [7]. However, abnormalities acquired in the above conditions re-

Figure 3 Windsor RL 19007v. Close up of the extra spinous process at T4 vertebra (arrow). This image is credited as: Royal Collection Trust/© Her Majesty Queen Elizabeth II 2020.



semble a phalanx or a supernumerary rib, and, therefore, look nothing like what Leonardo depicted.

We do not know to whom this vertebral column belonged, nor do we know the age or sex of the corpse. In the drawing of the vertebral column, irregularities of the vertebral bodies and apophyses can be observed, especially at the dorsal and lumbar levels, with hyperostosis or osteophytosis, typical of a subject with osteoarthritis (spondylosis deformans and intervertebral osteochondrosis) [8].

This favors the interpretation that the vertebral column drawn by Leonardo belonged to an elderly person, although certainly not to the centenarian that Leonardo examined and dissected in Florence in the Hospital of Santa Maria Nuova around 1508 to find out "the cause of his sweet death" (RL 19027v).

The anatomical irregularities seen in Leonardo's drawings of the spine recall images prompted us to consult images of vertebral degeneration. But what we know today, through radiology, about osteoarthritis and osteoporotic vertebral fractures was not part of common knowledge at the time Leonardo drew his spine.

Over the past four decades, radiological science has made it possible to define and measure anatomical complications of the spine. Osteoarthritis and osteoporosis of the spine have now been defined and are quantifiable. Vertebral osteophytosis is a common finding on CT and MRI scans. It reflects the presence of abnormal bony protrusions growing along the joints and related to the aging of the spine and the consequent degeneration of the intervertebral discs and articular facets. Dehydration of the nucleus pulpous and the loss of elasticity of the annulus fibrosus cause the intervertebral disc space to decrease, the shape of the vertebral end plates to change from concave to flat or irregular, and proliferation of the margins of the zygoapophyseal joints [9,10]. The intervertebral disc degeneration, subchondral sclerosis and osteophytes may parallel osteoarthritis in the articular joints and may be considered part of the natural aging process. These features are quite common, especially at the lumbar spine, in both sexes [9].

Vertebral fractures are among the most prevalent osteoporotic fractures and yet paradoxically the most undiagnosed, given the difficulty in diagnosing them [8]. In 1993, Genant *et al*. first described their semiquantitative method for defining the presence and severity of vertebral fractures [10]. By measuring the height of vertebral bodies at their two extremities (anterior: Ha and posterior: Hp) and in the middle part (Hm), and relating these measurements to each other, they were able to identify the presence of a wedge-like deformity (wedge) if Ha > Hp, a biconcave deformity if Hm < Hp and Ha, or a crush deformity if Hp < Hp in the upper or lower vertebra. Such deformities are graded 1 for a reduction of 20–24%, grade 2 for a reduction of 25–40%, and grade 3 for reduction of more than 40%. Borderline vertebrae presenting reductions of 15–20% may be given a grade of 0.5 [11, 12].

In the present paper, we set out to "read" Leonardo's anatomical illustrations of the spine, drawing on the knowledge we have accumulated through radiological interpretation of the degenerative disorders typical of the elderly. In so doing, although this is perhaps too ambitious an objective, we aimed to understand whether Leonardo, though his genius, may serendipitously have described conditions not known in his time.

Methods

We analyzed Leonardo's lateral projection drawing of the spine (RL 19007v) (Fig. 4). This was digitalized using a digital camera (Nikon D90) from a distance of 1.2 m. The file was then converted to DICOM format to be analyzed. The image produced was analyzed using medical software (Horos v. 3.3.6). Since this was not a radiographic projection, in which the margins of the vertebral bodies are naturally enhanced by projective effects and overlapping of high-density structures, it was necessary to highlight the edges of the various vertebral bodies to facilitate the analysis and, at the same time, allow reproducibility (Fig. 5).

Figure 4 Windsor RL 19007v. The vertebral column represented in the lateral (A) and antero-posterior (B) projections. This image is credited as: Royal Collection Trust/© Her Majesty Queen Elizabeth II 2020.

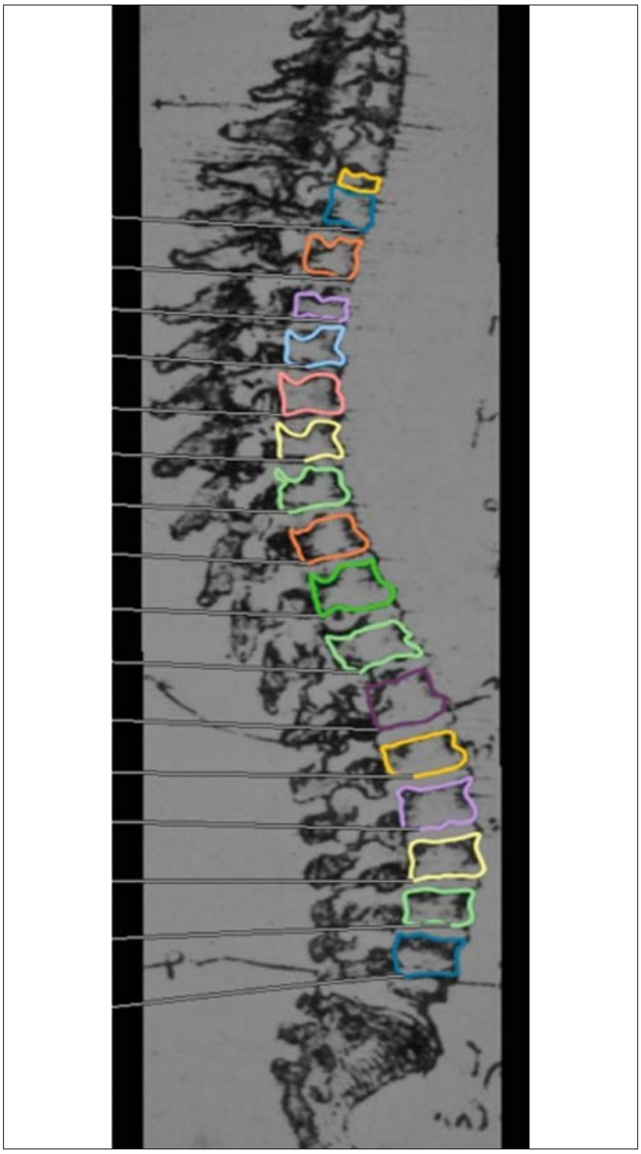


Figure 5 Vertebral morphometry of the spine drawn by Leonardo defining the borders of the vertebral bodies and using pixels as a method of comparative measurement of vertebral heights.

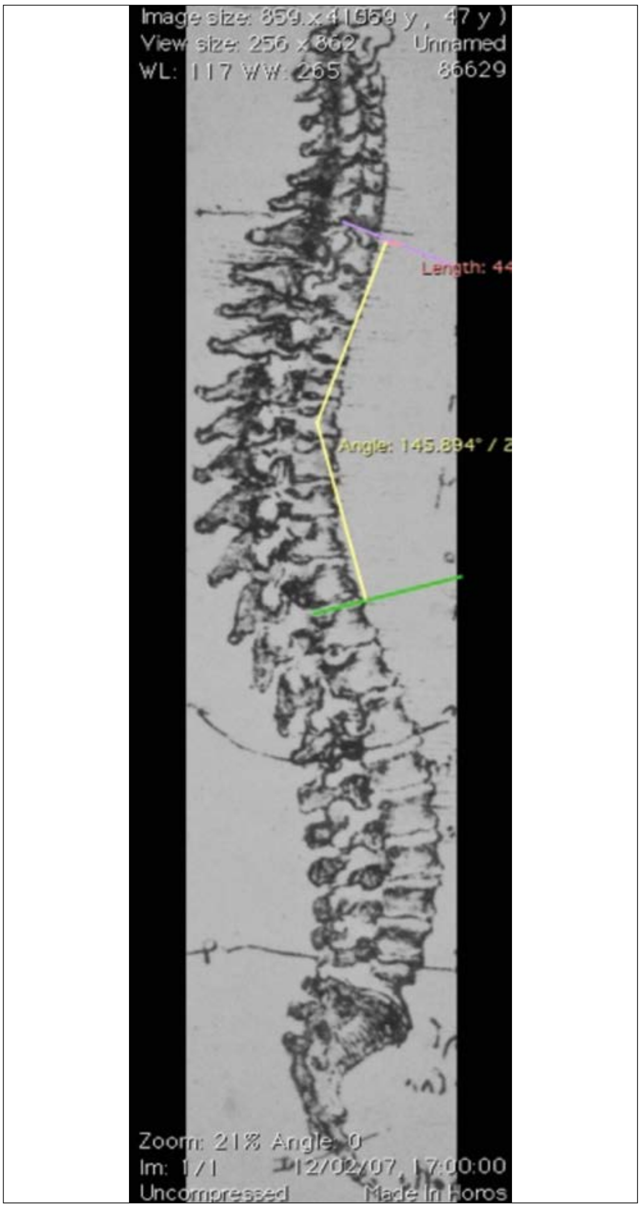


Figure 6 Evaluation of the Cobb angle.

Unfortunately, there was no possibility of identifying vertebral fractures, as it was difficult to identify the margins on the lateral projections. An anatomical drawing cannot fully replicate a radiograph for definition and accuracy.

Results

The posterior, middle and anterior height of the vertebral bodies, measured from T4 to L5, was found to be 22.4±0.9 pixel (mean±SE), 20.1±1.0 pixel, and 22.1±0.9 pixel, respectively (Tab. I). The standard error was very low, indicating substantial uniformity of the vertebrae. The greater height of the posterior compared with the middle-anterior values confirmed the presence of slightly wedge-shaped vertebrae. Anatomically, however, the lateral view of the vertebrae, especially at the dorsal level, did not allow us to define the margin of the posterior wall with the same precision as in a radiographic projection because the transverse processes depart seamlessly posteriorly to the vertebral body.

The Cobb angle was 26.9°, which is perfectly normal. The lordosis angle was 26°, also within the range of values considered normal (Fig. 6). The lumbar spine was found to show changes suggestive of degenerative disc disease (osteoarthritis), namely hypertrophic endplates with osteophytes and marked disc space narrowing (Fig. 7).

Discussion

Leonardo's "radiographical" drawings of the spine provide the earliest depiction of deformities of the spine related to ver-

Figure 7 Windsor RL 19007v, detail. Degenerative disk disease in the lumbar spine. This image is credited as: Royal Collection Trust/© Her Majesty Queen Elizabeth II 2020.

tebral degeneration.

While Leonardo's drawings did not allow us to define with accuracy the profile of the thoracic and lumbar vertebrae, the lumbar spine clearly showed osteoarthritic degenerative changes.

With his extraordinary eye for detail, Leonardo offered an unprecedented image that foreshadowed what radiology would later make available to clinicians for fracture diagnosis. He was not only a refined artist, but also a tenacious investigator, researcher and science communicator. Therefore, Leonardo, who was "without letters", having been unable to study (except for mathematics and Latin), as an adult, was able to proudly say: *"They will say that, because I do not have letters, I cannot say that which I want to study. They do not know that my studies are more to be taken from experience than words"*. (Codex Atlanticus, c 327v). Such was his awareness of having created admirable anatomical studies that, at the end of his efforts, he declared: *"You will give the true news of the drawings, which were impossible for the ancient and modern writers to ever give, without an immense and tedious and confused length of writing and time. And for this very brief way of drawing them in their different aspects, full and true news will be given, and so that such a gift that I give to all men shall not be lost, I teach a way to reprint them in order, and I pray you, as successors, to know that avarice does not require that you make wood prints"*.

Table I Morphometric evaluation of the dorsal and lumbar vertebrae of Leonardo's spine.

	HEIGHT POSTERIOR	HEIGHT MIDDLE	HEIGHT ANTERIOR	ANTERIOR WEDGE	MIDDLE WEDGE
T4	13.9	11.8	12.7	0.91	0.84
T5	18.5	16.6	21.3	1.15	0.89
T6	24.9	17.4	22.4	0.89	0.69
T7	22.0	15.7	20.9	0.95	0.71
T8	26.1	23.2	21.5	0.82	0.88
T9	20.7	23.3	22.5	1.08	1.12
T10	25.7	16.7	24.7	0.96	0.64
T11	25.4	21.9	25.0	0.98	0.86
T12	27.0	26.3	27.8	1.02	0.97
L1	19.7	22.3	21.4	1.08	1.13
L2	24.8	24.0	24.7	1.00	0.97
L3	23.5	22.1	24.1	1.02	0.94
L4	19.6	19.2	19.6	1.00	0.98
L5	23.0	21.0	20.9	0.90	0.91
Mean	22.4	20.1	22.1		
SD	3.52	3.84	3.35		
SE	0.94	1.02	0.89		

References

1. Clayton M, Philo R. Leonardo da Vinci. The mechanism of man. Royal Collection Publications, London, 2010.
2. Laurenza D. In search of a phantom: Marcantonio della Torre and Leonard's late anatomical studies. In Leonardo da Vinci's anatomical world. Language, context and "disegno". A Nova & D Laurenza eds, Marsilio, Venice, 2011.
3. Tonelli F. As Leonardo da Vinci discovered sarcopenia. Clin Cases Miner Bone Metab. 2014;11(1):82-3.
4. Oakes PC, Kirkpatrick C, Chapman JR, Oskouian RJ, Tubbs RS. Some of the earliest depictions of the humane spine: a glimpse into European history. Childs Nerv Syst. 2018;34(2):179-81.
5. Rengachary SS, Colen C, Dass K, Guthikonda M. Development of anatomic science in the late middle ages: the role played by Mondino de Liuzzi and Guido da Vigevano. Neurosurgery. 2009;65(4):787-93; discussion 793-4.
6. Clayton M, Philo R. Leonardo da Vinci anathomist. Royal Collection Publications, London, 2012.
7. Nakano Y, Aizawa M, Kako Y, Mizuno K, Itabashi K, Nishimura G. A neonate with anomalous bone attached to the cervical spine. Spine J. 2013;13(7):e5-7.
8. Resnick DL, Krausdorf MJ. Bone and joint imaging. 3rd ec. Elsevier, 2004.
9. de Schepper EI, Damen J, van Meurs JB, et al. The association between lumbar disc degeneration and low back pain: the influence of age, gender, and individual radiographic features. Spine (Phila Pa 1976). 2010;35(5):531-6.
10. Rustenburg CME, Emanuel KS, Peeters M, Lems WF, Vergroesen PA, Smit TH. Osteoarthritis and intervertebral disc degeneration: quite different, quite similar. JOR Spine. 2018;1(4):e1033.
11. Bouxsein M, Genant H. International Osteoporosis Foundation Vertebral Fracture Audit. www.iofbonehealth.org.
12. Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res. 1993;8(9):1137-48.

Acknowledgements: *This paper was supported by FIRMO Foundation (to MLB).*