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Computed Tomography Morphometry of the Lumbar Spine in Adults in Brazzaville

Léon Boukassa[1*], Mattvey Radia Koudimba[1], Regis Moyikoua[2], Ruth Ibara Wamé[1], Sinclair Brice Kinata Bambino[1], Olivier Brice Ngackosso[1], Hugues Brieux Ekouélé Mbaki[1]

[1]Neurosurgery Department, Brazzaville University Hospital Center, Brazzaville, Republic of the Congo
[2]Medical Imaging Department, Brazzaville University Hospital Center, Brazzaville, Republic of the Congo
Email: *lboukassalouf@gmail.com

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Abstract

Context and Justification: Reconstructive spine surgery and the design of implants depend on disc and vertebral measurements, which vary according to racial groups and geographic areas. This variability underscores the importance of studying the morphometric characteristics specific to each population. **Research Objective:** The primary aim of this research was to determine the measurements of spinal components in the Congolese population in order to establish references suitable for local clinical practice. **Materials and Methods:** Congolese individuals, free from any spinal disorders, participated in a study on vertebral and disc morphology of the lumbar spine after providing informed consent. They underwent computed tomography examinations at medical imaging centers in Brazzaville. The parameters studied included: in axial sections, the transverse diameter (TDb) and sagittal diameter (SDb) of the vertebral bodies, the pedicular transverse diameter (TDp), and in sagittal reconstructions: the height of the vertebral bodies (Hb) and intervertebral discs (Hd). **Results:** The sample size consisted of 100 subjects (70 men and 30 women), with an average age of 24.47 ± 3.72 years (18 - 30 years). Cranio-caudally, the TDb, DSb, TDp, and Hd showed increasing values, while Hb values were decreasing. In L1, values for both sexes were: TDb = 39.3 ± 3 mm; DSb = 27.3 ± 2.9 mm; Hb = 26.6 ± 2.1 mm; TDp = 8.2 ± 1.8 mm; in L5: TDb = 50.3 ± 4 mm; DSb = 33.6 ± 2.7 mm; Hb = 25.7 ± 2.2 mm; TDp = 14.8 ± 2.1 mm. The Hd values were 8.1 ± 2.1 mm for L1 - L2 and 11.1 ± 2 mm for L5 - S1. **Conclusion:** Reconstructive spine surgery and the design of implants depend on disc and vertebral measurements, which vary according to racial groups and geographic areas. This variability underscores the importance of studying the morphometric characteristics specific to each population.

Keywords

Vertebral Body, Intervertebral Disc, Pedicle, Computed Tomography,

Morphometry

1. Introduction

Reconstructive spine surgery is a dynamic and rapidly advancing field focused on restoring the function and integrity of the spinal column in patients afflicted by a range of pathologies. A pivotal element of this practice is the utilization of implants, which must be meticulously tailored to the specific anatomical measurements of spinal structures to ensure optimal outcomes. Disc and vertebral dimensions—including the diameters of vertebral bodies, pedicles, and intervertebral discs—are critical factors that significantly influence the success of surgical interventions.

It is well documented that these measurements exhibit considerable variability across different racial groups and geographic regions [1] [2]. This variability underscores the necessity for conducting comprehensive morphometric studies within specific populations to establish accurate and relevant anatomical references. Precise data on local anatomical dimensions not only facilitate the optimization of implant design but also enhance clinical outcomes, thereby improving patient care.

In light of these considerations, our study aims to systematically determine the measurements of spinal components within the Congolese population. By employing advanced imaging techniques such as computed tomography (CT), we meticulously examined a sample of Congolese individuals who are free from any spinal disorders. The findings from this research will provide a crucial foundation for clinical practice in reconstructive surgery and lumbar spine stabilization, ultimately contributing to improved surgical strategies tailored to the unique anatomical characteristics of this population.

2. Materials and Methods

We conducted a prospective cross-sectional study to assess vertebral body, pedicle, and intervertebral disc measurements using computed tomography (CT) images over a 6-month period from April 1 to September 30, 2023. The study population comprised adults of both sexes, aged between 18 and 30 years, residing in Brazzaville, who provided informed consent. Inclusion criteria required participants to have no history of spinal trauma, tumors, or infections. Additionally, female participants were screened to ensure they were not pregnant or at risk of becoming pregnant.

CT examinations were conducted at the Centre Hospitalier Universitaire and the Hôpital de Référence de Talangaï in Brazzaville, utilizing a Canon Aquilion 80-slice scanner and a Siemens Somatom Emotion 16-slice scanner, respectively. The acquired images were stored on Digital Versatile Discs. A medical student, under the supervision of a radiologist, performed the measurements using a computer equipped with Digital Imaging and Communications in Medicine (DICOM) software: Radiant DICOM Viewer Version 2022.

3. Measurement Parameters

The parameters studied included:

- For Vertebral Bodies:

  - Median sagittal diameter (SDb), transverse diameter (TDb) in mm, and surface area (Sb) in mm^2 measured on axial sections.

  - Height of the vertebral body (Hb) measured in mm on sagittal reconstructions.

- For Pedicles:

  - Transverse diameter (TDp) of each pedicle measured in mm on axial sections.

- For Intervertebral Discs:

  - Disc height (Hd) measured in mm on sagittal reconstructions.

The SDb was defined as the distance between the ventral wall and dorsal wall at its medial part (**Figure 1(a)**). The TDb represented the distance between the lateral faces of the vertebral body (**Figure 1(b)**). The Sb was calculated as the area bounded by the ventral, lateral, and dorsal edges of the vertebral body (**Figure 2**). The Hb was determined as the average height measured at the ventral, middle, and dorsal aspects between the cranial and caudal plates of the vertebra (**Figure 3(a)**).

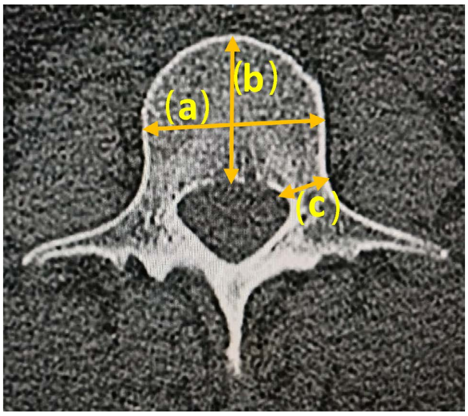

Figure 1. CT in axial section in bone window. (a) Body transversal diameter (TDb); (b) Body sagittal diameter (SDb); (c) Pedicle transversal diameter (TDp).

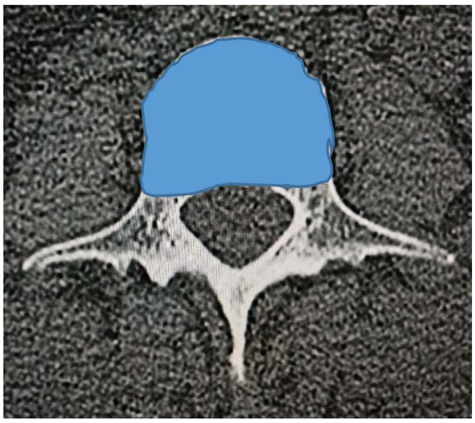

Figure 2. CT in axial section in bone window. Body surface area (Sb).

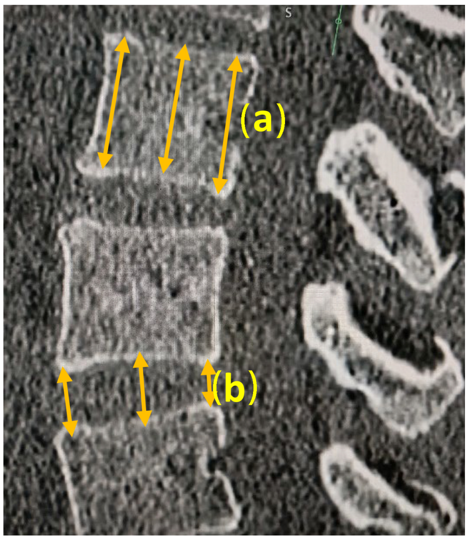

Figure 3. CT in axial section in bone window. (a) Body height (Hb); (b) Intervetebral disc height (Hd).

For pedicles, TDp was defined as the distance between the lateral and medial faces of each pedicle (Figure 1(c)). Intervertebral disc height (Hd) was calculated as the average height taken at the ventral, middle, and dorsal parts of the disc on sagittal reconstructions (Figure 3(b)).

4. Data Management and Statistical Analysis

Data entry and processing were performed using Microsoft Excel 2010, while statistical analysis was conducted using SPSS Statistics Version 26.0.0.0. Quantitative variables were expressed as means with standard deviations, while categorical variables were presented as proportions and ratios. Comparisons of means for quantitative variables were performed using Student's t-test, with significance established at a p-value less than or equal to 0.05 (≤5%). Confidence intervals were calculated at 95%, corresponding to a margin of error of 5%.

5. Results

We were able to include 117 subjects in this study. Among them, 17 cases were excluded following the discovery of abnormalities on CT scans. Thus, we included 100 cases, comprising 70 men and 30 women, resulting in a sex ratio of 2.3. The mean age was 24.47 ± 3.72 years (range: 18 - 30 years).

The measurements of the vertebral bodies are presented in Table 1 and Table 2, the dimensions of the pedicles in Table 3 and Table 4, and those of the intervertebral discs in Table 5 and Table 6.

Table 1. Overall morphometric values of the vertebral Bodies.

Items	L1	L2	L3	L4	L5
SDb (mm)					
Average	27.3	3.93	30.5	31.7	33.6

Continued

Standard deviation	±2.9	3	±2.7	±2.4	±2.7
Minimum	21.5	32.8	22.8	38.9	27.5
Maximum	34.2	47.8	39.8	31.7	45.6
TDb (mm)					
Average	39.3	40.6	42.2	44.4	50.3
Standard deviation	±3	±3	±3.2	±3.7	±4
Minimum	32.8	32.7	35.6	36.1	38.3
Maximum	47.8	50.3	52.4	54.1	61.7
Hb (mm)					
Average	26.6	26.2	26.2	25.9	25.7
Standard deviation	±2.1	±2.2	±2	±1.9	±2.2
Minimum	30.9	19.4	21.5	21.5	14.3
Maximum	25.6	31.3	31.5	31.1	30.8
Sb (mm^2)					
Average	1,083	1,182	1,253	1,329	1,478
Standard deviation	±173	±182	±185	±188	±203
Minimum	747	847	893	1,049	1,160
Maximum	1,657	1,743	1,809	1,821	2,133

Table 2. Morphometric values of the vertebral bodies of men and women.

Items	L1		L2		L3		L4		L5	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
SDb (mm)	27.5 ± 3	26.9 ± 2.9	29.5 ± 2.8	28 ± 2.5	30.9 ± 2.9	29.9 ± 2.1	32.1 ± 2.5	31.1 ± 1.7	34 ± 2.9*	32.6 ± 1.9
TDb (mm)	39.6 ± 3	38.6 ± 3	41 ± 3	39.7 ± 3	42.7 ± 3.1*	41.2 ± 3.1	45.1 ± 3.1*	42.9 ± 3.3	51 ± 4*	48.4 ± 3.2
Hb (mm)	25.9 ± 2.1	28 ± 2.2	26.3 ± 2.3	26.2 ± 2	26.3 ± 2	26 ± 2.1	26 ± 1.9	25.6 ± 1.9	25.9 ± 2.3	25.3 ± 2
Sc (mm^2)	1,098 ± 162	1,058 ± 199	1,198 ± 181	1,144 ± 184	1,269 ± 179	1,216 ± 198	1,358 ± 190	1,262 ± 167	1,502 ± 215	1,421 ± 164

*Significant difference between men and women on TD from L3 to L5 and SD in L5.

Table 3. Overall measurements of the vertebral pedicles.

Items	L1	L2	L3	L4	L5
TDp D (mm)					
Average	8.2	8.5	9.9	11.5	14.8
Standard deviation	±1.6	±1.9	±1.9	±2.1	±2.4
Minimum	4.8	4.9	5	7	10.9
Maximum	13.4	13	15	16.8	22.7

Continued

TDp G (mm)					
Average	8.2	8.2	9.7	11.6	14.9
Standard deviation	±1.4	1.6	±1.9	±2.1	±2.5
Minimum	5.4	5.1	5.9	7.3	10.3
Maximum	11.6	12.7	15.7	16.7	23.1

Table 4. Comparison of the measurements of the vertebral pedicles of men and women.

Items	L1		L2		L3		L4		L5	
	♂	♀	♂	♀	♂	♂	♀	♂	♀	♂
TDp D (mm)	8.3 ± 1.6	7.9 ± 1.6	8.7 ± 2	8.3 ± 1.7	10.2 ± 1.9	9 ± 1.6	11.9 ± 1.9	10.5 ± 2.2	15 ± 2.5	14.7 ± 2.1*
TDpG (mm)	8.3 ± 1.4	8 ± 1.3	8.2 ± 1.6	8.1 ± 1.7	10 ± 1.9*	8.9 ± 1.7*	12 ± 2.1*	10.7 ± 2*	15 ± 2.7	14.2 ± 2*

*Significant difference.

Table 5. Overall morphometric values of the discs.

Items	L1 - L2	L2 - L3	L3 - L4	L4 - L5	L5 - S1
Hd (mm)					
Average	8.1	9.1	10.6	11.6	11.1
Standard deviation	±1.3	±1.2	±1.3	±1.8	±2
Minimum	5	6.3	7.3	7.5	5
Maximum	12.2	12	14.2	19.4	18

Table 6. Morphometric values of the discs of men and women.

Items	L1		L2		L3		L4		L5	
	♂	♀	♂	♀	♂	♂	♀	♂	♀	♂
Hd	8.2 ± 1.3	7.8 ± 1.2	9.2 ± 1.2	9 ± 1.2	10.5 ± 1.3	10.8 ± 1.3	11.4 ± 1.9	11.8 ± 1.5	11.1 ± 2	11.1 ± 1.9

5.1. Type and Period of Study

Our descriptive cross-sectional study with prospective data collection lasted six months and involved 100 Brazzavillian volunteers who met the inclusion criteria. The accurate assessment of bony structures and soft tissues by CT makes it the appropriate means for evaluating spinal morphometry [3], rendering the use of standard radiographs less relevant in this type of study. However, the results of our study cannot be generalized due to the small size of our sample.

Our sample was predominantly male (sex ratio of 2.3). The Korean series by Lee [4] had an identical distribution, while that of Singh [5] in India had 57.6% men and 42.4% women. Our subjects were aged between 18 and 30 years, an age range in which, according to Coudert [6], bone growth is complete and degenerative lesions are rare. The series by Gocmen-Mas *et al.* [7] in Turkey included patients aged between 22 and 49, while Azu *et al.* [2] in South Africa studied a series of anatomical specimens ranging in age from 27 to 80 years.

5.2. Measurements of the Vertebral Body

5.2.1. Comparison of Manual and Automatic Measurements

To appreciate the difference between manual and automatic measurements, we compared the measurements from our current study with those from our first study, when the measurements were taken manually. By examining the sagittal diameters of the vertebral bodies in men (**Figure 4**) and the vertebral body height in women (**Figure 5**), we found that the values of the measurements taken manually were higher than those taken automatically from the CT images. Urrutia [8], who carried out both types of measurement on the same anatomical subjects, found similar overestimation with fluoroscopic values. This confirms the greater reliability of automatic measurements reported by certain authors such as Singh in India [5]. However, this assertion is contradicted by Kang [9], who found no significant difference between these two types of measurement.

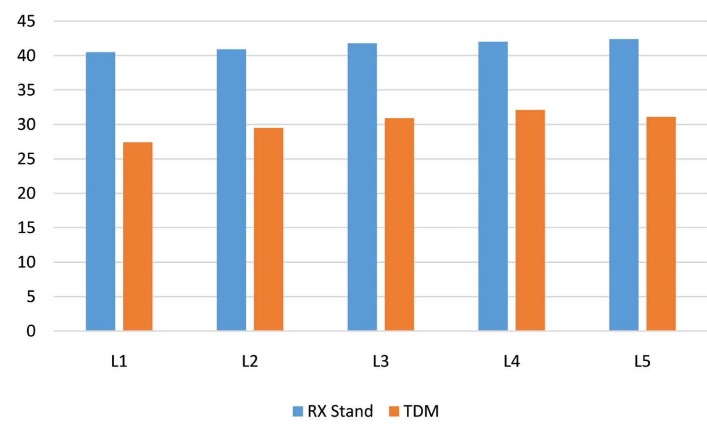

Figure 4. Comparison of sagittal diameters in men using standard X-ray and CT scan.

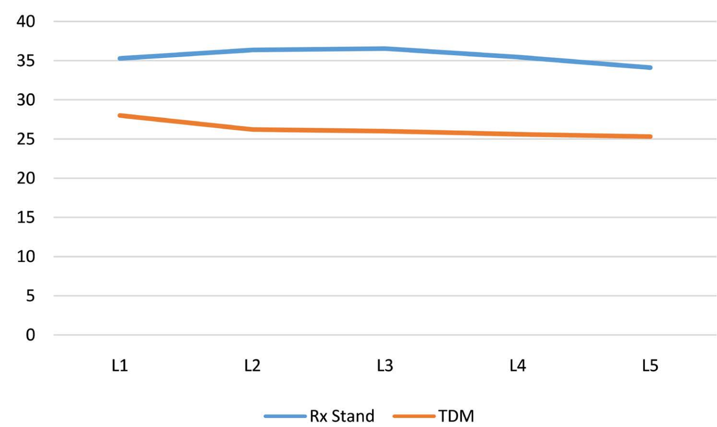

Figure 5. Comparison of vertebral body heights in women using standard X-ray and CT scan.

5.2.2. Body Measurements

There is a difference between men's and women's vertebral measurements, with men's being larger than women's. This observation, which was also found in our first study [10]-[12], has been reported by other researchers [5] [8].

Three of the four parameters measured on the vertebral body show values that increase craniocaudally from L1 to L5: these are the sagittal diameter, transverse diameter, and surface area. Height values increase from L1 to L2, then decrease from L3 to L5. In Singh's study [5], the transverse and sagittal diameters of the vertebral bodies were measured close to the upper and lower plates of the vertebral bodies, whereas we measured ours in the middle of the vertebral bodies. A direct comparison cannot therefore be made; however, we note identical evolutionary trends in these data (**Table 7** and **Table 8**). The decrease in vertebral body height

Table 7. Comparison of sagittal diameters of bodies between our study and that of Singh [5].

Items	Our study men	Our study women	Singh men	Singh women
L1	27.5 ± 3	26.9 ± 2.9	28.61 ± 2.46	26.53 ± 2.21
L2	29.5 ± 2.8	28 ± 2.5	30.37 ± 3.26	28.30 ± 2.36
L3	30.9 ± 2.9	29.9 ± 2.1	31,37 ± 2,78	29.77 ± 2.87
L4	32.1 ± 2.5	31.1 ± 1.7	31,56 ± 2,27	30.12 ± 2.22
L5	34 ± 2.9	32.6 ± 1.9	32.41 ± 2.35	30.94 ± 1.9

Table 8. Comparison of the transverse diameters of the bodies between our study and that of Singh [5].

Items	Our study men	Our study women	Singh men	Singh women
L1	39.6 ± 3.0	38.6 ± 3.0	40.15 ± 3.09	39.95 ± 3.14
L2	41.0 ± 3.0	39.7 ± 3.0	42.55 ± 4.08	39.49 ± 2.97
L3	42.7 ± 3.1	41.2 ± 3.1	44.34 ± 3.17	41.54 ± 3.47
L4	45.1 ± 3.1	42.9 ± 3.3	46.42 ± 3.98	43.59 ± 3.58
L5	51.0 ± 4.0	48.4 ± 3.2	48.79 ± 5.54	46.00 ± 3.66

Table 9. Comparison of transversal diameters right pedicles (TDpR) in males and females in our study and that of Singh [5].

	Homme		Femme	
	TDpR Our study N = 70	TDpR Singh N = 174	TDpR Our study N = 30	TDpR Singh N = 128
L1	8.3 ± 1.6	9.08 ± 1.6	7.9 ± 1.6	8.42 ± 1.45
L2	8.7 ± 20	9.60 ± 1.43	8.3 ± 1.7	8.61 ± 1.41
L3	10.2 ± 1.9	10.81 ± 1.69	9 ± 1.6	10.01 ± 1.47
L4	11.9 ± 1.9	11.85 ± 1.75	10.5 ± 2.2	11.14 ± 1.58
L5	15 ± 2.5	14.43 ± 2.24	14.2 ± 2.1	13.48 ± 2.29

observed in our study is due to our method of calculation, which involved averaging three heights: ventral, middle, and dorsal. Authors such as Singh *et al.* [5] and Alam *et al.* [13], who reported measurements of ventral and dorsal heights separately, pointed out the increasing nature of ventral diameters and the decreasing nature of dorsal diameters in the craniocaudal direction. This likely contributes to the formation of lumbar lordosis.

The surface area of the vertebral bodies was not calculated in their studies; however, since it is derived from the transverse and sagittal diameters, it would have evolved similarly to ours. The same trend would have been observed if we had calculated the approximate volume of the vertebral bodies, which are cylindrical overall with an oval base. All these factors seem to contribute to explaining the load-bearing role of these low-lying vertebrae. In fact, the vertebral bodies are composed of a cortical shell surrounding large trabeculae of cancellous bone, with spaces filled with bone marrow. Together, they form a system that absorbs energy from impacts applied to them. Thus, the craniocaudal increase in volume of the vertebrae is one adaptation to withstand increasing overlying forces [14].

5.3. Pedicle Measurements

Pedicle measurements are crucial as they are used for selecting implant dimensions for spinal stabilization procedures. Studies on vertebral morphometry [Singh, Urritia, Konan] refer to the transverse diameter of pedicles as the minor axis of this oval structure in cross-sections from L1 to L3 vertebrae. This diameter is widely accepted as a limiting factor in determining screw caliber due to its smaller size compared to pedicle height [15] [16]. This parameter was used exclusively in our study as well as in Alam's study [13].

The transverse pedicle diameter increased craniocaudally from L1 to L5. There was an asymmetry between left and right pedicles; however, this was not statistically significant. This inequality varies according to specific vertebrae considered. Between sexes, men exhibited greater diameters than women; however, this difference was only significant at L4 and L5. These observations have also been made by several authors who have worked on this subject, including Singh [5] (**Table 9**), Urrutia [8] and Konan [15]. As noted above and corroborated by other authors' work, measurements of lumbar vertebrae follow an overall craniocaudal growth pattern [Boukassa, Singh, Urritia]. We continue to link this pattern to biomechanical adaptation processes.

Cho *et al.* [17], who studied thoracic spine pedicle screws insertion—accounting for this transverse diameter—reported an increase in pedicle circumference following insertion procedures while noting that any bone breach resulting from large-caliber screws minimally affected vertebral foramen diameter. They proposed using such screws for osteoporotic bones and revision osteosynthesis procedures.

The transverse diameter is therefore an important factor when planning spinal stabilization surgery using a dorsal approach [15] [16].

5.4. Measurement of Intervertebral Discs

The mean heights of intervertebral discs progressively increase from L1 - L2 to L4 - L5 across both sexes; however, there is a slight decrease at L5 - S1—the only disc whose size is greater in women than men—though this difference is not statistically significant at all levels.

The intervertebral disc consists of two parts: nucleus pulposus at its center and annulus fibrosus at its periphery [18]. It has a viscoelastic composition subjected to two types of stress: short high-intensity stress (e.g., lifting) and long low-intensity stress (e.g., locomotion). While short-term stress relies on properties akin to an "elastic solid," long-term stress utilizes those akin to a "viscous fluid." In response to compressive stresses, nucleus pulposus expands and flattens—creating centrifugal tension forces on annulus fibrosus. This leads to pressure absorption and damping effects; thus greater disc surface area enhances absorption efficacy [14].

Consequently, craniocaudal increases in intervertebral disc surface area—transversely—resulting from increases in vertebral body surface area also contribute significantly toward pressure absorption capability [14].

This increase enhances resistance against axial compressive stress according to Kapandji and Mangione cited by Champain [19]—indicating that intervertebral joints endure only 25% - 47% of total vertical stress according to Yang also cited by Champain [19].

6. Conclusion

The results highlight the importance of using automatic measurements for more accurate assessments. While the data provide useful information for surgical planning and implant development, the limited sample size and male predominance restrict the generalization of the conclusions. Future research with a more diverse sample is necessary to validate these findings and better understand morphological variations within different populations.

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Conflicts of Interest

The authors declared no conflict of interest.

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