Nov. 11, 1969 J. M. JURIST, JR., ET AL 3,477,422

VIBRATORY BONE DENSITY DETERMINATION METHOD AND APPARATUS

Filed Oct. 15, 1965

FIG. 1.

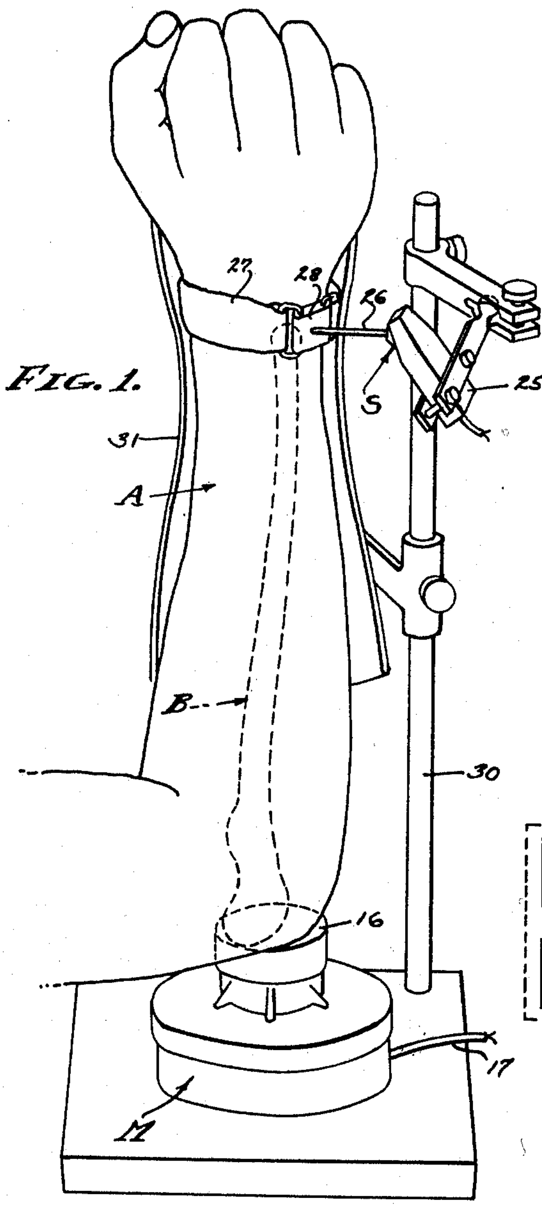
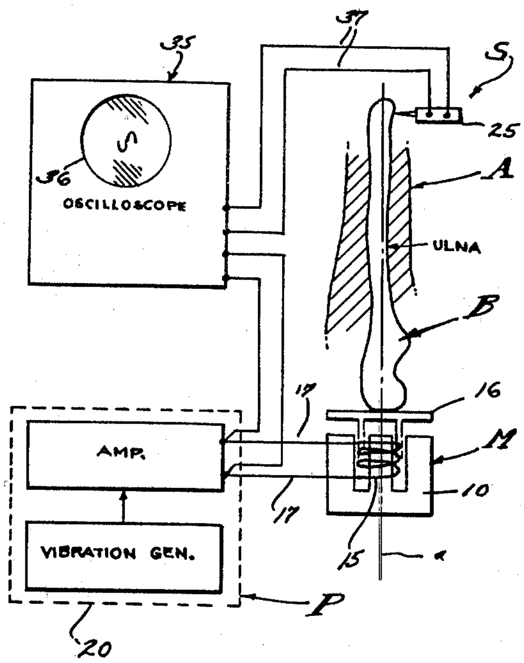


FIG. 2.



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United States Patent Office 3,477,422
Patented Nov. 11, 1969

3,477,422

VIBRATORY BONE DENSITY DETERMINATION METHOD AND APPARATUS

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Filed Oct. 15, 1965, Ser. No. 496,336
Int. Cl. A61b *5/10;* A61h *1/00;* A61n *1/32*
U.S. Cl. 128—2 14 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure relates to a diagnostic method and apparatus for determining the density of skeletal elements, namely bones, in vivo; the method comprising the steps of externally imposing vibratory motion into one end of the bone, varying the frequency of said motion and then detecting maximum resonance at the other end of the bone; the apparatus comprising spaced vibration generating and pick up means, the latter being juxtapositioned laterally of the bone in vivo and having a post-like sensing element adapted to detect both longitudinal and transverse modes of vibration in said bone, all in the presence of intact body tissues surrounding said bone.

There are many causes for bone deficiency, and the practice of geriatrics is prevalent with problems relating to the bones. For example, osteoporosis is a condition characterized by a shift in the anabolism-catabolism equilibrium of bone toward catabolism, and in senile or post-menopausal osteoporotic patients the equilibrium shift appears associated with increased bone resorption, as may be caused by defective adjustment of the body to a low calcium diet and/or defective intestinal absorption of calcium. As a result, deossification is often suspected but has not been easily detected by any of the known practices heretofore employed, and as a general rule a thirty percent accuracy is all that has been expected in the prior deossification detection practices. The significance of the above accuracy percentage approximation is that when such a percentage in deossification of trabecular bone occurs, an advanced stage has been reached and from which it is presently difficult if not impossible to reverse let alone arrest the deossification. As a matter of fact, in many cases the bone is so weakened by the deossification that the first evidence of osteoporosis is a fracture; often across the neck of the femur.

Briefly, the prior art practices include various radiographic methods, defective according to the accuracy and reliability of the present invention due to their lack of sensitivity or reliability. It is generally accepted that one cannot observe osteoporosis in a convenientional radiograph until there is at least said thirty percent depletion of mineral content from the bone. There are, however, radiographic techniques which are considered somewhat more sensitive: The first more sensitive technique involves the use of film densitometry. The least complicated of these techniques employs a metal step wedge placed beside the patient during exposure in order to provide a visual reference. A more complex of the more sensitive techniques employs controlled development combined with a photo electric densitometer. Generally, the densitometry technique is limited in accuracy because of its inability to successfully show comparative bone density in different areas which exhibit differences in surrounding soft tissue mass. Account should also be made that film contrast varies from different film batches and different sources thereof, and as a result the accuracy of the densitometry techniques range from thirty-five percent in areas with thick layers of surrounding tissue to about

fifteen percent in the areas of the phalanges for example: The second more sensitive technique uses the ratio of cortex thickness to medulla diameter of one of the cylindrical bones at a specified place as an indication of bone degeneration. The midpoint of the second metacarpal has been employed with some success. This technique is based upon the observation that osteoporosis is accompanied by a decrease in trabecular bone density and a decrease in cortical thickness. The accuracy of this method is limited due to the difficulty in locating with accuracy the boundary between the bone cortex and the medulla: The third more sensitive radiographic technique involves the measurement of the attenuation of a collimated, mono-energetic gamma ray beam to determine the bone density. One application of this technique employs the second joint of the third finger for detection because the surrounding soft tissue mass is minimal. Although this technique claims accuracy, its major disadvantages are that it is expensive, a radioisotope source is required, and rheumatoid or osteoarthritis can have thickened the joints and lead to erroneous results.

An object of this invention is to provide a feasible, practical and reliably accurate method and apparatus for the determination of the resonant frequencies in the skeletal system, whereby bone density is inherently determinable for diagnosis of osteoporosis and the like in its early stages.

It is an object of this invention to provide a method and apparatus utilizing phenomena inherent with vibratory motions to determine resonant frequencies useful in the determination of density in bone structures.

It is also an object of this invention to provide a method and apparatus wherein vibratory motion is applied at one place and sensed at another place related to bone structures and wherein resonance is advantgeously employed as a determining factor in establishing bone density.

The various objects and features of this invention will be fully understood from the following detailed description of the typical preferred form and application thereof, throughout which description reference is made to the accompanying drawings, in which:

FIG. 1 is a perspective view illustrating the apparatus as it is employed to carry out the method herein disclosed.

FIG. 2 is a block and electrical diagram showing an arrangement of components as they are employed in practicing the invention.

This invention advantageously employs vibrations in a method and apparatus for determining the density in bones (in vivo) of living persons, bones that are surrounded by flesh. Although various bones of the body can be treated according to the present invention the longest of the two forearm bones, the ulna, will be referred to herein as it is involved in the preferred form of the invention. A particular bone is singled out because bone conditions often occur generally throughout the skeletal structure, and this is the case in osteroporosis for example. Therefore, a detection means utilizing a bone such as the ulna is feasible, since observation of its effect and exact condition represents the condition of the remaining skeletal structure. In other words, osteoporosis is known to affect the entire skeleton including the ulna, all in a substantially equal manner, even though the adverse effect of the condition is most often observed at first in the pelvis.

With the above factors prevailing, osteoporosis is one affliction, at least, which can be detected and its extent determined by analysing the density of the ulna alone. To this end, therefore, the ulna B in its natural environment surrounded by flesh A is the preferred subject for analysis by this method and through the apparatus means of the present invention. In practicing this invention the ulna per se is treated as a bar, independent of other skeletal elements such as the radius, and which presents a mass that extends from the proximal end at the olecranon and coronoid processes to the distal end at the styloid process. Being surrounded by flesh A the ulna B is engagedly encased or surrounded by a damping medium of substantially uniform and known characteristics, in which case the harmonic solution of the equation of motion is $FL=KC$; where F is the resonant frequency of the ulna, L is the ulnar length, C is the speed of vibration (sound) in the ulna, and K is the proportional constant based upon environmental and geometrical considerations. By using Young's modulus and since elasticity is a function of density, the transmission of vibrations and/or speed of sound is a function of density. Therefore, the product of resonant frequency and length is a function of density, and all of which is applicable in the determination of density in the ulna as will now be described.

This method of vibratory bone density determination is carried out in two basic steps provided for the exposing of an otherwise hidden factor necessary for the determination of bone density. As is pointed out above, the factors of frequency F and length L must be known in order to practice the calculations referred to; the second factor L being externally apparent while the first factor F is hidden and/or an unknown factor. That is, a person's arm is easily measured in order to determine the length factor L with reasonable accuracy; while on the contrary the body flesh A surrounds the ulna B in the form of a damping medium and thereby prevents direct inspection of the said bone. Therefore, the primary objective of this method is to expose the frequency factor F without actual physical inspection of the ulna B per se. In other words, the method involves the accurate determination of bone density in the ulna B without disturbing the body flesh A, and to this end vibrations are applied and detected and thereby made known as they are related to bone length L and other known constants C and K.

In accordance with the first step of the method, vibratory motion is imposed externally and longitudinally to one end of the ulna B, and as a practical matter to the olecranon process. The vibratory motion is applied at a constant amplitude and is selectively variable to different frequencies. In practice the vibratory motion is sinusoidal and introduces vibratory motion into the proximal end of the ulna B.

From the above description of the first step of the method it will be seen that the mass comprising the ulna B is made to vibrate longitudinally as a bar, and that the induced vibratory frequency therein is selectively adjustable. In accordance with the second step of the method the said frequency is adjusted to a maximum amplitude response in the mass comprising the ulna B, or to the closest detectable approximation thereof which is equal to the resonant frequency F. Accordingly, the maximum amplitude as caused by seeking out the resonant frequency is detectable audibly through normal hearing, and preferably through instrumentation that unerringly indicates maximum amplitude in the ulna B. As a result of these two steps, with the adjustably selected and therefore known frequency of constant amplitude induced into the ulna B, the resonant frequency of said bone is exactly determined, and to which the density of the bone is directly related.

In accordance with the apparatus vibratory motion is produced by a motor M driven by a power means P, there being a sensor means S for the determination of vibratory motion in the ulna B. The motor M is disposed so as to introduce longitudinal vibrations into the proximal end of the ulna and the power means P drives the motor M so as to produce a constant amplitude and selectively variable motion for introduction into the ulna B. As is shown, the sensor means S is located at the remote end of the ulna B, at the styloid process, where it can detect transmission of wave motion longitudinally through the length of the ulna B.

The motor M is a vibration generator that can vary widely as circumstances require and which is adapted to produce a constant amplitude wave motion at varied frequencies. In practice, an operational range of frequencies is chosen throughout which the motor M is infinitely variable by means of selective adjustment with an indication of the frequency imposed thereby. In its preferred form the motor M is an electronic shaker of the type commonly referred to as an audio generator, although sound is not necessarily produced thereby. Thus, the motor M is shown as comprising a field **10** and an armature **15** reciprocably carried to oscillate along an axis *a* disposed concentrically within said field. The armature supportably carries an anvil **16** which it transports reciprocally on said axis *a* at said constant amplitude. In practice, a comfortable position for the disposition of a person's ulna is a vertical position, in which case the axis *a* is vertically disposed. The armature **15** is powered through conductors **17** as indicated.

The power means P can vary according to the type of vibration generator used and accordingly is adapted to drive the motor M at a constant amplitude and at varied frequencies. Although a purely mechanical motor M and power means P is feasible, the preferred electronic form is shown and in which case the means P is an electrical vibration generator and amplifier. Therefore, and in the preferred form, this invention provides a constant amplitude variable frequency power amplifier with voltage output leads connected to the conductors **17** that power the motor armature **15**. The output of amplifier **20** is sinusoidal at a constant voltage so as to establish a constant amplitude wave motion reciprocably along axis *a*, and the said output of amplifier **20** is adjustably selective throughout the operational range of the apparatus. Any suitable power amplifier having these required specifications is useable.

The sensor means S is provided for the detection of the vibratory motion induced by the motor M and power means P and in the broadest sense can be the investigating person's hearing or sense of touch. That is, it is feasible to detect maximum resonance with one's own sensing capabilities. However, all persons are not furnished with acute sensing abilities and for this reason it is most practical to employ the sensor means S, whereby any person can observe the results with surety. Accordingly, the sensor means S involves a vibration pickup **25** at the styloid process and which is responsive to the transmission of vibration longitudinally of the ulna B along the axis *a*. The pickup **25** can be an audio type crystal transducer, with a movable sensing element **26** extended laterally to engageably contact the most prominent projection of the styloid process. In practice, a wrist band **27** embraces the styloid process and carries a plate **28** engaged flatly through the skin and against the prominently projecting bone, and separated from the said bone only by the thin layer of skin, the skin layer being minimal at this bone prominence. As shown, the sensing element **26** is attached to the plate **28** and consequently transmits vibrations to the pickup **25**. As is clearly illustrated the element **26** is a post-like part disposed on an axis substantially perpendicular to the axis *a*, the pickup **25** being supported upon a motionless stand **30**, having a rest **31** to guidably position the forearm being examined. The pickup **25** can be suitably disposed depending upon its own axis of sensitivity, all as circumstances require. It is contemplated that the pickup **25** can be mounted upon the plate **28** so as to be directly sensitive and not subject to extraneous vibrations. For example, the signal is transmitted into the ulna in a longitudinal direction, while the bone vibrates in either a longitudinal mode or a transverse mode, or both modes. Consequently, this method and apparatus is operable when the pickup **25** is oriented to detect either or both of these two possible modes of vibration.

The pickup **25** is combined with intensity detection means **35** adapted to indicate when maximum amplitude response is reached in the ulna B. The form of means **35** can vary and a preferred form thereof is shown wherein an oscilloscope **36** is connected to the pickup **25** by conductors **37** and related to the wave motion applied through conductors **17**, whereby maximum response is visibly displayed. Thus, the variable power means P is adjusted until a maximum amplitude response is displayed by the oscilloscope **36**, whereupon a close approximation equal to the resonant frequency F is determined as it exists in the ulna B.

In actual practice the frequency factor F was empirically determined by examining excised ulnas of varying known density, and the resonant frequency for each ulna was determined graphically to show that FL is the increasing function of density. With said graphic information density in ulnas in vivo were proven by measurement of length L and by the instant and accurate determination of maximum resonant frequencies F therein. However, with the method and apparatus of the present invent it is now a simple matter, and practical from a clinical point of view, to employ FL directly as a measure of bone condition instead of converting it to density and then comparing the density to established norms.

Having described only a typical preferred form and application of our invention, we do not wish to be limited or restricted to the specific details herein set forth, but wish to reserve to ourselves the modifications or variations that may appear to those skilled in the art.

Having described our invention we claim:

1. The method of exposing the resonant frequency of a bone in vivo and useful in the determination of bone density, and comprising:

(a) imposing vibratory motion into one end of the bone from an external source;

(b) and varying the frequency of said vibratory motion and detecting the maximum resonance at the other end of the bone;

(c) whereby the resonant inherencies of said bone are made known.

2. The method of exposing the resonant frequency of a bone in vivo and useful in the determination of bone density, and comprising:

(a) imposing vibratory motion longitudinally into one end of the bone from an external source;

(b) and varying the frequency of said vibratory motion and detecting the maximum resonance at the other end of the bone;

(c) whereby the resonant inherencies of said bone are made known.

3. The method of exposing the resonant frequency of a bone in vivo and useful in the determination of bone density, and comprising:

(a) imposing vibratory motion longitudinally into one end of the bone from an external source;

(b) and varying the frequency of said vibratory motion and detecting the maximum resonance perpendicular to the other end of the bone;

(c) whereby the resonant inherencies of said bone are made known.

4. The method of exposing the resonant frequency of the ulna in vivo and useful in the determination of bone density, and comprising:

(a) imposing vibratory motion into the ulna at the proximal end thereof from an external source;

(b) and varying the frequency of said vibratory motion and detecting the maximum resonance at the distal end of said ulna;

(c) whereby the resonant inherencies of said ulna are made known.

5. The method of exposing the resonant frequency of the ulna in vivo and useful in the determination of bone density, and comprising:

(a) imposing vibratory motion longitudinally into the ulna at the proximal end thereof from an external source;

(b) and varying the frequency of said vibratory motion and detecting the maximum resonance perpendicular to the distal end of said ulna;

(c) whereby the resonant inherencies of said ulna are made known.

6. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) vibration generating means transmitting vibratory motion longitudinally on an axis and engageable with one end of the bone from an external source;

(b) means varying the vibratory frequency of said first mentioned means;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said axis and to the side of and at the other end of the bone and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonance of the bone;

(d) whereby the resonant inherencies of said bone are made known.

7. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) vibration generating means transmitting vibratory motion longitudinally on an axis and engageable with one end of the bone from an external source;

(b) means varying the vibratory frequency of said first mentioned means;

(c) and vibration pickup means held spaced from said first mentioned means and disposed on an axis perpendicular to and juxtapositioned laterally of and to the side of said first mentioned axis at the other end of the bone and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonance of the bone;

(d) whereby the resonant inherencies of said bone are made known.

8. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) a shaker with an anvil reciprocably operable on an axis and engageable at and with one end of the bone to vibrate the bone;

(b) drive means to reciprocate the shaker at constant amplitude and variable frequencies embracing the resonant frequency of said bone;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said axis and to the side of and at the other end of the bone and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonance of the bone;

(d) whereby the resonant inherencies of said bone are made known.

9. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) a shaker with an anvil reciprocably operable on an axis and to engageably oscillate against one end of the bone having a longitudinal axis substantially aligned with the first mentioned axis to vibrate the bone;

(b) drive means to reciprocate the shaker at constant amplitude and variable frequencies embracing the resonant frequency of said bone;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said first mentioned axis and to the side of and at the other end of the bone and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonance of the bone;

(d) whereby the resonant inherencies of said bone are made known.

10. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) a shaker with a horizontally disposed anvil reciprocably operable on a vertical axis to engageably oscillate against one end of the bone having a longitudinal axis substantially aligned with the first mentioned axis to vibrate the bone;

(b) drive means to reciprocate the shaker at constant amplitude and variable frequencies embracing the resonant frequency of said bone;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said first mentioned axis and to the side of and at the other end of the bone and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonance of the bone;

(d) whereby the resonant inherencies of said bone are made known.

11. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) a shaker with an anvil reciprocably operable on an axis and engageable with one end of the bone to vibrate the bone;

(b) drive means to reciprocate the shaker at constant amplitude and at adjustably variable frequency embracing the resonant frequency of said bone;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said axis and to the side of and at the end of the bone remote from the anvil and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the transmission of vibration therethrough and especially to determine the adjusted frequency of maximum resonance in the bone;

(d) whereby the resonant inherencies of said bone are made known.

12. Apparatus for detecting the resonant frequency of a bone in vivo and useful in the determination of bone density, and including:

(a) a shaker with an anvil reciprocably operable on an axis and engageable with one end of the bone to vibrate the bone;

(b) drive means to reciprocate the shaker at constant amplitude and at adjustably variable frequency embracing the resonant frequency of said bone;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said axis and to the side of and at the end of the bone remote from the anvil and having a post-like sensing element disposed normally to and engaged over the bone and detecting the transmission of both longitudinal and transverse modes of vibration therethrough and especially to determine the adjusted frequency of maximum resonance in the bone;

(d) whereby the resonant inherencies of said bone are made known.

13. Apparatus for detecting the resonant frequency of the ulna in vivo and useful in the determination of bone density, and including:

(a) a shaker with a longitudinally disposed anvil reciprocably operable on a vertical axis to engageably oscillate against the proximal end of the ulna having a longitudinal axis substantially aligned with the first mentioned axis;

(b) drive means to reciprocate the shaker at constant amplitude and variable frequencies embracing the resonant frequency of said ulna;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said aligned axis and to the side of and at the styloid end of the ulna and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the maximum resonant frequency therein;

(d) whereby the resonant inherencies of said bone are made known.

14. Apparatus for detecting the resonant frequency of the ulna in vivo and useful in the determination of bone density, and including:

(a) a shaker with a longitudinally disposed anvil reciprocably operable on a vertical axis to engageably oscillate against the proximal end of the ulna having a longitudinal axis substantially aligned with the first mentioned axis;

(b) drive means to reciprocate the shaker at constant amplitude and adjustably variable frequencies embracing the resonant frequency of said ulna;

(c) and vibration pickup means held spaced from said first mentioned means and juxtapositioned laterally of said aligned axis and to the side of and at the styloid end of the ulna remote from the anvil and having a post-like sensing element projecting substantially normal to and into engagement with said other end of the bone and detecting the transmission of both longitudinal and transverse modes of vibration therethrough and especially to determine the adjusted frequency of maximum resonance in the ulna;

(d) whereby the resonant inherencies of said bone are made known.

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U.S. Cl. X.R.

73—67.2; 128—24