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ULTRASOUND VELOCITY IN BONE UNDER DISRUPTED BLOOD SUPPLY

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The reported ultrasonic velocity measurements have been performed using a device in which the transmitter and the detector of sound vibrations are rigidly mounted at a constant distance from each other to avoid statistical errors at measuring the distance travelled by acoustic waves. The accuracy of measurements was thus dependent only on the resolution of the device determined by the frequency of time reference signals, its stability, the travelled distance, and the sound velocity.

The velocities measured in six objects exhibit a common behaviour with time, reaching a maximum between the 9-th and 33-rd hour after complete disruption in the blood supply and remaining higher compared with the initial value at least for 80 h after disruption. The obtained values of sound velocity are consistent with the results found by other authors, while the rise after disruption in the blood supply – with the increase in elasticity of the bone tissue.

1. INTRODUCTION

Measuring the velocity of ultrasound (US) propagation as a possible method for investigation of bone is widely applied in Latvia [1–7]. A variety of factors and pathological processes have been found to affect the sound velocity in the research into the heterogeneity and anisotropy of cortical bone tissue [8–11].

The velocity of sound propagation − as one of the acoustic properties determined by elasticity and density − allows making conclusions about the structural organization and architecture of the bone. The measurements, being neither harmful nor invasive while having good sensitivity and sensibility, are rather easy to perform; besides, the method is cheap.

Changes in the acoustic properties of the bones of upper extremities have been recently studied [9–12] with regard to different diseases. Nevertheless, there is little knowledge within the framework of the composite (holistic) model regarding the mechanisms of bone regeneration and the role of bone in the result and complications at replantation of upper extremities.

The present experimental study has been made as the first step for possible applications of ultrasonic diagnostics in the reconstructive surgery, with the purpose to find detectable changes of the sound velocity in the bone after acute total disruption in the microcirculation of blood. The measurements made on rabbit paws (using the animals dispensed for another study) were aimed at disclosure of possible regularities that might serve as the basis for applying ultrasound diagnostics at replantation of avulsed extremities.

2. METHOD AND SAMPLES

The measurements were made with an "Osteo-1" laboratory ultrasonovelocimeter used to measure the US velocity at a frequency of 250 kHz corresponding to the natural vibrations of a piezoelectric transducer excited by shock pulses generated at discharge of its capacity at a rate ~ 70 Hz providing long enough intervals between successive US pulses to ensure complete relaxation of the excited vibration. Another piezoelectric element was used as the ultrasound sensor excited by the travelling ultrasonic pulse. The two piezoelectric elements are rigidly mounted at a constant distance from each other to avoid any random error at measuring the distance travelled by the ultrasonic pulse from the emitter to the receiver. Such a design of the US measuring unit allows straightforward calibration by comparing the velocity of sound propagation with its known value in a standard material (e.g., Plexiglas). This way of measuring the sound velocity is reduced to simply measuring the time required for the US pulse to travel the fixed distance between the piezoelectric vibrators. The time span is equivalent to the number of electric pulses generated by a time reference generator at constant frequency (50 MHz); the equal time intervals (0.02 μs) between signals for measuring the time span determine the resolution depending on the actual sound velocity. At sound velocities between 2000 m/s and 3000 m/s the resolution is 8–18 m/s with the basis of 10 mm, and 4–9 m/s with the basis of 20 mm, respectively. A simplified block diagram of the device is shown in Fig. 1.

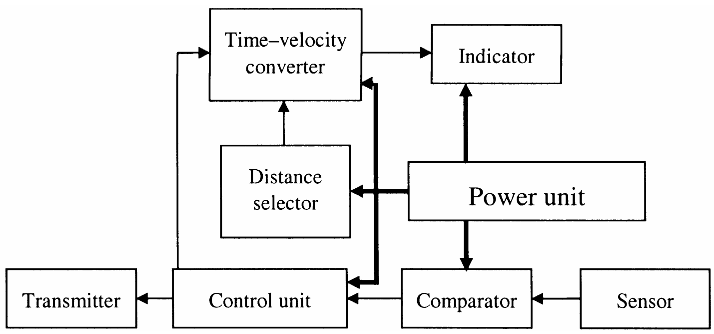

Fig. 1. Block diagram of the ultra-sonovelocimeter

The control unit generates the pulse exciting oscillations of the transmitter and triggers the time reference count interrupted by the signal received from the sensor at the moment the US pulse is detected, and transfers a pulse of the corresponding length to the time-velocity converter unit, which then transforms it into velocity displayed on the screen of the digital indicator. The distance selector provides easy adjustment of the distance between the transmitter and the sensor of the selected measuring unit to the electronic circuit converting time to velocity.

The unrepeatable time sequence of ultrasonic measurements made on the front paws of animals (selected for and used in cooperation with another study) were scheduled at time intervals of 3, 10, 17, 33, 52 and 80 h after the total disrupttion in the blood circulation. To have a reference, the ultrasonic velocity in each of the objects was measured immediately after disruption in blood circulation. Since the animals were not sacrificed the same day, the series of sequent measurements on the objects were started separately in different days.

Four measurements were taken on each of the objects at the selected time intervals. Statistical analysis of the data was performed by "GraphPad Prisma 3.02" (professional software) after the measured values from all objects had been collected. The mean of the four measurements obtained with a given object at the selected time is presented as the result related to a particular object.

3. RESULTS AND DISCUSSION

The data of the six series of sound velocity measurements with respect to time after disruption in the blood circulation were found to exhibit the same general behaviour in all of the objects revealing an unexpected anomalous increase in the sound velocity between the 10th and the 33rd hour after the supply of blood had ceased. Assuming the US velocity distribution among the objects to be statistical, the values related to a given time interval are averaged over the six objects. These are presented in Table 1 and (linked by the solid line) in Fig. 2 showing the overall trend. After having passed its maximum, the sound velocity decreases monotonically, remaining though higher than the initial value of 2140 m/s for at least 80 h after interruption in the blood supply.

Table 1

Ultrasound velocities averaged over the samples

Sequence of measure-ments	Time, hours (±0,5)	Mean value of sound velocity, m/s	Standard deviation, m/s
1	0,5	2140	65
2	3	2130	28
3	10	2220	35
4	17	2340	71
5	33	2220	59
6	52	2210	62
7	80	2195	64

The highest mean of the measured US values (2340 m·s^{-1}, see Table 1) is about 1.1 times the initial value. Its square shows the elasticity-to-density ratio of the bone tissue having increased by a factor of 1.2. Assuming the density of bone to be of the order of 2 g/cm^3 [13], the modulus of elasticity determining the sound velocity is estimated to change from 9.2 to 11 GPa. The order of magnitude of the calculated values reasonably compares to the data on bone elasticity [14].

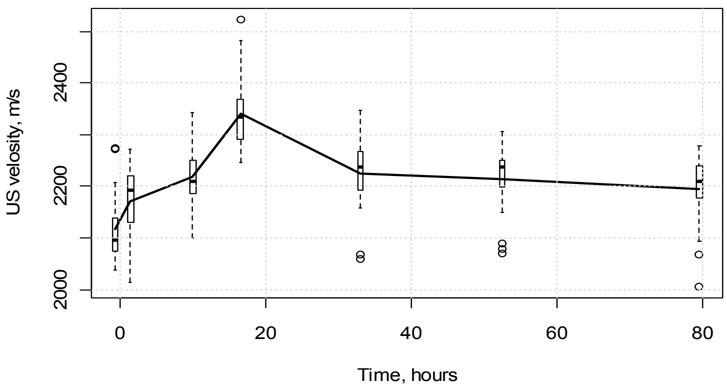

Fig. 2. The general behaviour of US velocity in bone with time after disruption in blood circulation (presented by five-number summary boxplot of all measured values).

It seems reasonable to suppose the observed increase in the sound velocity being related to the change of elastic properties rather than to the density decrease by 17%. Most likely, the increase in elasticity is due to ordering of collagen macromolecules [15] in deteriorating bone tissue. The rise in the sound velocity observed in the present study is in agreement with decreasing elastic shear compliance detected in bone samples after having been extracted from live individuals [16]. This points to rather a sharp behaviour transition of the compliance around the 5th hour – the time at which the sound velocity in the present experiment is on rise to the maximum. The data on the shear compliance with time in bone specimens [16] suggests that the presently revealed maximum of sound velocity after disruption in the blood supply is due to change in the elasticity of bone tissue conducting the longitudinal oscillations.

To obtain a complete picture of the advancement of sound velocity with time after disruption in the blood circulation and to provide answers to questions concerning the mechanism of the observed phenomenon a comprehensive experimental study is needed.

4. CONCLUSIONS

In our experiments, the velocity of sound in bone (measured independently in six objects) has been shown to exhibit a common general behaviour with time, increasing to a maximum between the 10-th and 33-rd hour after complete disruption in blood circulation, with its value remaining at least for 80 h higher than that measured immediately upon interruption.

The observed anomaly of sound velocity is obviously related to the restructuring processes in the bone tissue after cutting off the supply of nutrients supporting the metabolism in living systems. This means that measurements of the sound velocity in bone may provide useful diagnostic information for replantation and rehabilitation. Moreover, the details of biochemical mechanism (the revelation of which requires further comprehensive studies) would help to acquire fundamental knowledge about the damaged parts of bone in the composite model.

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ULTRASKAŅAS ĀTRUMA IZMAIŅA KAULAUDOS
PĒC PĀRTRAUKTAS ASINSRITES

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K o p s a v i l k u m s

Ultraskaņas ātruma mērījumi veikti ar ierīci, kurā ultraskaņas ierosinātājs un uztvērējs samontēti fiksētā attālumā viens no otra, kas nodrošina to, ka mērījuma precizitāte ir atkarīga tikai no ierīces izšķišanas spējas, kuru nosaka bāzes attālums, laika atskaites signālu frekvence, tās stabilitāte, ultraskaņas impulsa izplatīšanās ātrums un tā noietais ceļš mērāmajā paraugā. Pie skaņas ātruma ap 3000 m/s un bāzes attāluma 10 mm ierīces izšķirtspēja ir 20 m/s robežās

Pētījums veikts ar nolūku detektēt iespējamas skaņas ātruma izmaiņas, kuras varētu izmantot atrautu locekļu replantāciju gadījumos kaula stāvokļa diagnosticēšanai. Ultraakustiskajiem mērījumiem izmantoti izmēģinājumu dzīvnieki, kooperējoties ar citiem pētījumiem, kuros nepieciešama dzīvnieku eitanāzija. Mērījumus izdarīja pēc asinsrites pārtraukšanas un atkārtoti dinamikā pēc 3, 10, 17, 33, 52 un 80 stundām.

Pēc visu mērījumu statistiskās apstrādes visiem sešiem objektiem konstatēta vienāda skaņas ātruma uzvedība atkarībā no laika pēc asinsrites pārtraukšanas – neparedzēts un negaidīts ātruma maksimums laika intervālā no 9 līdz 32 stundām, kas labi parādās, viduvējot iegūto ātruma mērījumu vērtības pa objektiem. Pēc maksimuma skaņas ātrums lineāri samazinās, saglabājot augstāku vērtību nekā sākotnējo visa eksperimenta laikā.

Eksperimentā novērotās skaņas ātruma anomālijas cēloņu pilnīgai noskaidrošanai nepieciešama turpmāka kompleksa izpēte. Salīdzinot veiktā eksperimenta rezultātus, kuri ir saskaņā ar kaulaudu dinamiskās elastības mērījumiem pēc asinsrites pārtraukšanas [15], var secināt, ka novērotā anomālija saistīta ar akustisko svārstību pārvadošās vides elastisko īpašību izmaiņām, mainoties tās struktūrai.

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