On the form of the human spine and some aspects of its mechanical behaviour

Citation for published version (APA):
Snijders, C. J. (1969). On the form of the human spine and some aspects of its mechanical behaviour. *Acta Orthopaedica Belgica*, *35*(3-4), 584-594.

Document status and date:
Published: 01/01/1969

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 23. Oct. 2021

On the form of the human spine and some aspects of its mechanical behaviour

by Ir. Ch.J. SNIJDERS (Eindhoven)

Mechanical Engineer at the Technical University of Eindhoven
(Department of Mechanical Engineering ;
Section : Farm Machinery and Other Small Implements)

Although the spine is flexible, we are again and again struck by its typically individual form in a person when he assumes a natural erect posture.

The description of this form as also the determining of its dimensions and position in space has been the work of many. Mostly the aim was to distinguish the pathological forms from the healthy ones.

Statistical research with respect to the form of the human spine requires the determination of numerical geometrical data.

The numerous inquiries in this field are mainly based on the comparison of a practise-imposed limited number of data determined by graduator or ruler. The present study aims at removing this limitation.

The starting point was that the mechanical behaviour of the spine corresponds to a certain degree with that of an elastic rod. In the newborn baby the whole spine shows a slight kyphotic curvature, which during standing and walking (after the period of raising the head from the prostrate position) assumes the always recognizable basic form in the sense of the S-shape.

Consequently, it is obvious to presume that the curved form of the spine is brought about, among other causes, by the influence of forces exerted on the spine and that particularly that form is developed which corresponds in a certain measure with that of an elastic rod of « technical » material loaded under analog conditions. For the rest, in what follows description of form is exclusively aimed at, while concepts of another nature will be used to offer suggestions in related spheres.

Henceforth, the form of the spine will be understood to be the smooth line on which lie the geometrical centres of the vertebrae and the intervertebral discs as visible in laterally taken X-ray pictures. To describe this form, a method taken from Applied Mechanics is used by which the path of the axis of a bent rod, loaded at its extremities, is described in a two-dimensional system of axes with a function $y = f(x)$ satisfying the conditions at the extremities (fig. 1).

In consideration of statistical aims the form of the spine will be described from the most dorsal point of the kyphosis down to the sacrum, because :

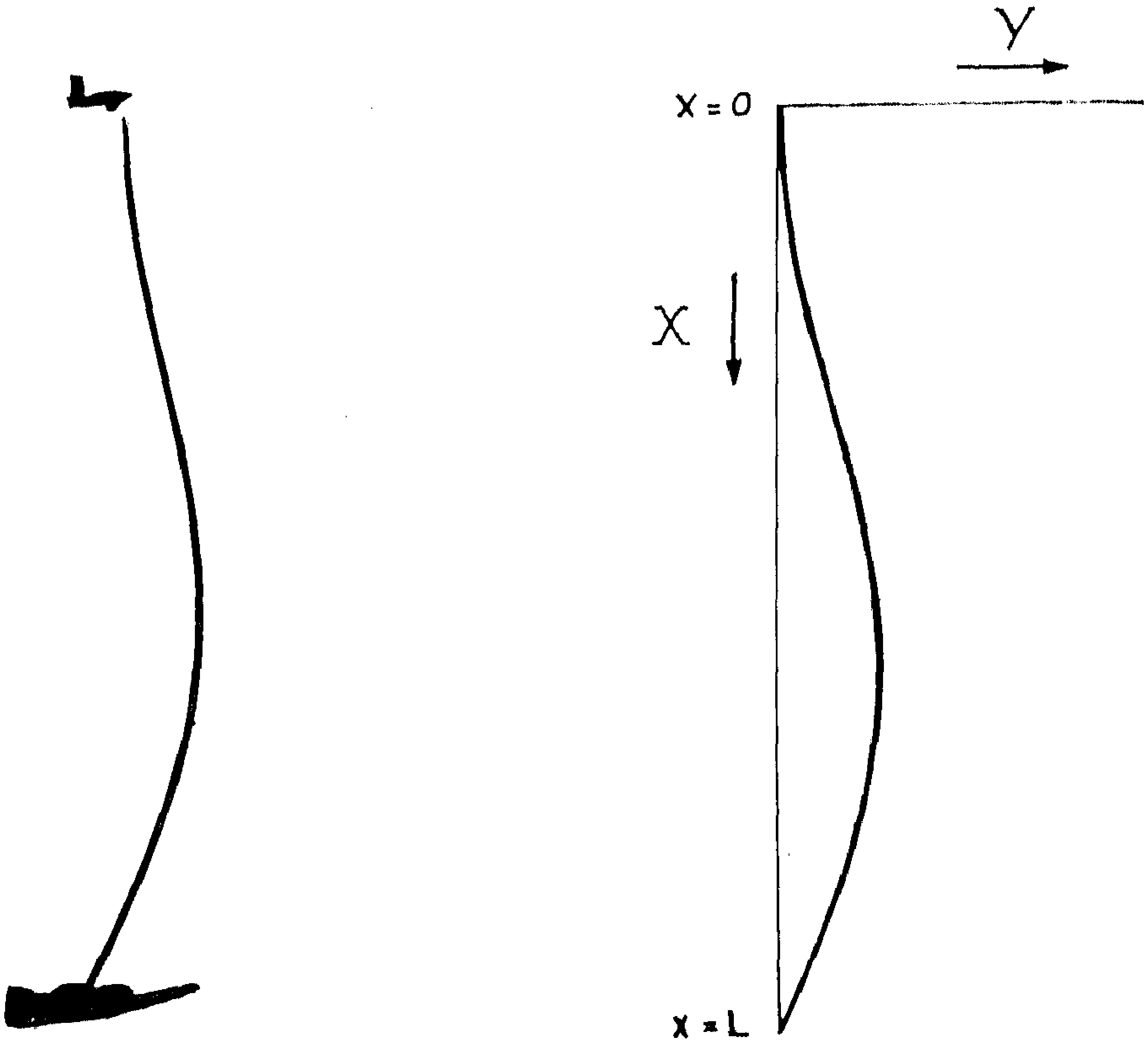


FIG. 1. — A bent rod, loaded at its extremities.

1. In that region the largest number of dorsal complaints occur, which is the reason that X-ray pictures are commonly made of that region.

2. The conditions at the extremities are salient (reference is made to the line in the direction of gravitation which is in the most dorsal point of the kyphosis the tangent to the smooth curve through the geometrical centres).

The X-ray pictures are made of individuals in a natural standing posture with their feet joined, because :

1. In this posture the individual form is expressed most clearly.

2. The action of the dorsal muscles and the intra-abdominal pressure are least.

A simple formula which has turned out to answer our purpose is :

$$y = \frac{1}{L}\left(\frac{m}{6} - \frac{A}{3}\right)x^3 + Ax^2 - L\left(\frac{m}{6} + \frac{2A}{3}\right)x + \frac{R}{L}x + \left(\frac{m}{6} + \frac{2A}{3}\right)\frac{L^2}{\pi}\sin\frac{\pi x}{L} - \frac{R}{\pi}\sin\frac{\pi x}{L}$$

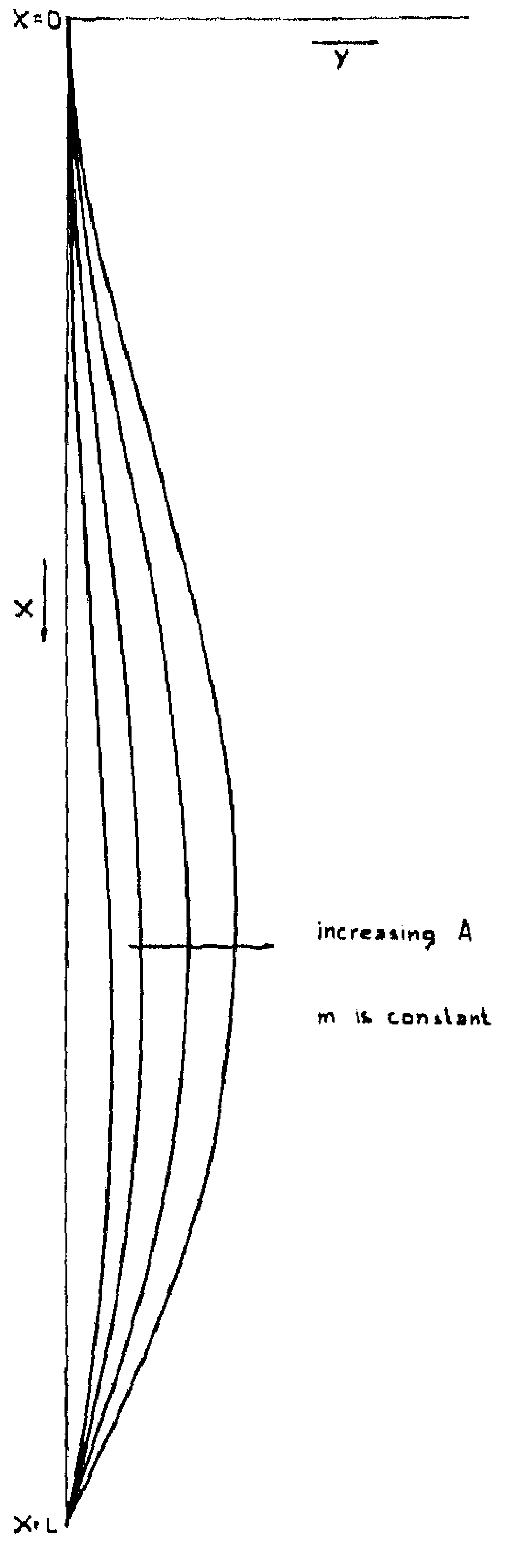


FIG. 2a. — Influence of parameter A.

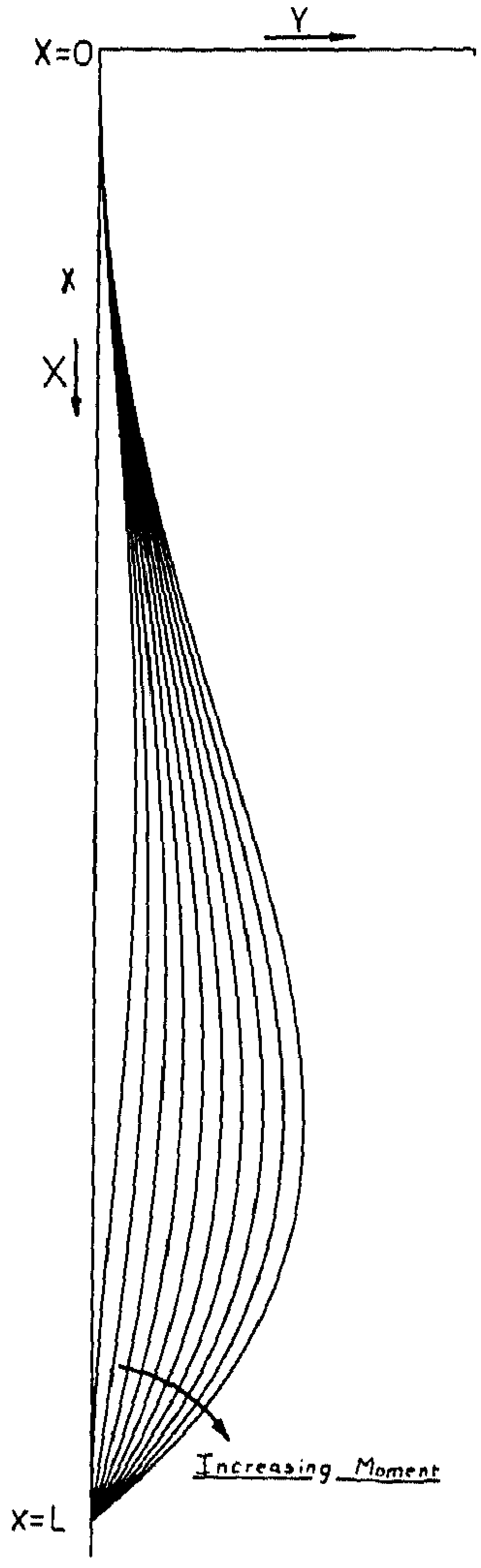


FIG. 2b. — Influence of parameter m

The number of parameters is limited to a minimum. A indicates the height of the top of the curve (fig. 2 *a*), m can be conceived as the quotient of the moment exerted on the column at the point x = L (fig. 2 *b*) and the « stiffness of the column ». R is the y-coordinate of the bottommost point.

Figure 3 *a* gives a result.

The coordinates of the geometrical centres of the vertebrae and the intervertebral discs were fed into a digital computer which, using the method of least squares, determined those values of A and m that produced a curve showing the optimum correspondence with the centres measured.

For this case $A = 0.0042 \left(\frac{1}{mm}\right)$ and $m = -0.0135 \left(\frac{1}{mm}\right)$.

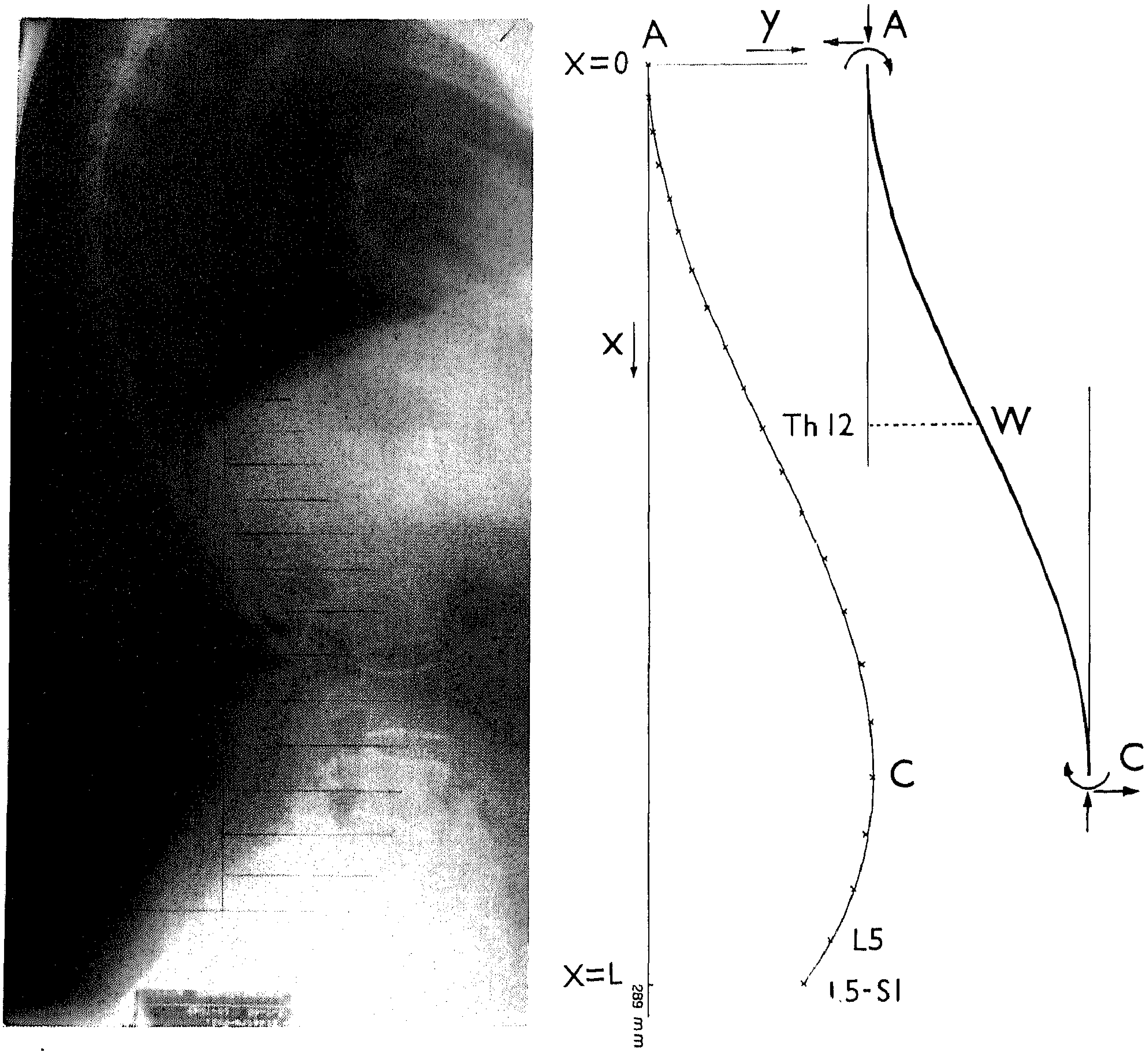


FIG. 3a. FIG. 3b.

FIG. 3a. — Description of form of a spine by a woman. Area kyphose-sacrum. Centres measured are marked with X. The fluent curve is determined by a digital computer.

FIG. 3b. — The form of a symmetrically loaded elastic rod which is e.g. straight in unloaded position.

The differences between the measured and calculated values of y were in many cases as in figure 3 *a*, viz. smaller than 1 mm (0.04 in.), i.e. in the order of the error of measurement.

The numerical values of the parameters or the data to be directly derived from them can, for purposes of statistical investigation, be compared with information of another nature, e.g. clinical picture.

For an elastic rod which in unloaded condition is straight, m = — 0.0135 would mean that at point x = L a clockwise moment would act (the sign (—) indicates the sense of rotation of the moment in the illustration concerned).

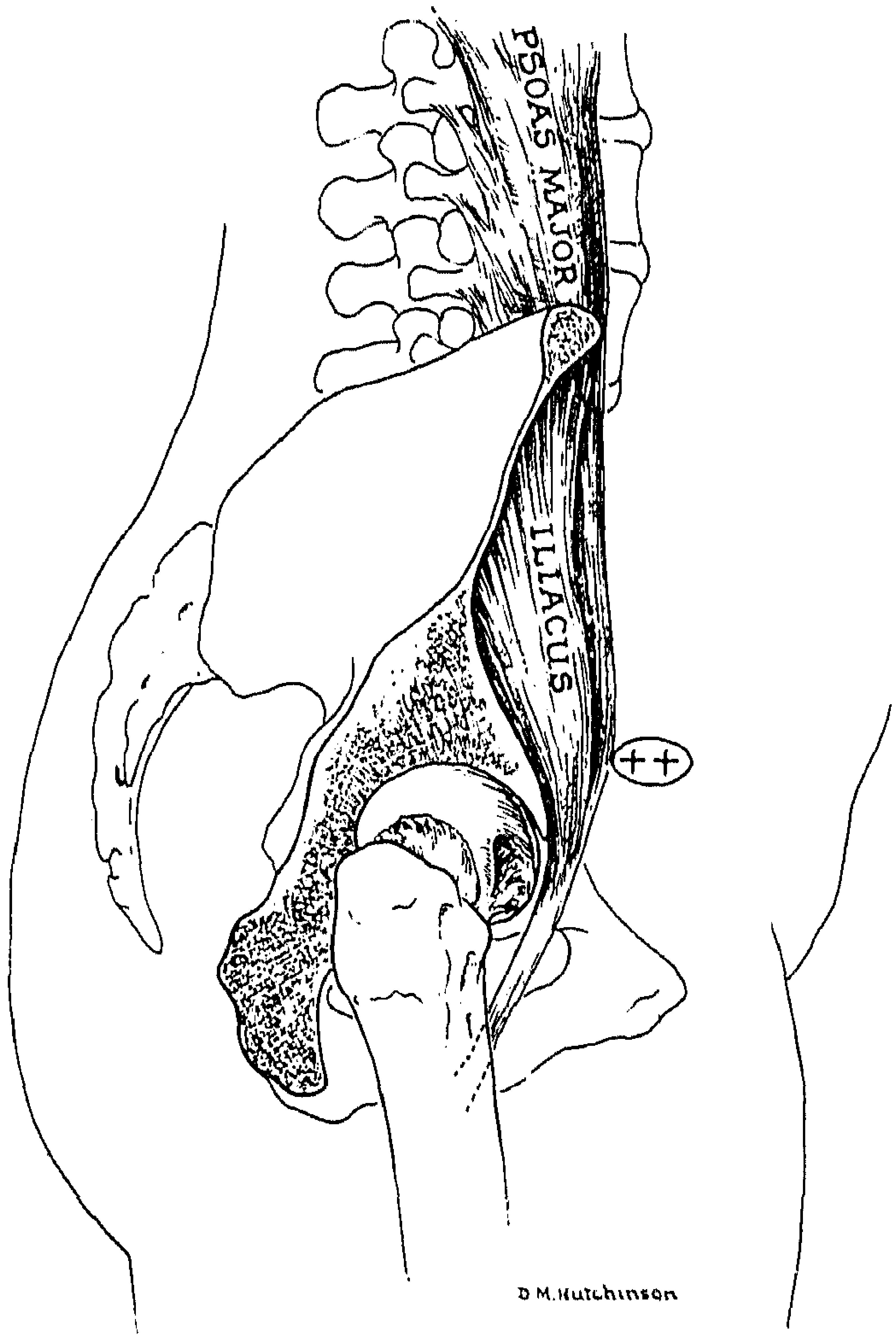


FIG. 4. — Basmajian, 1961.

The fact that in all X-ray pictures examined by us this sign (—) appeared, raises the impression that the tension in the M. ilio-psoas puts its stamp on the curvatures in the lumbar part of the spine.

In fact :

1. The position of its spots of insertion allows the M. ilio-psoas to exert a clockwise moment with respect to the support of the spine.

2. Electromyographic investigations (Basmajian, 1961) showed « that ilio-psoas remains constantly active in the erect posture in contrast to

the other large thigh muscles. It would appear that ilio-psoas functions as a ligament to prevent hyperextension of the hip joint while standing » (fig. 4).

In most of the X-ray pictures examined by us the area AC (in C the tangent is parallel to the x-axis) has with good approximation the property of the loaded elastic rod of figure 3 *b* : when this page is turned 180° on the bending point W, the same form of curvature returns.

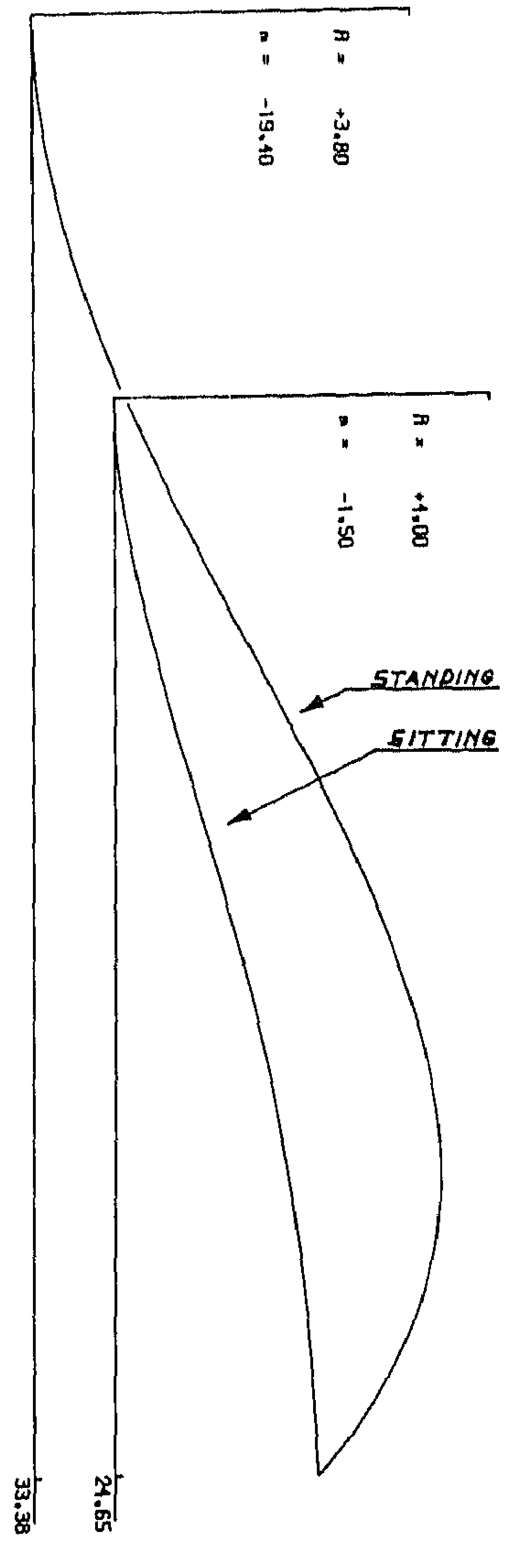


FIG. 5. — Description in standing and sitting posture of one person.

In an analogous way can be described the region above the most dorsal point of the kyphosis, the form of the spine in the natural sitting posture (fig. 5), and front-back projections (fig. 6, scoliosis).

To make possible investigation of the dorsal periphery of the spine, apparatus has been developed to record this form in an optical way on a sheet of paper, after which a characterization with parameters can be made (fig. 7).

Furthermore, changes in the form after some time can be easily found in this way (fig. 8).

Fundamental investigation in relation to the mechanical behaviour of the intervertebral disc has also been carried out by doctor Bonne and myself.

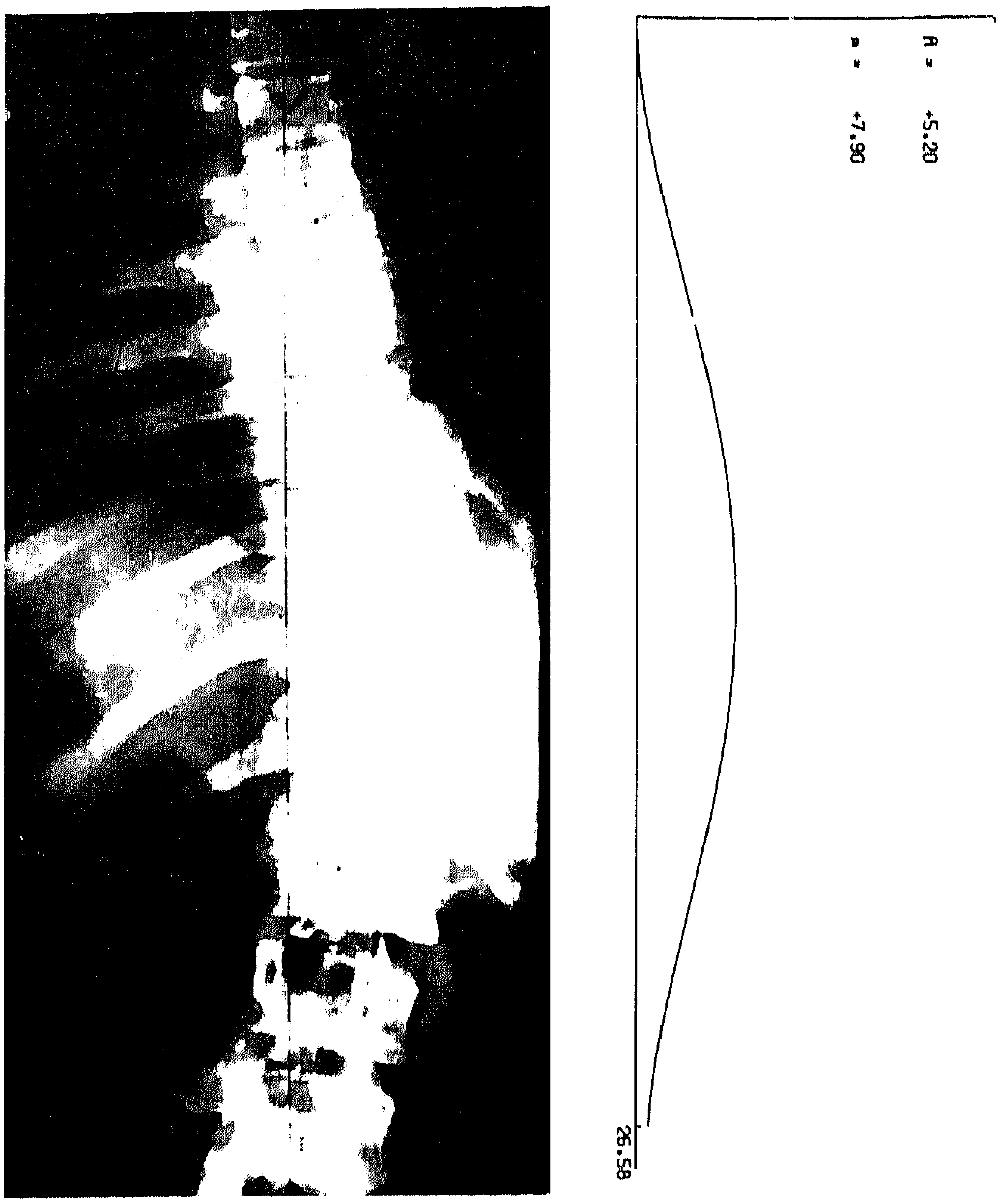


FIG. 6. — Scoliosis.

From the results I mention here :

A wear and tear mechanism in the fibres of the annulus fibrosis.

In the article of Brown, Hansen and Yorra, published in the *Journal of Bone and Joint Surgery* 1957, it was described how two vertebrae with their intervertebral disc taken from a cadaver, were exposed to an alternating bending moment under a slight axial load.

It was stated that eventually failure had occurred as the result of a straight horizontal tear parallel to the cartilaginous plates and approximately midway between them (fig. 10).

Reference to the model of a netting of crossed fibres may explain this phenomenon (fig. 11).

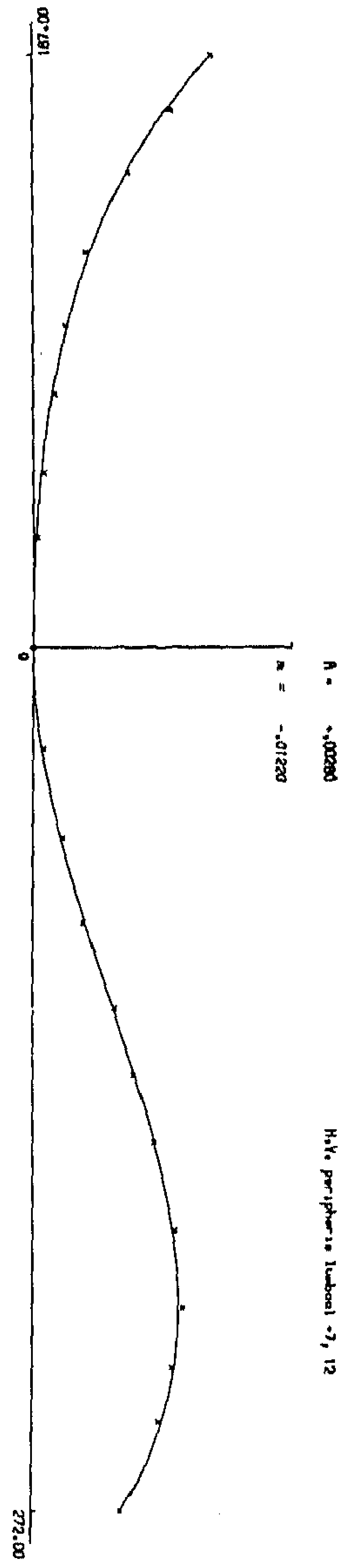
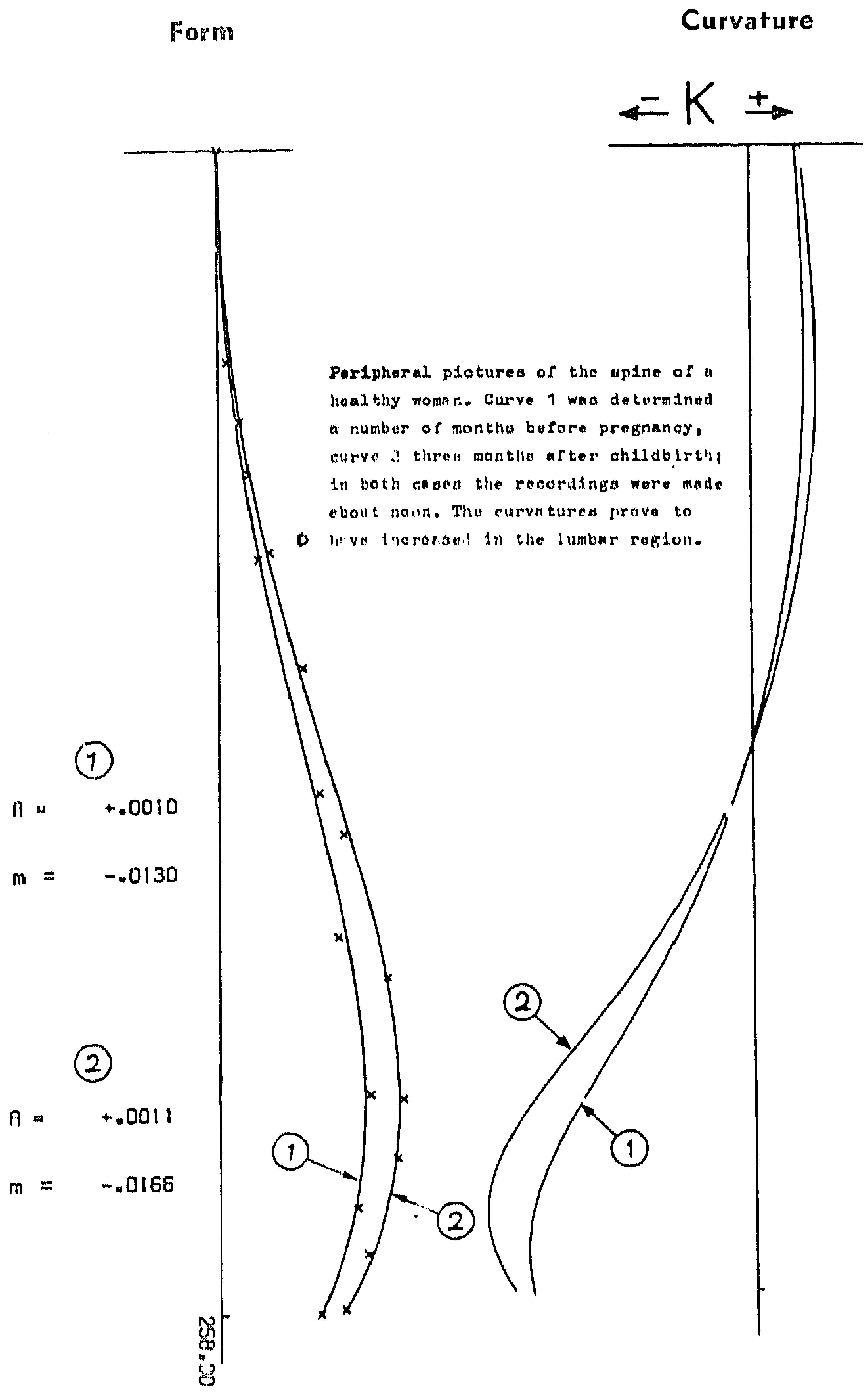


FIG. 7. — Description of the dorsal periphery of the spine.

In the position of rest, point A on fibre 1 lies against point B on fibre 2 (fig. 12).

If a bending moment acts on the vertebrae, the points A and B separate. This means that the fibres glide along each other in we think an unfavourable direction because, when the fibres are pressed together a relatively high surface stress is produced in the instantaneous area of contact.



Peripheral pictures of the spine of a healthy woman. Curve 1 was determined a number of months before pregnancy, curve 2 three months after childbirth; in both cases the recordings were made about noon. The curvatures prove to have increased in the lumbar region.

FIG. 8. — Changes in the form after some time.

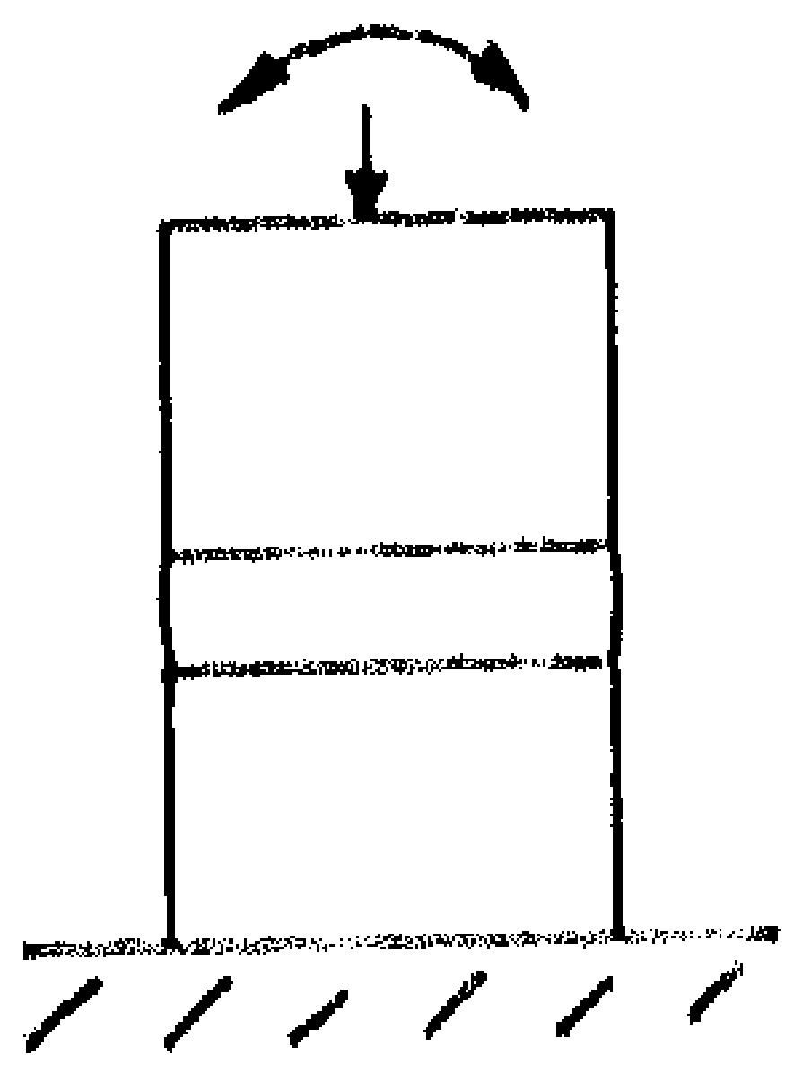


FIG. 9. — Alternating bending moment under a slight axial load.

Wear and tear will then occur in these areas.

With a mathematical derivation* we can show that, making allowance for the relative elongation of each part of each fibre separately :

1. Wear and tear is the same in points of intersection lying on a horizontal line and equidistant from the two vertebrae.

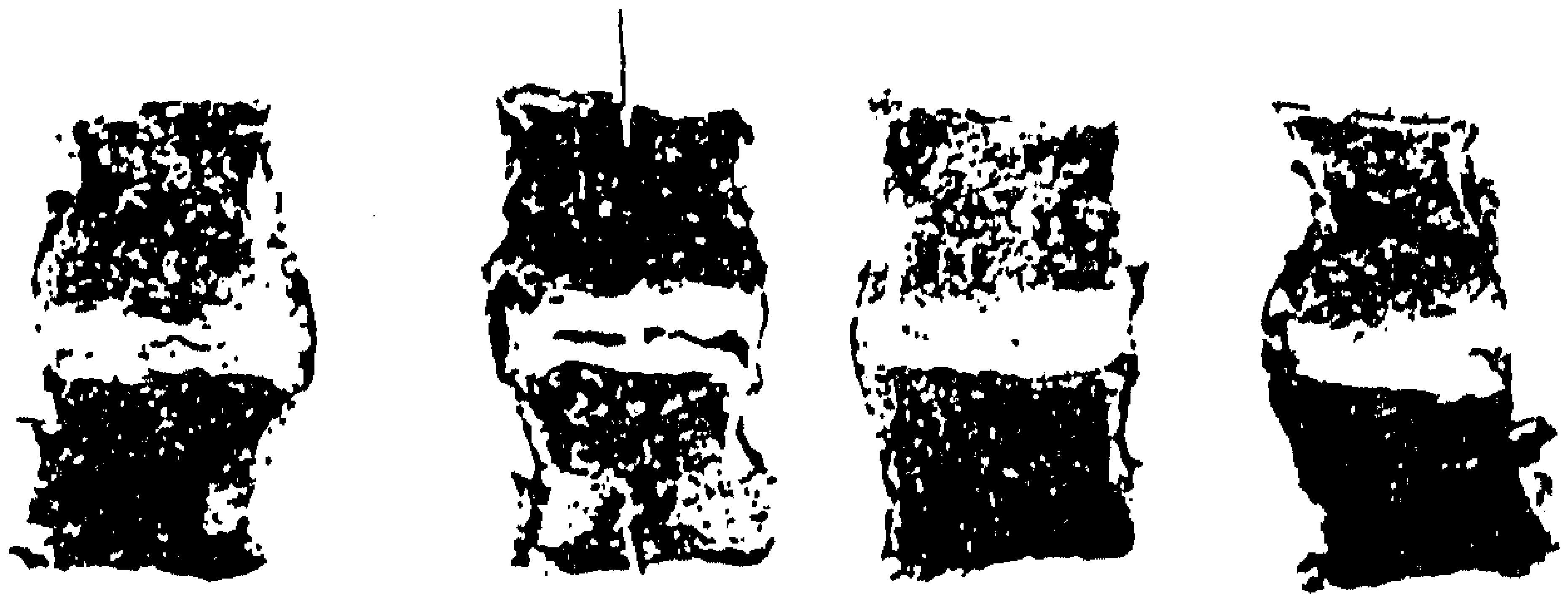
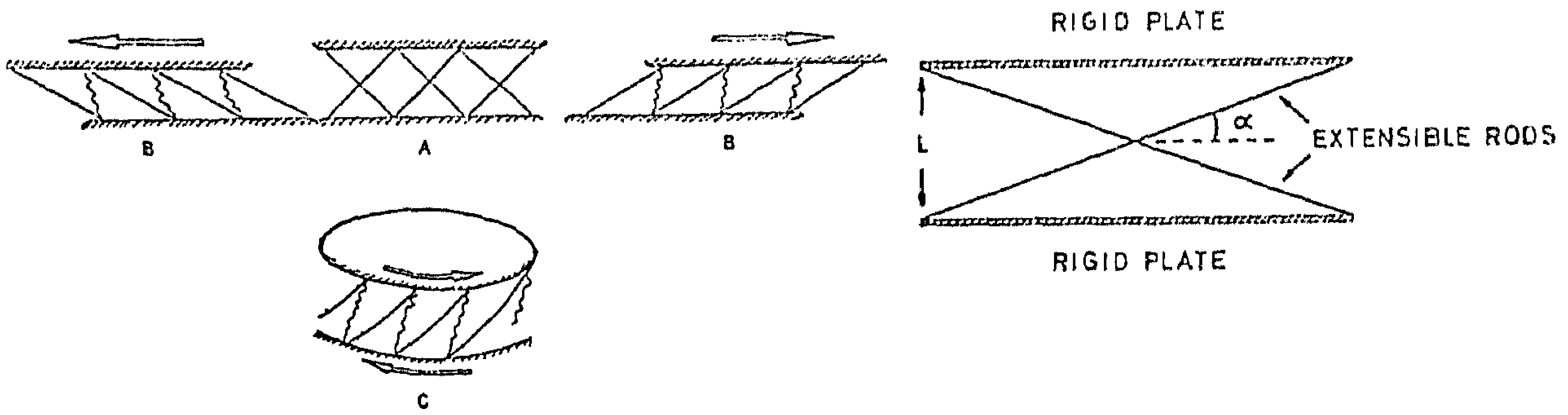


FIG. 10. — Brown, Hansen and Yorra, *Journal of Bone and Joint Surgery*, 1957.



Model of Caillet

Model of Galante

FIG. 11. — Model of a netting of crossed fibres of the annulus fibrosus.

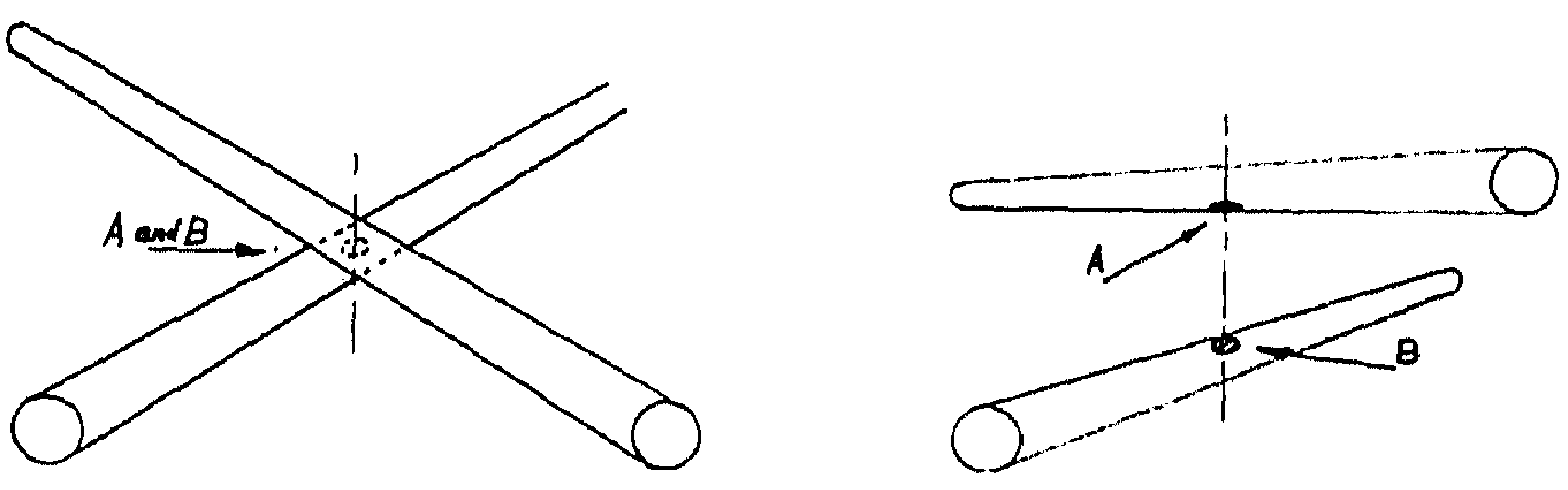


FIG. 12. — Fibres gliding along each other in the areas of contact A and B. —

2. Wear and tear in the netting is heaviest in areas in the middle of the distance between the two vertebrae.

3. Wear and tear increases linearly as the angular rotation of the two vertebrae increases.

---

* Intern Report, Eindhoven University of Technology, Netherlands, Snijders 67/6.

4. Wear and tear is greatest in the highest discs.

5. Wear and tear is greatest where the angle (α in fig. 11) between fibres and cartilaginous plate is smallest. In longitudinal arranged fibres this angle is great, viz. $\varphi = 90^\circ$, and here the expression describing this phenomenon becomes zero which leads to the conclusion that there will be no wear and tear.

Starting from the foregoing reasoning one can say that this form of wear and tear, if it occurs under physiological circumstances, will be greatest in places in the spine where :

1. The angular rotation between adjacent vertebrae is greatest.
2. The rotating movements are most frequent.
3. The pressure in the space bounded by the netting is heaviest.
4. The discs are highest.

The lumber part of the spine possesses all these properties.

Ir. C.J. SNIJDERS
Eindhoven
Pays-Bas