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Why We Are Taller in the Morning than Going to Bed at Night – An *in vivo* and *in vitro* Study

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***Abstract*—**Intradiscal and intervertebral pressure transducers were developed. They were used to map the pressures in the nucleus and within the annulus of the human spinal segments. Their stress-relaxation were recorded over a period of time for nucleus pressure, applied load, and peripherial strain against time. The results show that for normal discs, pressures in the nucleus are viscoelastic in nature with the applied compressive load. Mechanical strains which develop around the periphery of the vertebral body are also viscoelastic with the applied compressive load. Applied compressive load against time also shows viscoelastic behavior. However, annulus does not respond viscoelastically with the applied load. It showed a linear response to compressive loading.

***Keywords*—**Intradiscal pressure transducer (IDPT), intervertebral pressure transducer (IVPT), mechanical strains of vertebral bone, viscoelasticity of human spinal disc.

I. Introduction

THE earliest time-dependent response of the human spinal disc has been mentioned by the Scotland Yard of the United Kingdom. Recruiters who did not qualify for the height requirements for enlisting in the police force were told to come back in the morning and thus recording an increase in height, a clear record of viscoelastic behaviour of the human spinal discs. Another incident observed by the first author goes back to early seventies when it was observed that the viscoelastic behaviour of the spinal discs, that there is an overall increase in body height overnight, and as a result of this one has to adjust the car mirror in the morning [Ranu, 1]. Also, in the absence of a gravitational effect, as the case in outer space, one would expect an increase in intervertebral disc volume. Therefore, there is a need to measure the changes in the intervertebral disc volume in humans both non-gravitational and on earth [Ranu, 1, 2 and 3].

It is known that the nucleus pulposus (Fig. 1) of the spinal disc of young human beings have gel-like characteristics. The intervertebral discs lie between the vertebral bodies, separated from them by a thin cartilaginous endplate and consisting of two main regions, an inner, soft and highly hydrated structure, the nucleus pulposus, and an outer, firm, collagenous annulus fibrosus consisting of concentric lamellae encircling the nucleus (Fig. 1). These consist of bundles of collagen fibres running obliquely from one vertebral body to the next and firmly anchoring these to the bone or the cartilaginous endplate. The angle of the collagen bundles alternates between successive lamellae thus forming a cross-woven and re-inforced structure

In order to investigate this phenomenon, young human spinal column was subjected to simulated *in vivo* loading [Ranu, 4]. Their non-linear and time-dependent response of the human disc and the vertebral column to loading were studied.

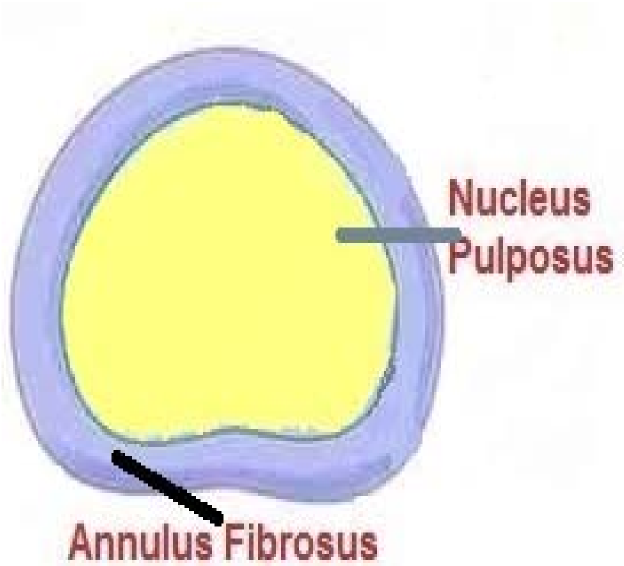

Fig. 1 Cross-section of a spinal disc showing nucleus pulposus and annulus fibrosus

II. Materials and Methods

In *in vivo* study, male (n=30) and female students (n=10) were asked to measure their heights before going to bed at night and then first thing in the morning when just getting out of bed. In *in vitro* study, an intradiscal pressure transducer (IDPT) (Fig. 2) and an intervertebral pressure transducer (IVPT) (Fig. 3) were developed to measure the pressures in the nucleus pulposus [5] and around the annulus [6]. They were capable of measuring pressures up to 3450kN.m^{-2}[5] and 4830nkN.m^{-2}[6]. Spinal segments were obtained from unembalmed young human bodies within short period after death. Radiographs were used to determine their suitability.

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Top and bottom ends of the segments were moulded in an alloy. The IVPT's (Fig. 4) were inserted to controlled depth of penetration. The instrumented needle was inserted by a specially developed probe as described by Ranu and King [5].

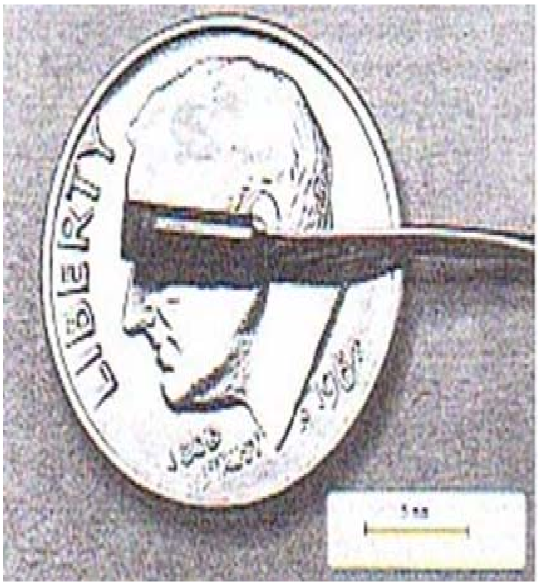

Fig. 2 Ultra-miniature pressure transducer

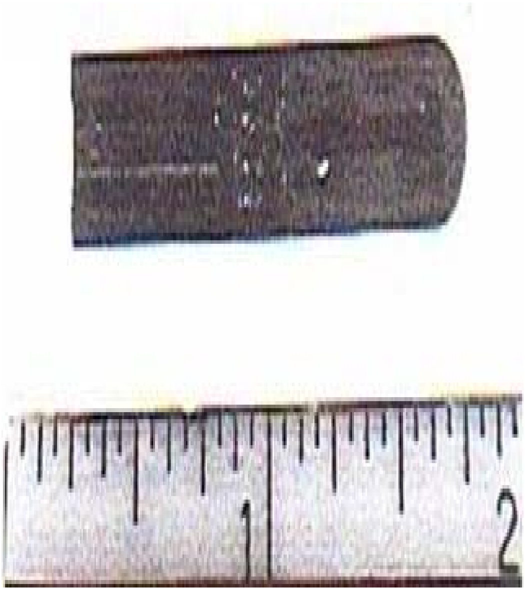

Fig. 3 Bottom of the intervertebral pressure transducer (IVPT)

Spinal specimens from lumbar region of spine were obtained from unembalmed bodies, within a short period after death. Their suitability for experimentation was determined by taking radiographs. After this, the specimens were stripped off all muscle, making sure that none of the ligaments, bone and discs was damaged.

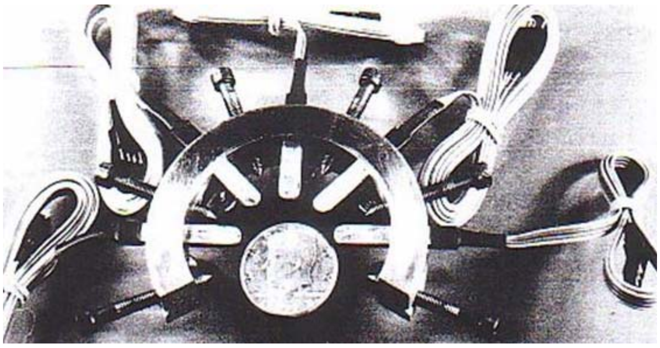

Fig. 4 Intervertebral pressure transducers in a holder (a partial ring)

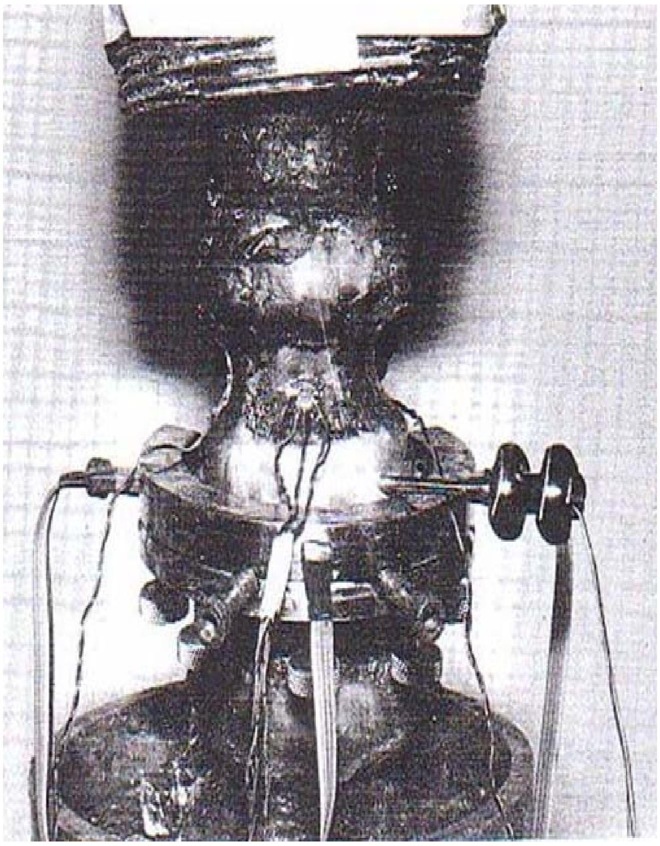

Fig. 5 Experimental test set-up

The spinal segments were prepared by moulding the top and bottom ends of the segments in an alloy (Ostalloy m.p. 47.3°C) thus providing an adequate load bearing surface for the specimen. *In vitro* testing was done by applying a quasi-static compressive load on the specimen by a Universal Testing Machine (Figs. 5 and 6). A three-dimensional loading platform equipped with a six-axis load cell was incorporated into the test set up (Fig. 6). Loading eccentricity was carried out by moving the platform in controlled increments along the two (X and Y) orthogonal axes (Fig. 6). Loading rate was 0.13 mm.s-1. The segment was loaded up to 2.0 kN Ranu [7]. The following data were recorded.

a) Intradiscal pressure as a function of time.

b) Intervertebral pressure as a function of time for anterior and lateral edges of the vertebra.
c) Strain as a function of time for anterior and lateral right and left sites of the vertebra.
d) Applied compressive load as a function of time.

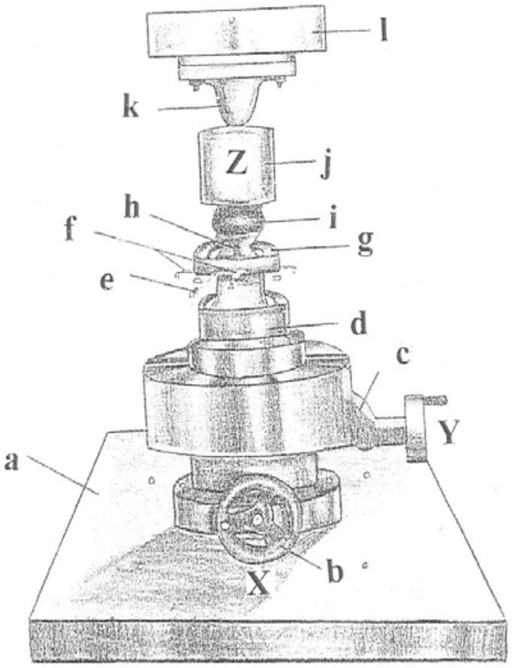

Fig. 6 Arrangement of test set-up

a. Six – axis load cell attached to the base of a testing machine.
b. Moment applicator (antero-posterior) direction [X].
c. Moment applicator (lateral) direction [Y].
d. Vertebral body holder at the bottom.
e. Intradiscal pressure transducer [IDPT].
f. Intervertebral pressure transducer [IVPT].
g. Ring holder for IVPT's.
h. Strain gauges on the vertebral body.
i. Spinal unit [Specimen].
j. Vertebral body-holder [Upper End].
k. Loading head [Specially Developed].
l. Testing machine [Cross-Head].

e) Stress-relaxation of the complete segment as a function of time

III. Results

In vivo study on students, it is observed a significant increase in their height (1-3 cm). While *in vitro* study, typical results for several cadaver illustrate the loading behaviour of the lumbar spinal segment. The variation of load, intradiscal pressure, strains, intervertebral pressures and stress-relaxation with time (Figs. 7, 8 and 9) for a 26-year-old female cadaver having no disc degeneration when loaded to a compressive load of over 2.0 kN, all show the same response to loading and to stress-relaxation (Fig. 7, 8 and 9) . However, annulus pressure does not respond to stress-relaxation (Fig. 10). This is due to the functional aspect of the annulus, i.e. it distributes the pressures evenly in all directions when the non-degenerated nucleus of the intervertebral disc is loaded in compression. It is further observed that the annulus only responds to stress-relaxation in the direction in which bulging of the disc takes place. Annulus fibres also respond to stress-relaxation.

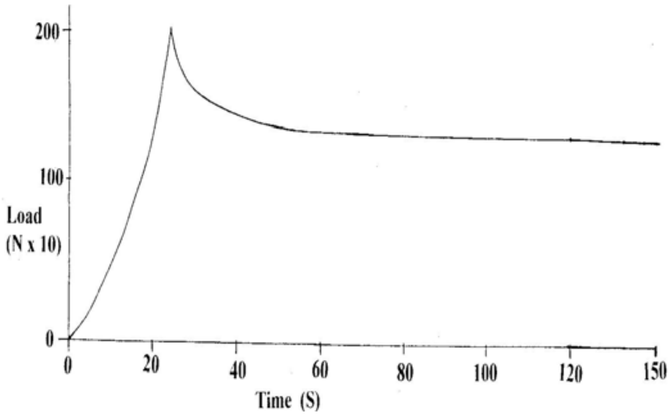

Fig. 7 Applied load on spinal segment against time. (Stress-relaxation of applied load)

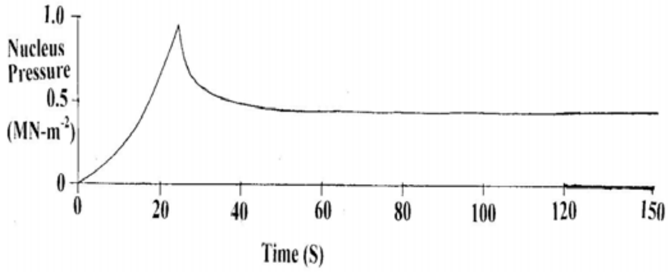

Fig. 8 Nucleus pressure against time. (Stress-relaxation of spinal disc)

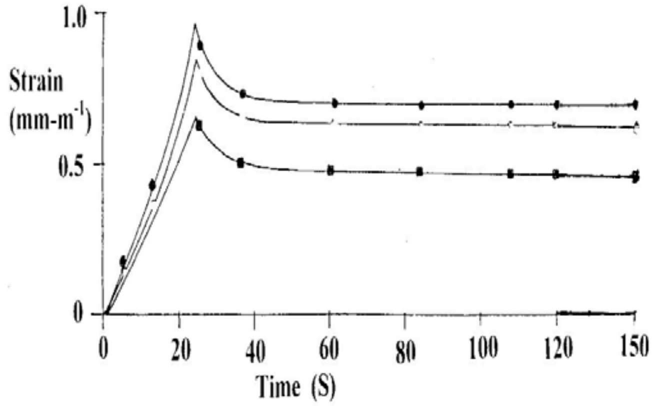

Fig. 9 Strains against time (Anterior, lateral left and lateral right). (Stress-relaxation of vertebral bone)

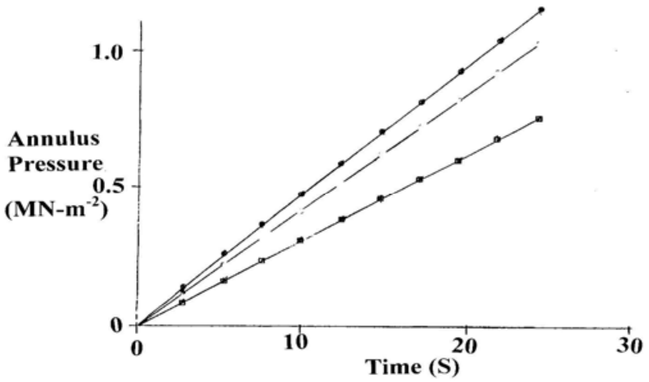

Fig. 10 Annulus pressure (as measured by IVPT's) against time. (No stress-relaxation of annulus)

Stress-relaxation results show that in more than 150 S, load relaxed by more than 800 N (42%), nucleus pressure by 0.5 MN.m-^{2} (50%) and an average strain by 0.3 mm.M^{-1} (30%). These specimens were allowed to relax for more than 40 min. Stress-relaxation of the spinal segment was recorded up to 150 seconds as there was no change in this phenomenon after this time period. It is further suggested that this stress-relaxation phenomenon of the spinal disc be used to look into monitoring the low back pain and disc degeneration.

IV. Conclusions

It is concluded that:

a) the response of the normal young lumbar spine to loading is time-dependent.
b) the normal disc and the vertebral body show a significant amount of stress-relaxation.
c) the nucleus and the annulus pressures have a linear relationship with applied compressive load. Nachemon [8] postulated that pressure in nucleus is three times the annulus pressure. However, these findings suggest that there is a one-to-one relationship between the annulus and the nucleus pressures.

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