Advances in Biomaterials, 8

Implant Materials in Biofunction

Proceedings of the Seventh European Conference on Biomaterials, Amsterdam, The Netherlands, September 8–11, 1987

edited by

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ELSEVIER

Amsterdam — Oxford — New York — Tokyo 1988

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Implant Materials in Biofunction,
edited by C. de Putter, G.L. de Lange, K. de Groot and A.J.C. Lee,
Advances in Biomaterials, Volume 8,
Elsevier Science Publishers B.V., Amsterdam, 1988 — Printed in The Netherlands

AN INVESTIGATION INTO THE TRANSMISSION OF SHOCK THROUGH THE VERTEBRAL COLUMN

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ABSTRACT

Six fresh specimens from the lumbar vertebrae were examined under mechanical stress (a blow applied to the under surface of the lowest vertebra with or without loading of the specimen from above). To determine the relative importance of the trabecular bone and its contained marrow as 'shock-absorbers' in the spinal column, the specimens were examined after removal of spongy bone and marrow and subsequent filling with Palacos. It has been demonstrated that both bone and marrow are necessary for efficient damping, especially in the higher frequeny range, although their importance depends on the frequency in decibels of the transmitted shock. The intervertebral discs are important when blows applied to the column are light, and the normal kyphoses and lordoses also play a part in the absorption of shock.

INTRODUCTION

In the course of everyday life the vertebral column is subjected to a large number of blows which it can only sustain without damage for any length of time if its shock-absorbing mechanism is functioning satisfactorily. This capacity for shock absorption and shock transmission is still only imperfectly understood. It is quite uncertain, for instance, what the respective roles of the intervertebral disc and the vertebral body itself may be.

Our previous investigations (ref. 1) on several volunteers have established that an essential component of this mechanism is provided by the natural curves of the column. White and Panjabi (ref. 2) have also expressed the opinion that its normal anatomical lordoses and kyphoses act to some extent as shock-absorbers.

Nevertheless, the support given by these curves is, by itself, insufficient to account for its capacity to absorb shocks without being damaged. According to Inoue (ref. 3), the intervertebral discs act as shock-absorbers by assimilating compression forces applied to the vertebral column. This shock-absorbing capacity of the disc is, in part, dependent on the fact that the anulus fibrosus can expand or bulge outwards in response to the outward thrust of the nucleus pulposus when it is under pressure from its neighbouring vertebrae (ref. 2). Inoue maintains, however, that the cartilaginous end-plates play an important part too.

Trabecular bone is also supposed to contribute towards the absorption of impacts (ref. 4), and its function is considered to be greatly enhanced by the presence of bone-marrow (ref. 5).

We are here considering the question: what part does the vertebral body, including its contained marrow, play in the absorption of shock ?

MATERIAL

We used six fresh specimens from the intact lumbar column, being careful to check that there was nothing in the history of any of them to suggest pathological change. Before we began, we obtained AP and lateral x-rays of each specimen. The age of the subjects (four male and two female) lay between 15 and 66 years. Each section of the column consisted of 2 to 5 "Bewegungssegmente" (JUNGHANNS' "locomotion segment") (Table 1).

TABLE 1

Specimen	Age	Sex	Number of segments
No.1	60 years	male	4
No.2	65 years	female	5
No.3	66 years	female	2
No.4	57 years	male	3
No.5	15 years	male	2
No.6	45 years	male	2

METHODS

A machine has been constructed which makes it possible to submit segments of the vertebral column to various degrees of loading from above (Fig.1). It is also possible with this machine to apply shocks of different strengths (2-6 'g') to the lowest vertebra from underneath. In order to measure the force of the shock, we screwed accelerometers (ICP Accelerometer; PCB Model No. 303 All - Piezo- tronics - range: + 10 to - 10 g) to the spines of the lowest and highest vertebrae. The data collected were then transmitted through an AD-converter directly into a PC for further computation. The distortion of the intervertebral discs was measured with strain gauges (HBM DMD 20) stitched to them in a horizontal position, and the values of the signals registered with a yt-writer.

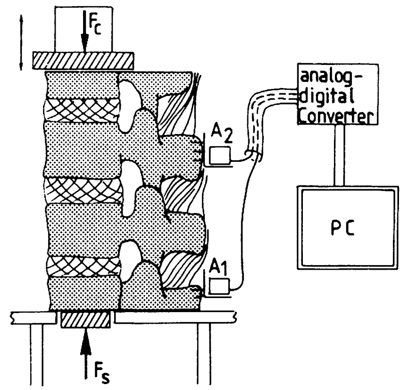

Figure 1 : Diagrammatic representation of the apparatus used for the experiment

In order to calculate the frequency-dependence of the shock attenuation, a discrete Fourier transform was used to obtain the frequency spectrum of the acceleration values. Since the maximum Fourier coefficients lay in the frequency range of 100 - 200 Hz, steps at intervals of 5 Hz from 5 to 250 Hz were more closely investigated. If one divides the value of the Fourier amplitude measured by the higher recording position with that measured by the lower, a value for the so-called "frequency response function" is obtained. The value of this function - which is measured in decibels - provides information about the relative dependency of the shock-absorbing capacity on the frequency. Negative decibel values signify efficient shock-absorption. Peaks with positive decibel values indicate resonance points, which means that at this frequency the shock is increased.

RESULTS

The ability of the specimens to absorb shock deteriorates if the experiment is continued for too long (Fig.2.). Within 35 minutes of loading the specimen with 20 kg the greater part of the frequency response function remains in the negative range; in other words, shock-absorption is efficient.If,however, as the experiment is continued, the frequency response function begins to shift into the positive range, the capacity for shock-absorption becomes less and less.

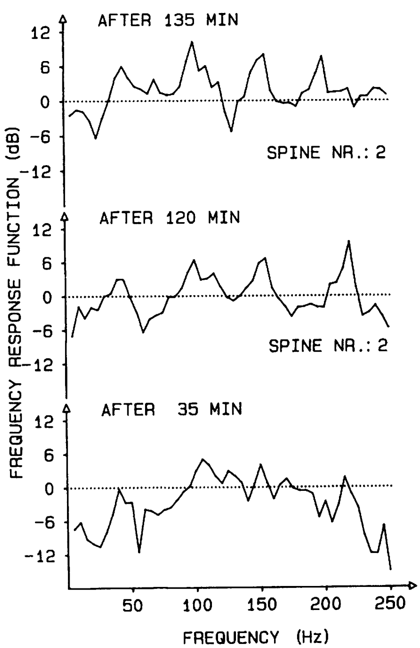

Fig. 2

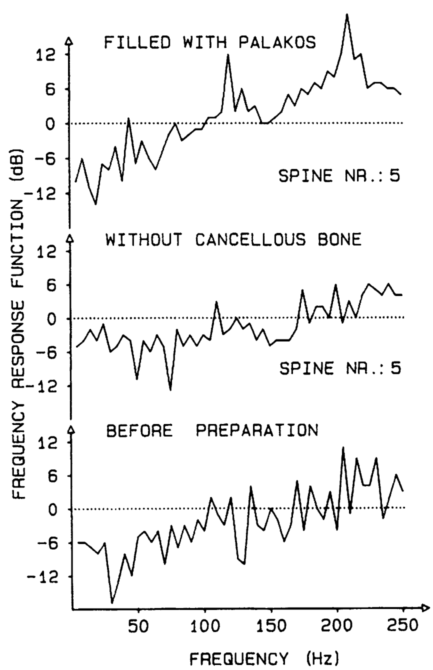

Fig. 3

Figure 2 : Frequency response function and its dependence on the duration of the experiment.

Figure 3 : Frequency response function in the intact specimen (lower curve) after removal of the spongy bone and marrow (middle curve) and their replacement with Palacos(upper curve) in specimen No.5

In order to assess the part played by the vertebral bodies in absorbing shock, we removed the trabecular bone from the middle vertebra and filled it up with methyl methacrylate (Palacos) in specimens No.5 and 6. Fig.3 shows the behaviour of specimen No.5 at all stages of the procedure: while still untouched, after the removal of the spongiosa and following its replacement with Palacos. After the spongiosa had been taken away from the middle vertebra the frequency response function showed fewer peaks. If the frequency (abscissa) is above 100 Hz, the corresponding decibel value (ordinate) is lower than with the intact specimen. In contrast to this, with frequencies below 100 Hz, the decibel value rises 1.7-fold, which corresponds to a deterioration in the damping effect. After we had filled the vertebral body with Palacos, the frequency response function (particularly in the higher frequency range) showed a 3.3-fold increase, whereas only a 1.4-fold increase was found in the lower range. Specimen No.6 responded in the same way.
The more uniform the curve of the acceleration values, the more contradictory did the measurements produced by the strain gauges become. A rhythmical oscillation was found in all cases. Entirely against our expectations, the initial response was one of contraction. With only one specimen did the oscillation of the intervertebral disc begin with expansion.

DISCUSSION

The deterioration of damping efficiency observed in the vertebral column as the stress applied to it continues, is probably due to the expulsion of fluid from the intervertebral disc into the surrounding tissues. Longer intervals between the blows allow sufficient time for this fluid to be replaced.

The effect of removing the spongiosa from the vertebral body and replacing it with Palacos clearly demonstrates the contribution of the trabecular bone and its contained marrow to the damping capacity of the whole column, the degree of which is, however, frequency-dependent. It is more important in the higher frequency range than in the lower.

The support contributed to shock-absorption by the discs comes to the fore when the blows are weak. With a frequency of more than 100 Hz - that is to say, following stronger blows - the significance of the spongiosa/marrow system increases. Judging from the damping curves obtained, the inside of the vertebral body is an important component of the damping system.

We have here an experimental confirmation of the views expressed by Patwardhan and his co-workers (1985) on the role of spongy bone; and our results also agree with the findings of Hayes et al. (1976), who attributed a similar function to the bone-marrow.

This means that all the elements of Junghanns' "locomotion segment", including both vertebral bodies, are necessary for the damping system of the spinal column to be fully effective; and only when all parts are intact and functioning properly can blows be effectively taken up and rendered innocuous.

Efficiently trained back muscles are also, of course, presupposed. They should be in a position to control the flexion of the whole column in an optimal manner (ref. 1).

The paradox of the rhythmical oscillation of the intervertebral disc, which initially shows either compression or expansion, is probably bound up with the different direction and pull of the fibres of the anulus fibrosus. Very likely its texture - the layout of the fibrous lamellae - is responsible.

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