Vibration Behaviour of Bone Fractures Fixed with Biocompatible Material Plates

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Monitoring of bone fracture healing evolution is performed in practice by repeated radiographic examination. We describe the use, on a clinical case of tibial diaphyseal fracture, of a method that records in progress the change of basic frequency of the healing fractured bone segement compared with the uninjured one. We ascertain an increasing evolution of the basic frequency of the fractured tibia tending to the values of parameters recorded in the unfractured segment. Approximately 100 days after trauma the recorded values enter the plateau phase, tending to those recorded contralaterally, which overlaps the healing period seen in practice. We, therefore, show the possibility to monitor the evolution of a diaphyseal bone fracture healing by the means of vibrations.

Keywords: basic/main frequency, tibial fracture, biocompatibil material, accelerometer, bone healing

In this paper is studied a method that allows the completion of missing data in the routine radiological investigation of diaphyseal fractures regarding mechanical features compared with the uninjured contralateral bone segment (1). Furthermore, as this is a completely noninvasive and unharmful method, it offers the possibility to perform more often the measurements, depending on clinical or scientifical needs.

The results obtained in laboratory conditions show a negligible influence of biocompatible implants used for fracture treatment over the basic frequency of the bone (1).

Determinations were made on diaphyseal lesions of tibia, as it presents two subcutaneous formations at its extremities (tibial tuberosity and tibial malleolus), easily accessible to the excitation device, as well as to accelerometer transducer, which allows capturing the response of the bone segement to vibration.

Determinations were made on a 31 patient group within 18 months, over 2000 measurements being made. All the patients in the study underwent surgical treatment, which enabled the testing procedure in the absence of plaster cast. The group covered the whole set of osteosynthesis techniques, starting with external fixator and ending with plate and screws, made of titanium or other biocompatible metallic alloys implants, noticing even in this stage that irrespective of the osteosynthesis material used, we were able to monitor the evolution of fractured bone healing over time (2).

Experimental part

Considering the conclusions from the study of vibrations on beams and bone moulds made of plastic materials (2,3,4), we have built the experimental setup (shown in fig. 1) needed for the study of *in vivo* vibration behaviour of bone tissue.

The injured segment is placed on a plane surface in order to perform the measurements. Mechanical excitation is exerted on tibial tuberosity through a metallic sphere (ball) that gravitationally falls inside a tubular guide, applying ~50 J impact energy.

This also ensures the repeatability of excitation by assuring a constant distance from which the ball falls.

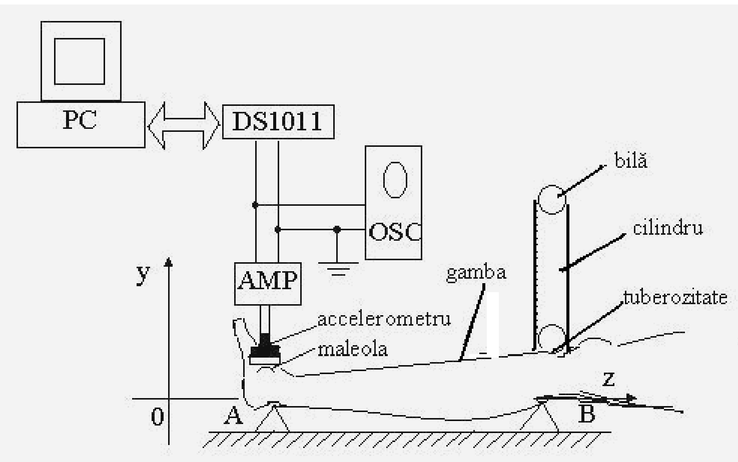

Fig. 1 Experimental setup for measuring the vibrations *in vivo* OSC-oscilloscope, AMP - amplifier, DS1011 – acquisition board, PC – IBM computer,

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Fig. 2. Radiography of fractured tibial diaphysis

In the signal acquisition and measurement system we have used an AE 101 type 11072 amplifier, which was adjusted at the 19.2 dB(5.6) value.

Results and discussions

We present below the most significant case, by the particularities of injured anatomical region due to lesion evolution, analysis of bone frequency spectrum being compared with the radiographic stage of the fracture. The experimental results are graphically shown, the left image representing the time variation of the signal received by the means of vibration transducer, and the right image representing the spectrumge obtained after the computer processing of the acquired signal.

In accordance with the current medical methods used in scientific presentations, we have used only the initials of patient in this study.

Patient B.A, aged 52 years, has suffered a distal 1/3 right tibial diaphyseal fracture and proximal 1/3 right fibular diaphyseal fracture following a domestic accident (fig. 2). Surgical intervention required osteosynthesis with a titanium alloy plate and screws (fig. 3).

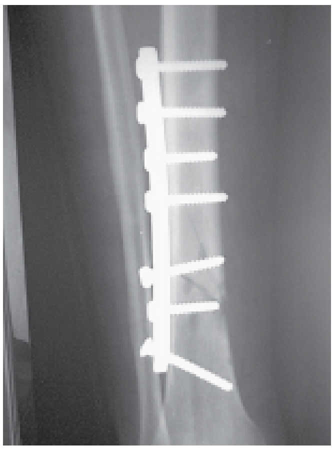

Fig. 3. Fractured tibial diaphysis, post-surgery radiography

After surgery, we have determined the frequency spectrum of the uninjured tibia, as well as of the fractured one, thus obtaining the charts in figures 4 and 5.

By analysing the frequency spectra in the two cases, we can see that in the uninjured diaphysis there is a specific oscillation frequency of 970 Hz that characterises the studied bone segment as regards its mechanical properties (7,8) (longitudinal elasticity modulus, density and physical sizes). This specific frequency is marked in the figure by a vertical dotted line. Interruption of bone continuity causes a lessening of frequency bandwidth transmitted over the fracture, which causes a lessening of specific frequencies values. This is shown by the spectrum obtained in the case of operated tibial diaphysis where, although the continuity was restored by firm metallic osteosynthesis, specific frequencies values lessened, getting the maximum value of 300 Hz (value marked by dotted line in fig.5). We also see a decrease in the number of specific frequencies (9).

Thirty days after surgery (fig. 6), the bone healing process is demonstrated by transmission of higher frequencies over the fracture focus (600 Hz), its values tending to those recorded in the uninjured bone.

These are the specific (resonance) frequencies of the bone segment. Once the specific frequencies move to the right, a 250 Hz specific frequency remains, which also exists in the intact bone spectrum, being masked at the time of determinations performed immediately after surgery. This low frequency is due to the waves transmitted through the soft tissues surrounding the bone, being present throughout the fracture focus evolution.

Towards the above presented determination, it can be seen the frequency spectrum enhancement with higher frequencies transmitted over the fracture focus (650 Hz), even though this increase is less spectacular than after 30 days (fig. 7). This indicates the beginning of a stage with a

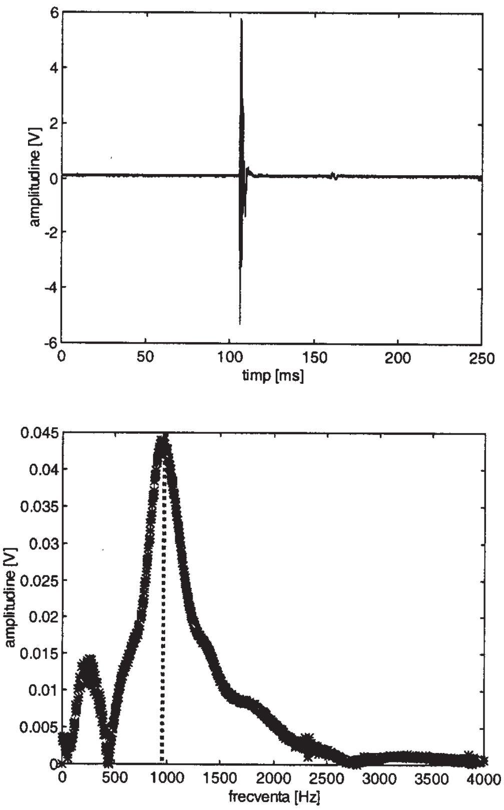

Fig. 4. Behaviour in frequency spectrum of uninjured tibial diaphysis

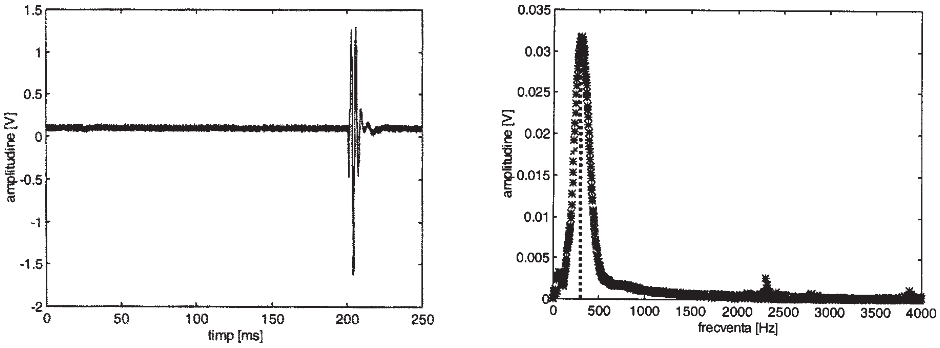

Fig. 5. Frequency spectrum of fractured tibial diaphysis, immediatly after surgery

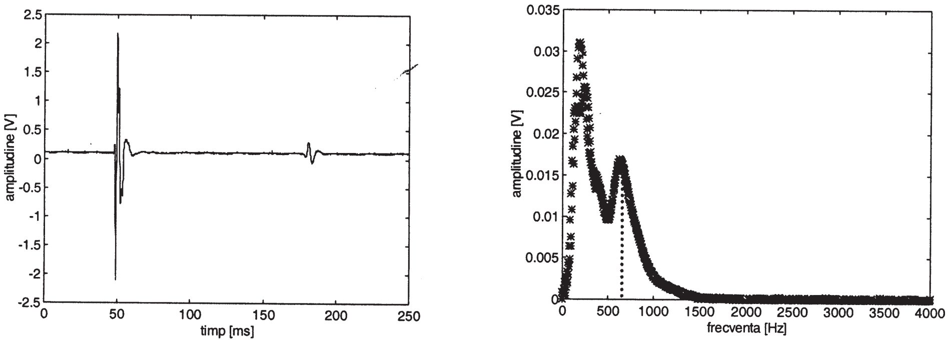

Fig. 6. Fractured tibial diaphysis, 30 days after surgery

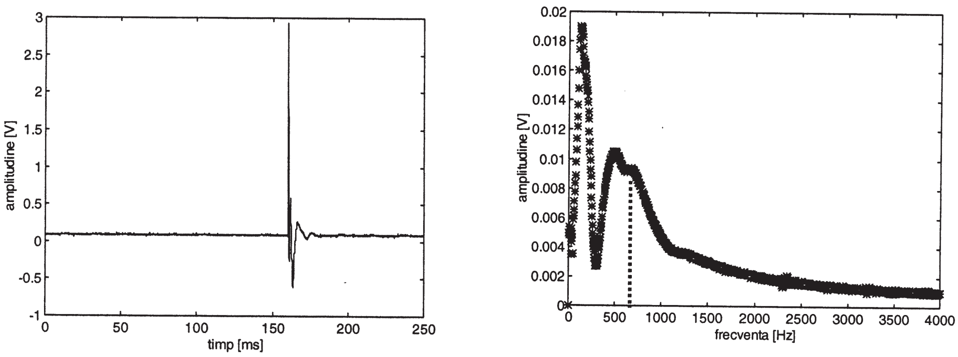

Fig. 7. Fractured tibial diaphysis, 2 months after surgery

lower growth gradient of the spectrum frequencies maximum values. At the same time, the radiographic examination reveals the presence of callus in the fracture focus (fig. 8).

The maximum spectrum frequency (800 Hz) is getting close to the value determined on uninjured bone (970 Hz), as seen in figure 9, which shows the measurements performed 3 1/2 months after surgery. We can notice lower amplitude of 800 Hz component. The increase of spectrum frequency is also supported by the radiographic aspect of bone lesion, which is practically bridged with a spindle-shaped callus of radiologic intensity close to that of the intact bone, this being a sign of propper bone union (fig. 10).

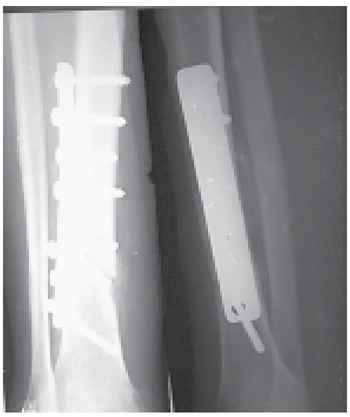

Fig. 8. Radiographic aspect of the fractured tibial diaphysis, 2 months after surgery

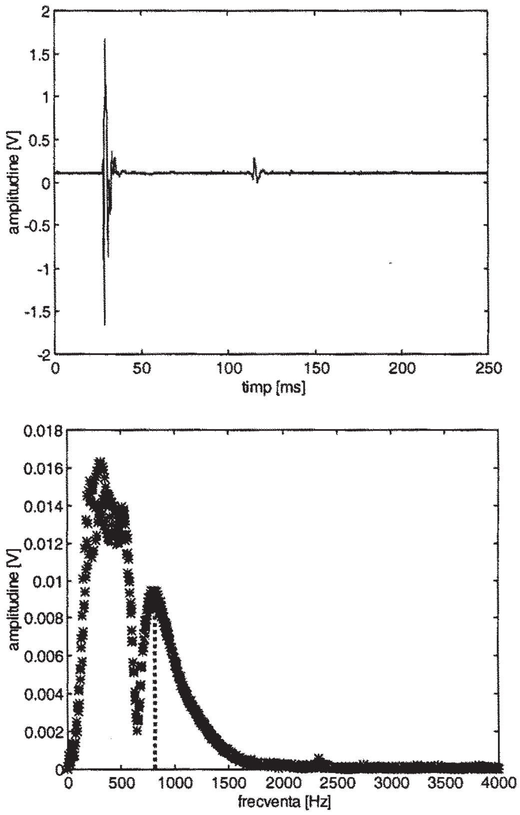

Fig. 9. Fractured tibial diaphysis, 31/2 months after surgery

Fig. 10. Fractured tibial diaphysis, 31/2 months after surgery

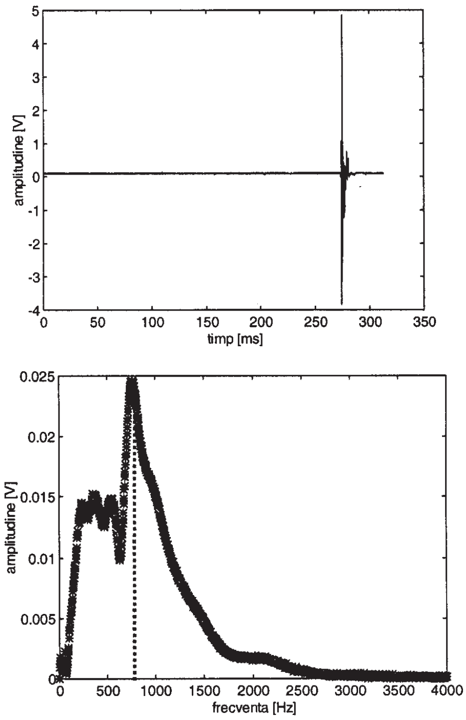

Fig. 11. Fractured tibial diaphysis, 6 months after surgery

Six months after surgery we ascertain the spectrum has been enriched with higher frequencies than in the previously presented determination in the frequency domain of the uninjured bone. However, the dominant frequency remains around 800 Hz, but we observe the increase of its amplitude to 25 mV towards the 10 mV previously measured (fig.11). In the radiographic image reproduced in figure 12 bone bridging along with increase of callus density can be noticed (10,11).

The correlation between main frequencies and the number of days after surgery has been graphically represented in order to follow the evolution over time of fracture healing (fig. 13).

By analysing the chart curve we find it similar to that obtained in laboratory determinations (2,4,12, 13) This validates the rightness of chosen experimental model (14), as well as the possibility to apply the proposed method on clinical cases.

Conclusions

The results of researches presented in this paper show that, although the classical, routine diagnostic methods to assess the evolution and establish the healing stage of bone

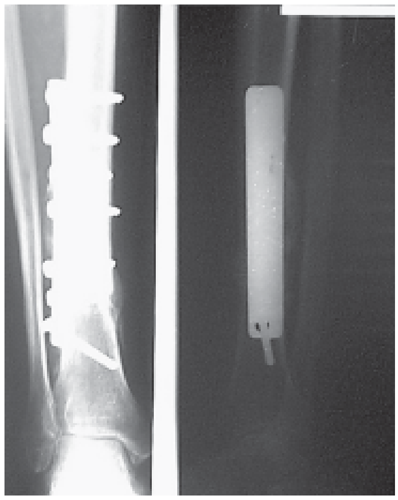

Fig. 12. Fractured tibial diaphysis, 6 months after surgery

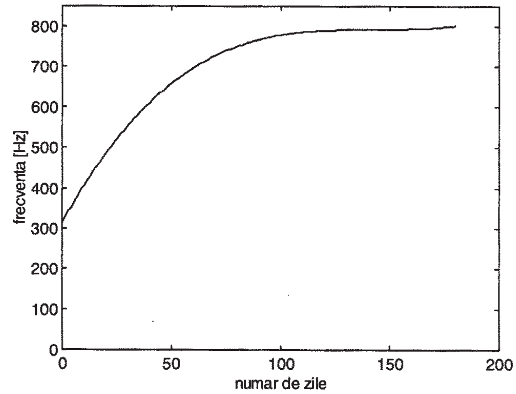

Fig. 13. Chart of time evolution of fractured focus as regards the frequency spectrum

fractures are very useful, they do not ensure a thorough characterisation of the stage of fracture evolution and of the moment when the injured segment may resume its functional role.

As it is highly exact, the proposed method allows the completion of missing data in the routine radiological investigation regarding mechanical properties by comparing them with the contralateral bone segment. Moreover, this method being entirely noninvasive and unharmful, provides the opportunity to perform the measurements more often, depending on the clinical or scientifical needs.

The results obtained in laboratory showed a negligeable influence of the osteosynthesis material over the bone main frequency. Thus, as the fracture heals, we have noticed an increase of this values close to those of the uninjured contralateral bone segment. The method provides data regarding mechanical properties of the analysed bone. Our results show that we can estimate by this procedure the moment when the fractured bone is evolving close to the normal biomechanical features earlier than by radiographic examination.

In the chart presented in figure 13, we can see the plateau phase of parameters measured ~100 days after surgery, which overlaps the conclusions in clinical practice that show the fracture can be considered healed, at this level, ~ 3 months after the trauma.

Consequently, by standardising this method, it is possible to achieve an objective assessment of the biomechanical status of the injured bone. Clinical experimental results confirmed the hypotheses elaborated in laboratory conditions and showed the experimental model was close to the real clinical situations.

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