TI 1313-66-2

# PHASE IV - INVESTIGATION OF STRENGTH OF ISOLATED VERTEBRAE

Period 30 January 1966 through 29 May 1966

PREPARED FOR:

NASA Headquarters
Human Research Branch
Washington, D. C.





BY:

Technology Incorporated
7400 Colonel Glenn Highway
Dayton, Ohio 45431

Contract No.
NASw-1313

PREPARED BY:

Jeremy F. Crocker
Senior Bioengineer

Lawrence S. Higgins, M.D.
Principal Investigator

APPROVED BY:

C. E. Oelker

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## 1. INTRODUCTION

Achievements during this quarter centered upon practical aspects of how to prepare specimens and instrumentation for testing. Pork specimens were used to develop techniques, and then a test was made of a fresh human specimen from an individual within the desired age range. Displacement transducers with frequency response suitable for dynamic tests were developed These will measure axial and lateral deflections of the specimen.

A pressure transducer with a stiff diaphragm was incorporated into a housing which minimized the volume between diaphragm and needle tip. This will be used for measurement of intradiscal pressure of specimens under dynamic as well as static testing.

Hydraulic parts to modify the testing machine for shock loading have been received. These will drive the present cylinder and ram from the present hydraulic pump, but at higher speeds.

The literature on strength of vertebrae in compression has been critically reviewed with the objective of setting criteria for the results of our static load experiments.

Minor problems were experienced with equipment during the reporting period, but the major problem remains that of obtaining first class specimens. Despite indications that the supply is improving, success in acquiring a sufficient number has not been assured.

Plans for the next quarter are to complete the instrumentation and then test the available specimens, while seeking to broaden the range of sources for specimens.

## 2. ACHIEVEMENTS DURING THIS QUARTER

### 2.1 Fresh Vertebral Specimens

Groundwork laid during the last quarter yielded a four-vertebra section of the lower thoracic and upper lumbar spine of a 40 year old man. Further search has uncovered a source with potential for fulfilling the requirements of the experimental design.

### 2.2 Test

The four vertebra section (T11, T12, L1, L2) was excised, complete with processes and ligaments, from the spine of a 40 year old male passenger who died in an automobile accident. Time of death was 4 a.m.; the specimen was removed before 10 a.m. Cause of death, established by autopsy, was rupture of the liver sustained during impact against the right-seat dash.

The section was divided into two-bone preparations by cutting across the disc between T12 and L1. The exposed surfaces were photographed with a centimeter scale in the plane of the disc to permit calculation of the cross-sectional area by planimetry (Figure 1), and both preparations were weighed. The upper surface of L1 and the lower surface of L2 were squared with a rasp to a depth that eliminated disc tissue and the vertebral end plate, exposing a uniform surface of spongiosa.

An excess of quick-setting dental plaster was applied to both surfaces, and steel plates of 1/4 inch thickness were pressed against them in a jig that maintained the plates parallel until the plaster had hardened. This preparation was then placed in the testing machine and loaded, (Figure 2).

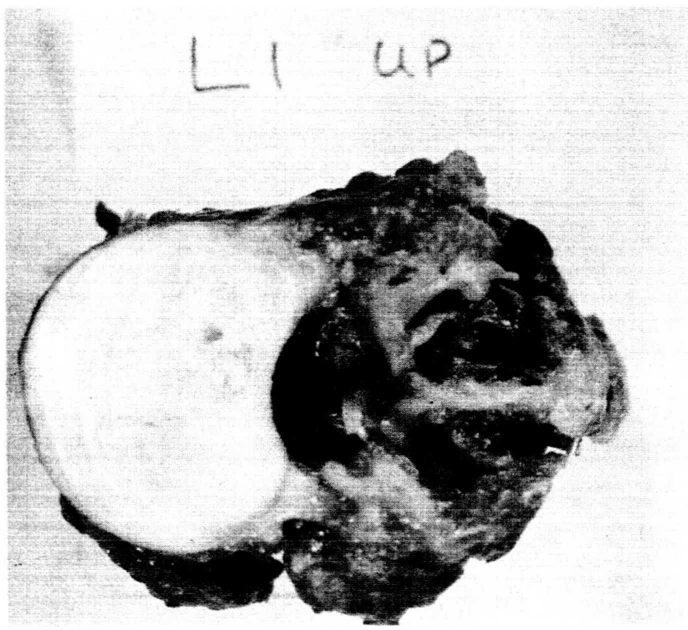



Figure 1. Spinal column of 40 year old man sliced across at the disc between L1 and T12 and then disarticulated. The centimeter scale at the left is in the plane of the disc. Lens-to-disc distance was 50 cm. Supraspinal ligament is intact at the end of the spinous process.

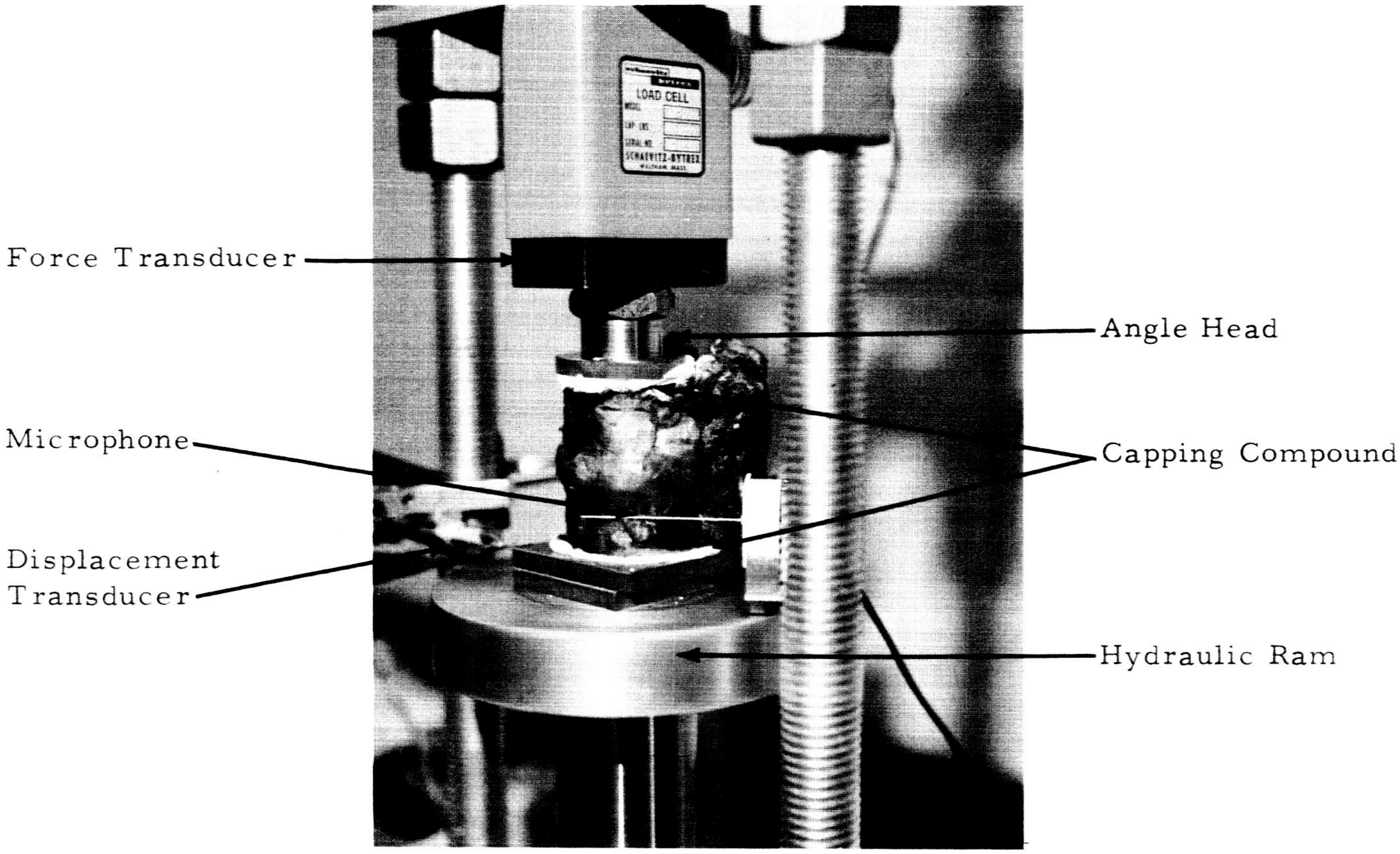



Figure 2. Human L1 and L2 Vertebrae under Load

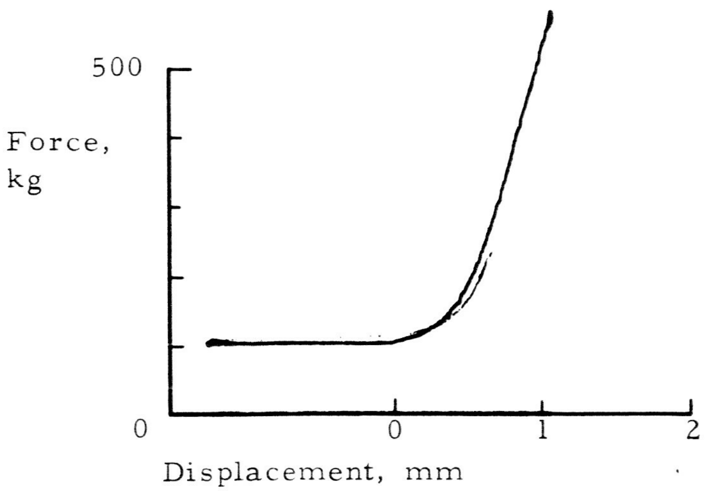



Figure 3. X - Y Recording with the Preparation above at a Ram Speed of 0.14 mm/sec.

The loading was intentionally limited to reversible levels. The reason for this decision was that the instrumentation was not complete, and thus to fail the specimen would be to lose potential data on lateral displacement and intradiscal pressure.

Instead a force-displacement curve (Figure 3) was generated by applying transducer outputs to a Houston Model HR-96 X-Y plotter. The ram was driven hydraulically at a constant displacement rate of 0.18 mm/sec to a peak force of 500 kg. When the test was complete, both the L1, L2, and the T11, T12 preparation, which had not been tested, were sealed in polyethylene bags and placed in a -20°C freezer at 5 p.m.

The L1, L2 preparation will be thawed and retested under identical conditions prior to loading to failure, thus providing an independent check on the general evidence in the literature (Perey, 1957, and Nachemson, 1960) that quick-freezing is an acceptable method of preservation of vertebral specimens. Freezing was used for transport and storage of the seven-centrum specimen from a 47 year old test pilot that was received during the last reporting period, and will be used for future specimens from new sources.

## 2.3 <u>New Sources of Specimens</u>

A mailing to coroners of the most populous of Ohio's 88 counties brought forth an affirmative response from the coroner of a county with a population over 800,000, including a major city, in which 60 to 70 autopsies per month are performed.

In addition, civil aircraft accidents remain a potential source, since CAB investigators are empowered to order autopsies. We have not been able thus far to obtain permission to excise vertebrae when no autopsy is scheduled.

### 2.4 Transducer for Intradiscal Pressure

In order to correlate pressure of the nucleus pulposus with deflection of the annulus fibrosus and thus test the analytical model of the disc developed in the last reporting period, a transducer was constructed. The design in general followed the findings of Nachemson (1960, 1963), with the addition that volume and diaphragm diameter were minimized in order to increase the frequency response of the measuring system. A 2000 psi disc transducer measuring 0.290 inches in diameter was purchased (Scientific Advances, Inc., Columbus, Ohio) and incorporated into the housing showing in Figure 4. Fluid volume between needle tip and diaphragm is only 15 cubic millimeters.

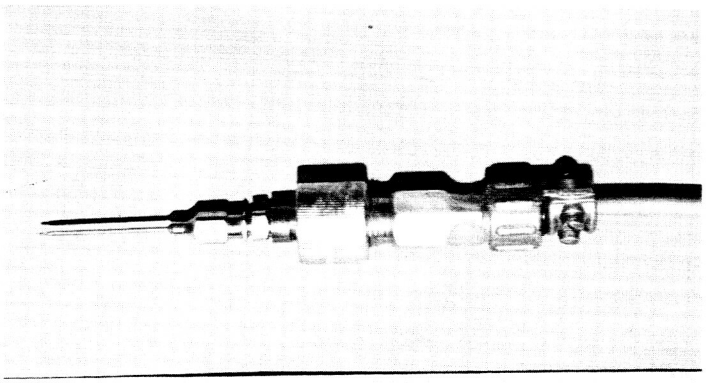


Figure 4. Intradiscal Pressure Transducer

## 2.5 Strength of Vertebrae Under Static Load

The scientific literature contains values for 300 vertebrae fractured during test. Of these, 37 vertebrae are identified as being taken from men in the 19 to 40 years age range exposed to ejection, (Chubb, 1965). Despite the inevitable omissions and discrepancies in description of the methods, we would hope to be able to derive from the results an approximate value for the strength of human vertebrae.

In particular, it was our intention to prove our experimental technique at "zero" frequency by showing correspondence of results with previous work under slowly applied load before progressing to high frequency-content (high rate of onset) inputs.

However, upon review of the literature, it proved impossible to explain the contradictions in results on the basis of the information supplied. With a two-to-one range in published values, how could we critically test whether the results of any method we chose were in agreement with others?

To resolve this problem, we adopted the following argument. Since manipulation is more likely to weaken than strengthen specimens, then the highest values are more likely to be accurate. Therefore, Ruff's values (1950), reinforced by those of Nachemson (1960), define a band of breaking strength vs position (Figure 5) for men in the 19 to 40 age range.

Perey made static tests of 22 specimens from persons (sex unstated) under 40 years of age. The values found were lower than Ruff's. His method appears

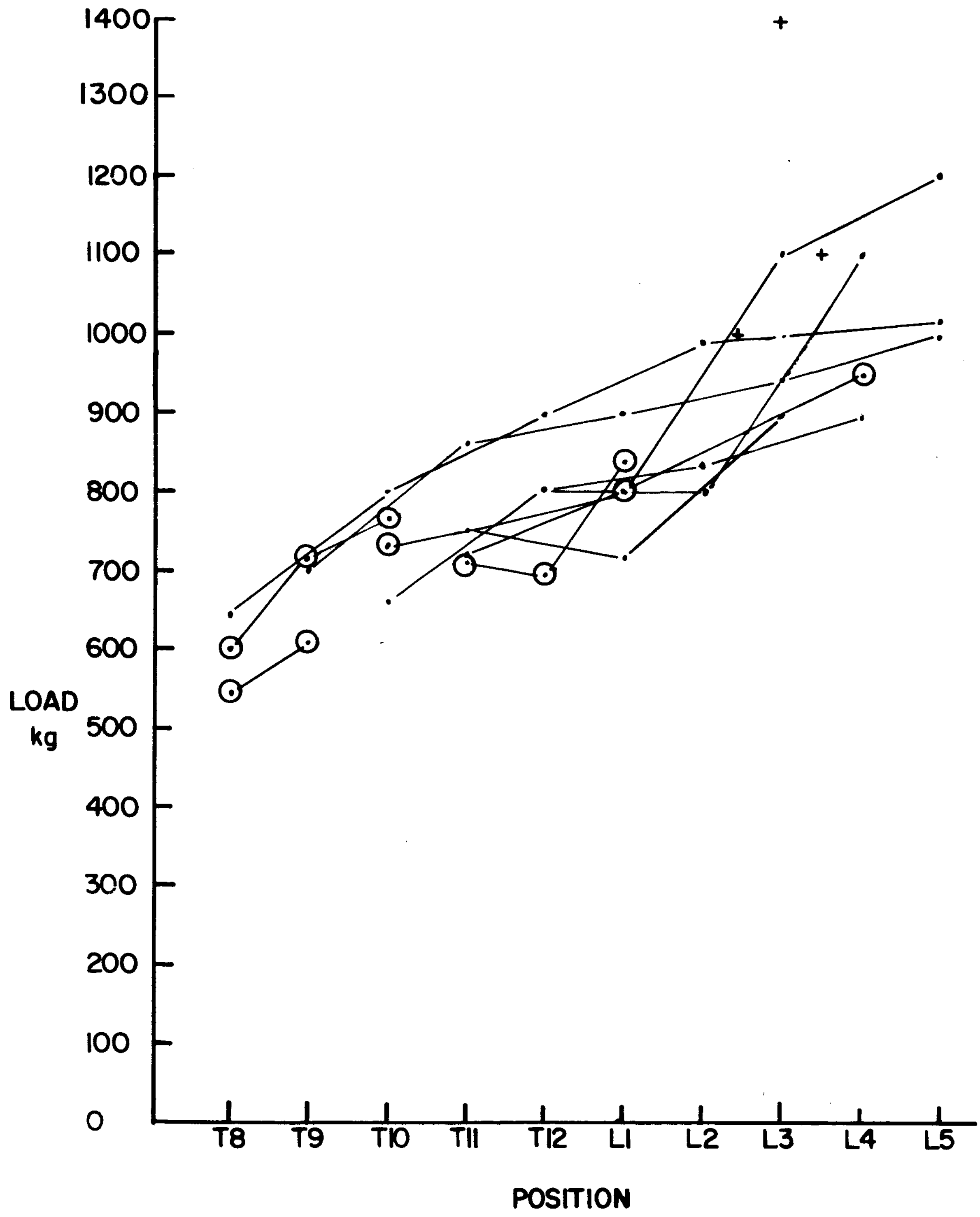



Figure 5.

Plot of the breaking load of vertebrae. Dots are the values tabulated in Figure 9. Circles indicate that the spacing between values was greater than two. The three points plotted as plus marks are from Nachemson, 1960, who used the preparation shown in Figure 12.

to have differed from Ruff's, since the frail articular processes, in addition to the centrum, were under compression. (See his Figure 16, Page 46, reproduced here as Figure 6). Perey's definition of "breaking-point" is "the greatest value for stress which can be obtained before the materials breaks". This is consistent with Ruff's definition of "breaking-load" as that at which "the stress-strain curve has its first peak", (defined graphically as $P_{Br}$ in Figure 7). Thus, we conclude that Perey's method, rather than any difference in the inherent strength of his specimens, is responsible for the lower values.

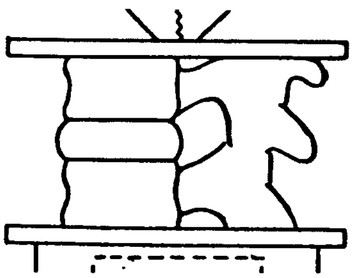


Figure 6.

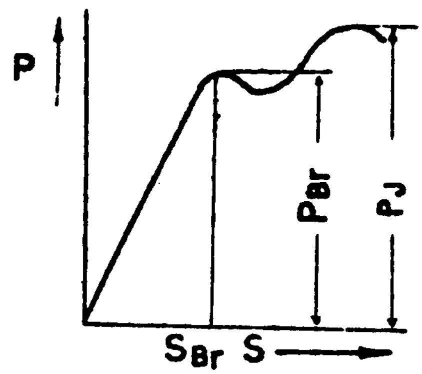



Figure 7.

Compression(s) of a vertebra under load (P). $P_j$ refers to a higher end-point used in the tests tabulated in Junk, 1925.

In studying the details of Ruff's method, we discovered a contradiction between the preparation diagrammed, and the results listed.

Portions of an English translation[1] of a thesis by Geertz (1944), who is credited by Ruff with the experimental work, provided the means to explain this

[1] The translation was obtained by Dr. H. E. von Gierke from Dr. Ruff via Dr. R. R. Coermann in Germany.

contradiction. The translation includes two graphs described verbally but omitted from Ruff's chapter. To increase their presently limited availability, the graphs are reproduced here.

The consecutive peak loads on the graph marked XXXI (Figure 8) are 690, 720, and 840 kg. This graph was recorded during test of a 6 vertebra preparation. These values are identical with those tabulated in Geertz's results (Figure 9) for the second 21 year old individual. Peak loads on the graph marked XXXII (Figure 10) from a 7 vertebra preparation are similarly related to the values tabulated for the 23 year old individual. Extrapolating, it seems likely that the values for the 36 year old also were obtained from test of a multiple-vertebra preparation. In all but one of the remaining individuals, the values are tabulated for every second vertebra, in which case the preparation must have had a repeating interval of two spinal units (vertebra-plus-disc). Thus, the "end vertebrae forming the bearing" must actually have been half-vertebrae, sawn across at mid-centrum.

This is supported by the absence of pedicles and processes on the end vertebrae in Ruff's Figure VI-54 (Figure 11). A preparation of two vertebrae and one disc would have had a two-unit repeating interval but is less likely to have been used in view of the stated objective "to determine the breaking strength of individual vertebral bodies".

In contrast, the results of Nachemson (1960) who tested preparation of two vertebrae and one disc from persons ages 20 and 22, yield somewhat higher values than Ruff's. His preparation was loaded across the centrum, (his Figure 45, reproduced here as Figure 12) and in that way differed from Perey's.

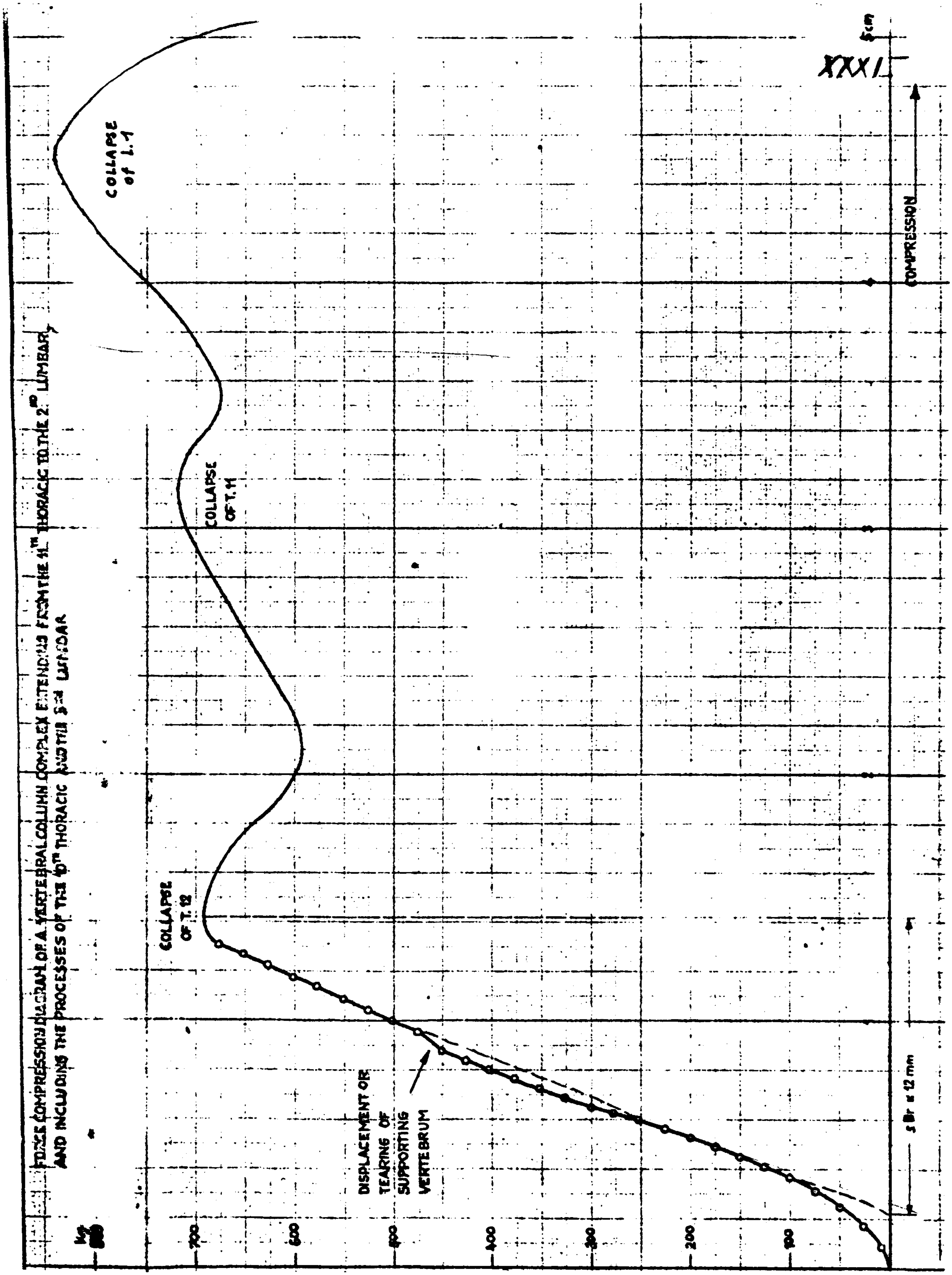
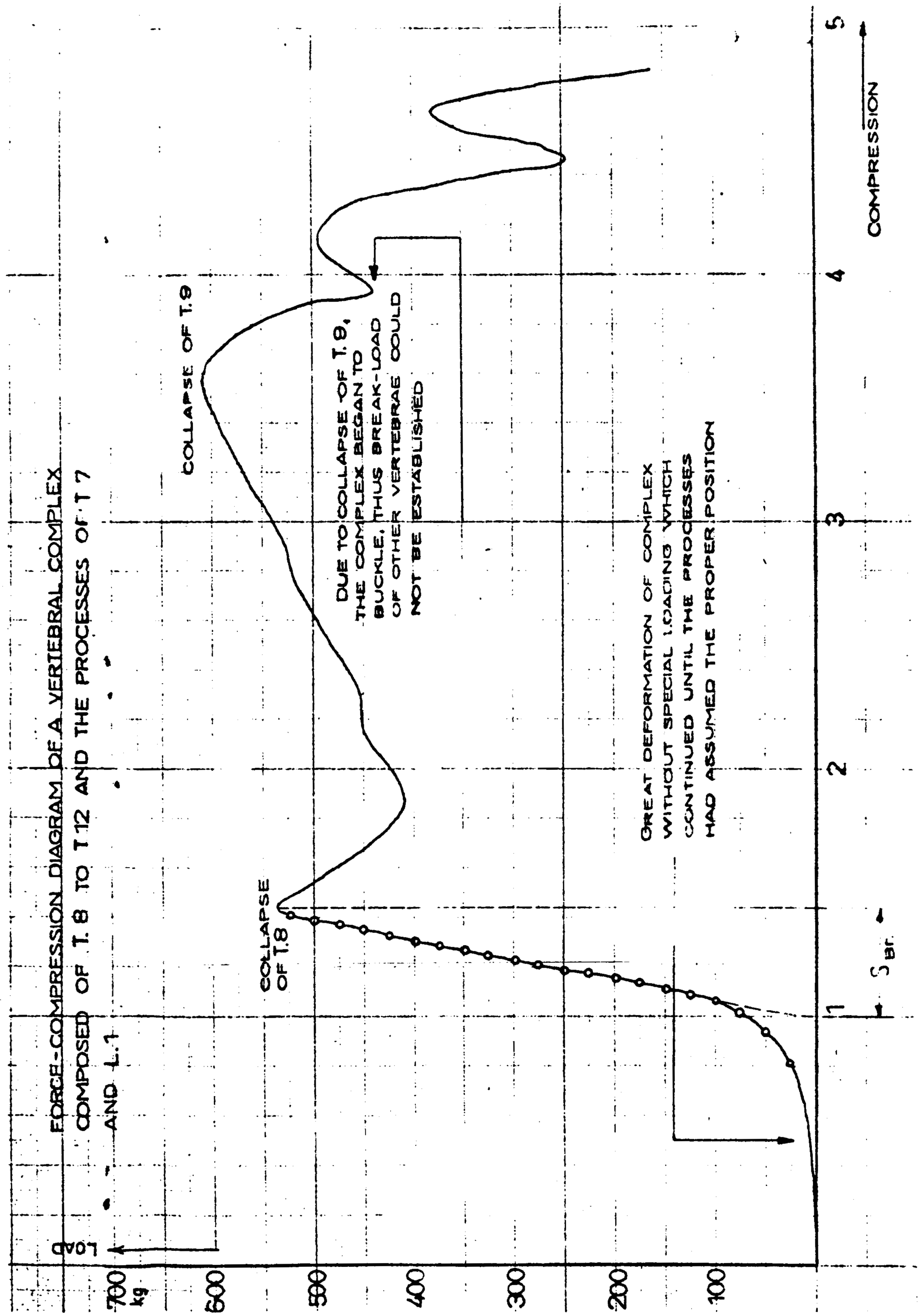

FORCE COMPRESSION DIAGRAM OF A VERTEBRAL COLUMN COMPLEX EXTENDING FROM THE 11TH THORACIC TO THE 2ND LUMBAR, AND INCLUDING THE PROCESSES OF THE 10TH THORACIC AND THE 3RD LUMBAR
kg
700
600
500
400
300
200
100
COLLAPSE OF T. 12
COLLAPSE OF T. 11
COLLAPSE of L. 1
DISPLACEMENT OR TEARING OF SUPPORTING VERTEBRUM
s Br ≈ 12 mm
COMPRESSION
5cm
XXXI

Figure 8.

| age (years) | | 19 | 21 | 21 | 23 | 33 | 36 | 38 | 43 | 44 | 46 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | breaking load (kilograms) | | | | | | | | | |
| T | 8 | | 640 | | 540 | | 600 | | | | |
| | 9 | | | | 610 | | 720 | | 700 | | |
| | 10 | | 800 | | | 660 | 770 | | | 730 | |
| | 11 | 750 | | 720 | | | | | 860 | | 755 |
| | 12 | | 900 | 690 | | 800 | | 800 | | | |
| L | 1 | 720 | | 840 | | | | | 900 | 800 | 800 |
| | 2 | | 990 | | | 800 | | 830 | | | |
| | 3 | 900 | | | | | | | 940 | | 1100 |
| | 4 | | | | | 1100 | | 900 | | 950 | |
| | 5 | | 1020 | | | | | | 1000 | | 1200 |

Figure 9. Table of breaking loads, from Geertz. Values are identical with those in Table VI-6 of Ruff.



FORCE-COMPRESSION DIAGRAM OF A VERTEBRAL COMPLEX
COMPOSED OF T.8 TO T.12 AND THE PROCESSES OF T.7
AND L.1
LOAD
700 kg
600
500
400
300
200
100
1
2
3
4
5
COMPRESSION
COLLAPSE OF T.8
COLLAPSE OF T.9
DUE TO COLLAPSE OF T.9, THE COMPLEX BEGAN TO BUCKLE, THUS BREAK-LOAD OF OTHER VERTEBRAE COULD NOT BE ESTABLISHED
GREAT DEFORMATION OF COMPLEX WITHOUT SPECIAL LOADING WHICH CONTINUED UNTIL THE PROCESSES HAD ASSUMED THE PROPER POSITION


Figure 10.

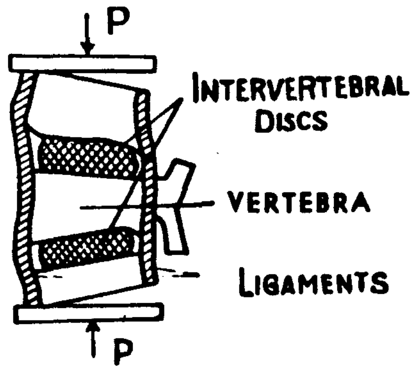


Figure 11

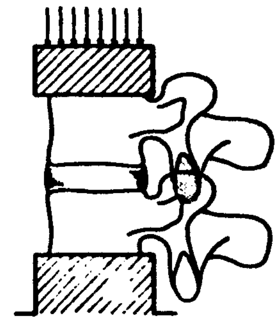


Figure 12

Nachemson also tested preparations obtained from persons aged 46 and older. These fractured at loads below 460 kilograms, showing that youth rather than the preparation itself was responsible for the higher strength of the preparations from the 20 and 22 year old persons.

From the foregoing argument, we have come to the conclusion that the 200 kilogram band defined by the results of Ruff and Geertz, plus those of Nachemson, (Figure 5) for vertebrae between T8 and L5 should serve as the criterion for the adequacy of our methods, and that specimens should be from persons in the 19 to 40 age range.

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