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THE BREAKING STRENGTH OF NORMAL AND IMMOBILIZED CORTICAL BONE FROM DOGS

By

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Osteoporosis is defined as a condition with a reduced amount of bone compared to normal. There are only few reports in the earlier literature on investigations of physical properties of bone from osteoporotic subjects, and published results are a little divergent (*Allison & Brooks* 1921, *Gillispie* 1954, *Vose, Stover & Mack* 1961). The data on physical properties of bone from osteoporotic subjects obtained up to the present are in most cases established on investigations of whole bones (*Allison & Brooks* 1921, *Gillispie* 1954).

Allison & Brooks (1921) immobilized one fore leg of dogs in different ways and were able to demonstrate an osteoporosis in the non-used bones. The authors found that the breaking strength was decreased in immobilized whole bones but normal when related to the cross section area of the bones. *Gillispie* (1954) caused disuse osteoporosis in kittens by cutting the lumbar ventral nerve roots and in hind limbs of rats by denervation. When testing the physical properties of whole osteoporotic bones from kittens, normal values for the breaking stress and modulus of elasticity were found. The breaking stress was decreased in immobilized rat bones, but the modulus of elasticity was normal.

In the last decade, however, new methods have been developed for investigations of the physical properties in smaller, more homogenous bone specimens (see *inter alia Evans* 1957). *Sedlin* (1965) has performed a comprehensive investigation of the physical properties of standardized specimens from human femurs under differing external circumstances in conjunction with storing, preparing and testing bone specimens of different shapes and sizes.

In conjunction with other investigations of different parameters of non-used bones the present author considered it to be of interest to include an investigation of the breaking strength of such bone tissue, especially as earlier investigations of the physical properties of osteoporotic bone have given somewhat varying results.

MATERIAL AND METHODS

Twelve adult mongrel dogs were used. In 9 cases one fore leg was immobilized with plaster casts. In 3 dogs one fore leg was paralyzed by brachial plexus resection. The immobilization periods varied between 4 and 112 days (Table 1). The dogs received ordinary dog food during the investigation periods and could move about freely, partly in ordinary cages and partly outdoors twice daily. They moved supported only on the three unaffected legs.

After different immobilization periods the animals were killed with an overdose of pentobarbital sodium (Nembutal). Material for testing of physical properties was taken from the distal part of both radial bones and the bone pieces were put in plastic bags and in a refrigerator (—20° C) in a fresh state and kept in this condition prior to preparation and measuring. It was shown by *Sedlin* (1965) that storing of cortical bone at —20° C does not affect its physical properties.

Table 1

Animal No.	Type of immobilization P = plaster D = denervation	Duration of immobilization (Days)
1	P	4
2	D	4
3	P	10
4	D	10
5	D	20
6	P	21
7	D	28
8	P	29
9	P	35
10	P	49
11	P	59
12	P	112

Preparation of specimen. One 5 cm long piece of both radial bones was removed proximally to a level two cm from the radiocarpal joint. These bone pieces were divided longitudinally with a handsaw in 6 separate samples from different sectors of the bone cross section in accordance with Figure 1. The further shaping of the specimens was done by manual grinding using special shaping tools described by

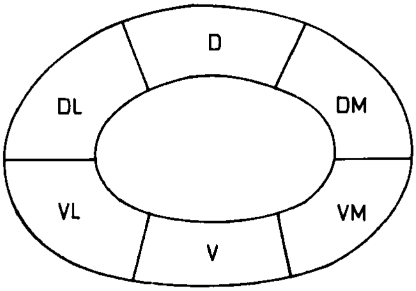

Figure 1. Outline of a cross section from the sampling region, showing the distribution of the different samples (D: dorsal; DM: dorsal-medial; DL: dorsal-lateral; V: volar; VM: volar-medial; VL: volar-lateral).

Sedlin & Hirsch (1966). During all preparation the samples were continually cooled with water.

After the final shaping of the specimens their breadth and thickness at the midpoint were measured by a friction release micrometer accurate to 0.005 mm. Each specimen had the approximate size 50 × 2 × 1 mm. Except at shaping and measuring the specimens were stored at —20° C in Ringer's solution.

Method of testing. Before the tests the specimens were brought to room temperature in their containers and maintained at room temperature for about one hour. The tests were performed in a room with controlled temperature (21° C ± 1°) and humidity (66 per cent ± 2 per cent). All specimens were placed in Ringer's solution of room temperature during the tests, according to the method used by *Sedlin & Hirsch* (1966) and *Sedlin* (1965).

All tests were performed with the same equipment (An Instron TT-CM tensile test machine with clasimeter head). The specimens were placed on supports, and loaded as simple beams with a progressive central load to failure. The rate of deformation was 1 cm/min and the distance between supports was 15 mm. A 5 × 9.81 N* full scale load was chosen, and the results were recorded at a recorder speed of 50 cm/min. The data were then obtained from the recordings.

The modulus of elasticity was calculated from the formula $\sigma = \frac{3/2PL \times 9.81}{BD^2}$ N/mm²*.

The modulus of elasticity was calculated from the formula $E = \frac{PL^3 \times 9.81}{3Iy}$ N/mm²*

(*Roark* 1954). Energy absorbed to failure was determined utilizing the area under the load-deformation diagram and a constant speed, calculated from data from load speed and the specimen size. The area under the curve was measured with a planimeter (less than 1 per cent error).

σ = Stress.	L = Span length of specimen.
P = Load.	B = Breadth of specimen.
I = Moment of inertia.	D = Depth of specimen.
E = Modulus of elasticity.	y = Deflection in bending.

* In this work Kp has been converted to N (Newton), the new international measuring standard.

RESULTS

In Table 2 the results are presented as mean differences of some physical properties of untreated and immobilized bone samples. Samples from one region of all the untreated radial bones were matched against samples from the corresponding region of all immobilized bones. In calculating the mean differences, the different immobilization times in the animals were not taken into consideration.

*Table 2. The differences in some bending properties of untreated and immobilized cortical bone from different regions of the dog radius. The values are mean differences ± standard error of the mean.**

	Mean differences control – immobilized bone		
Site of specimen †	Ultimate fiber stress N/mm^2	Modulus of elasticity $N/mm^2 \times 10^2$	Energy absorbed to failure $Nm/mm^3 \times 10^{-4}$
D	3.6 ± 10.6	—6.0 ± 9.1	1.5 ± 25.0
DL	0.0 ± 8.7	—7.1 ± 7.6	—0.4 ± 17.7
DM	—7.2 ± 7.9	—9.9 ± 6.5	8.0 ± 17.7
V	11.2 ± 7.3	—0.8 ± 6.7	23.1 ± 19.7
VL	19.7 ± 14.2	—4.7 ± 12.9	13.9 ± 17.8
VM	0.1 ± 7.8	—0.1 ± 8.0	14.3 ± 20.9
No. of samples	12	12	12

* The values are given in accordance with the new international system of measures (S.J): N = newton, Nm = newton meter.

† D: dorsal; DL: dorsal-lateral; DM: dorsal-medial; V: volar; VL: volar-lateral; VM: volar-medial.

In no sample region was there any significant mean difference of the physical properties tested in untreated and immobilized bones. Nor were there any definite trends to differences of physical properties in treated and untreated samples according to the length of the immobilization periods.

Microradiographs from the ends of the sample region showed evident signs of osteoporosis consisting of increased numbers of resorbtion cavities and/or reduced volume of trabecular bone, when the immobilization periods were at least 3 weeks (Figure 2).

In Table 3 some physical properties of untreated cortical bone from different regions of dog radius are shown. The ultimate fiber stress

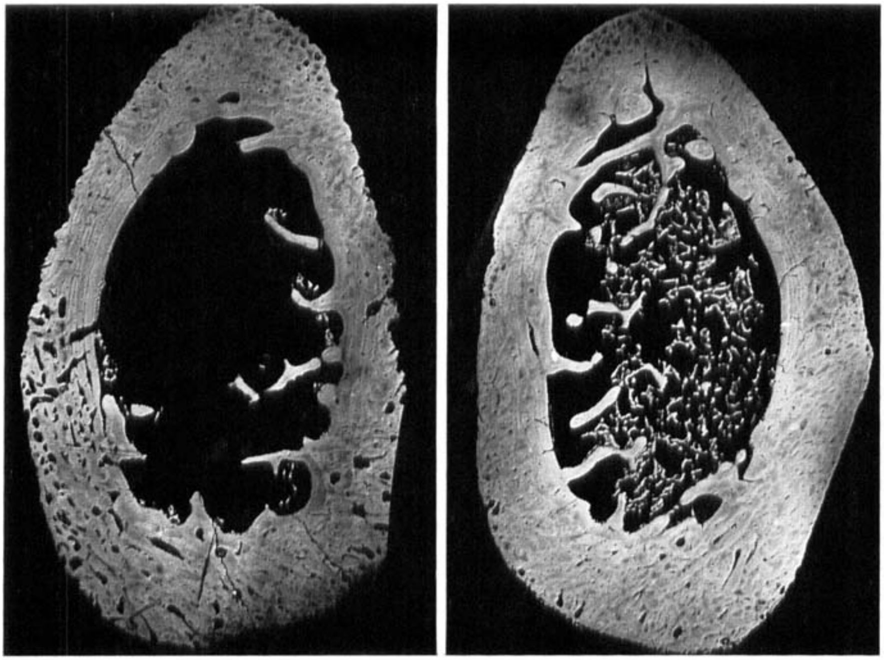

Figure 2. Microradiographs of cross sections (100 microns) taken from the distal ends of the radial bone samples from a dog with one fore limb immobilized in plaster cast for seven weeks. Note the reduced amount of bone trabeculae, the cortical thinning and the increased numbers of resorbtion cavities in the immobilized (A) bone compared with the the control (B) bone.

*Table 3. Some bending properties in different regions of untreated cortical bone from dog radius. Mean values ± standard error of the mean.**

Site of specimen	Ultimate fiber stress $N/mm^2 \times 10$	Modulus of elasticity $N/mm^2 \times 10^3$	Energy absorbed to failure Nm/mm^3
D	22.3 ± 0.9	15.2 ± 0.8	2.68 ± 0.16
DL	22.7 ± 0.5	15.5 ± 0.5	3.09 ± 0.23
DM	21.1 ± 0.7	14.6 ± 0.5	2.79 ± 0.12
V	22.6 ± 0.9	15.5 ± 0.6	2.81 ± 0.21
VL	23.1 ± 1.2	15.6 ± 0.9	2.75 ± 0.13
VM	24.1 ± 1.0	17.0 ± 0.7	2.62 ± 0.17
No. of samples	12	12	12

* For nomenclature and symbols, see Table 2.

was significantly higher in cortical bone situated volar-medial than in dorsal-medial bone (24.1 ± 1.0 and 21.1 ± 0.7 $N/mm^2 \times 10^1$ respectively). The modulus of elasticity was significantly higher in volar-medial cortical bone than in dorsal-lateral and dorsal-medial bone (17.0 ± 0.7, 15.5 ± 0.5 and 14.6 ± 0.5 $N/mm^2 \times 10^3$ respectively). Concerning the energy absorbed to failure there were no significant differences between samples from different regions.

DISCUSSION

In the actual investigation the bone samples tested were of cortical origin. There were no significant mean differences of the breaking strength in control and immobilized bone. Thus it is evident that the increased porosity noted in most of the immobilized cortical bone samples did not affect the physical properties to such an extent as to be revealed by the methods used. This fact is in agreement with earlier findings. Thus *Maj* (1938) found no correlation between the microanatomy and bending strength when the Haversian canal volume was less than 50 per cent. No significant correlation between ultimate yield loading and the size and frequency of Haversian canals was noticed by *Vose* (1962). Nor could *Sedlin & Hirsch* (1966) and *Sedlin* (1965) find any correlation between the Haversian canal volume and individual values for ultimate fiber stress and energy absorbed to failure. Only a weak nonsignificant correlation was noticed between porosity and the modulus of elasticity. However, *Evans* (1958) found that the ultimate tensile strength was lower in bone with an increased number of small osteones than in bone with a few large osteones, but he also noticed that specimens with fewer osteones occasionally were weaker than specimens with more osteones although their origin was the same bone. Also *Currey* (1959) demonstrated a negative correlation between the ultimate tensile strength and the number of Haversian system. He explained his results by the large canals in young Haversian systems which reduced the breaking area, and by the lower mineral contents in growing Haversian systems.

The increased fragility of osteoporotic bone, causing above all femoral neck, rib, and vertebral fractures, involves all of the bone including cancellous and cortical bone. The first roentgenological signs of osteoporosis in a tubular bone are usually noticed in the metaphyseal regions, where both cortical thinning and increased translucency of cancellous bone can be seen. This fact is in agreement with the findings of *Vose et al.* (1961). These authors demonstrated lower breaking stresses in 5 out of 6 intact femurs from osteoporotic subjects and lower breaking loads in all 6 osteoporotic femurs tested. They also noticed that osteoporotic femurs had a tendency to fracture near the distal end when centrally loaded, while normal femurs ordinarily fractured at the middle of the shaft at the point of loading. Their results thus indicate a lower resistence to loading in the distal metaphysis, where both cortical and cancellous bone are greatly reduced in osteoporosis. However, the same authors also demonstrated that the breaking strength of machined samples from osteoporotic femurs was 30 per cent higher than that of samples from normal femurs. Their findings thus indicate higher intrinsic breaking strength in femoral bone from osteoporotic subjects than in normal femoral cortex but lower breaking strength of osteoporotic whole femurs. They also demonstrated a higher degree of mineralization in osteoporotic cortical bone than in normal bone. They ascribed the higher intrinsic strength to the increased degree of mineralization. It was concluded that the loss of bone substance was responsible for the increased fragility. The results of the present investigation support this conclusion, as there was no significant decrease in the intrinsic breaking strength in immobilized cortical bone although in bones immobilized for at least 3 weeks there were evident signs of osteoporosis. *Allison & Brooks* (1921), also postulated that decreased breaking strength of immobilized bones is caused by diminution in the thickness of the bone rather than by any changes in the nature of the bone substance.

It might seem illogical to present the results as mean values of data from all animals independent of the length of immobilization, as definite microradiographic signs of osteoporosis were noticed only after three weeks immobilization. However, the aim of the investigation was to detect any intrinsic changes in the physical properties of the nonused bone substance. Other qualitative changes, consisting of decreased phosphorus uptake in certain microscopic cortical bone structures from immobilized metacarpal dog bones have been found by the author after an immobilization in plaster cast or by denervation for only four days (*Semb* 1966). That is why the results are given as mean values from all animals used in the investigation.

There were some differences in ultimate fiber stress and modulus of elasticity in cortical bone samples from different areas of untreated cortical bones from the radius. The samples from the volar-medial sector had the greatest strength in bending. Regional differences in physical properties of one bone have earlier been demonstrated by *inter alia Evans & Lebow* (1951), *Sedlin & Hirsch* (1966) and *Sedlin* (1965).

SUMMARY

One fore leg of twelve dogs was immobilized with plaster cast or by denervation for periods varying from 4 to 112 days. Standard specimens were prepared from different sectors of the distal part of immobilized and untreated radial bones.

Using a tensile test machine the specimens were centrally loaded to failure as supported unfixed beams. There was no significant difference between the ultimate fiber stress, the modulus of elasticity, and the energy absorbed to failure in samples from untreated and immobilized bones. The results indicate that the intrinsic strength of osteoporotic cortical bone is normal. The increased fragility of osteoporotic bone must be due to the reduced bone volume.

Untreated cortical bone from the volar-medial sector of the distal part of the radius showed increased ultimate fiber stress and modulus of elasticity.

RESUME

Une patte avant shez douze chiens a été immobilisée dans le plâtre ou par dénervation pour des périodes variant entre 4 et 112 jours. Des spécimens standard ont été préparés de différents secteurs de la partie distale de l'os immobilisé et d'os radial non traité.

Utilisant une machine de testage de la tension, les spécimens ont été chargés centralement jusqu'à rupture comme des poutres supportées non fixées. Il n'y avait pas de différence sensible entre la tension finale de la fibre, le module de l'élasticité et l'énergie absorbée jusqu'à rupture dans les échantillons d'os non traités et immobilisés. Les résultats indiquent que la force intrinsèque de l'os cortical ostéoporosique est normal. La fragilité accrue de l'os ostéoporosique doit être due au volume réduit de l'os.

L'os cortical non traite du secteur antérieur-médian de la partie distale du radius montre une augmentation de la tension finale de la fibre et du module d'élasticité.

ZUSAMMENFASSUNG

Ein Forfuss von zwölf Hunden wurde mittels Gipsverband oder Denervation für eine Zeitspanne von 4 bis 112 Tagen ruhiggestellt. Standardproben wurden von verschiedenen Abschnitten der distalen Partie von ruhiggestellten und nichtbehandelten Radiusknochen präpariert.

Unter Verwendung einer Beanspruchungsmachine wurden die Präparate als unterstützte nichtfixierte Stangen bis zum Nachgeben belastet. Kein bezeichnender Unterschied zwischen der äussersten Fiberbeanspruchung, dem Elastizitetsmodulus und der bis zum Nachgeben absorbierten Energie konnte zwischen den unbehandelten und ruhiggestellten Knochen gefunden werden. Die Ergebnisse weisen darauf hin, dass dis wirkliche Stärke von osteoporotischem Knochen normal ist. Die vermehrte Brüchigkeit osteoporotischen Knochens muss mit dem verminderten Knochenvolumen zusammenhängen.

Nichtbehandelter Knochen vom volarmedialen Sektor der distalen Partie des Radius zeigte gesteigerte Fiberendbeanspruchung und Elastizitetsmodulus.

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