

ASSESSMENT OF FRACTURE HEALING BY VIBRATION

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The wave signal from percussion of a bone (i.e. percussion-note) has been used to evaluate the extent of bony consolidation after fracture.

Forty-one cases with a fresh tibial fracture and eight cases of delayed union of the tibia were investigated. The medial malleolus of the tibia was struck with a tapper and the vibration signal was picked up at the medial region of the tibial tuberosity. The changes in the signal waveform of the percussion-note with time were investigated.

As healing proceeds, the signal waveform of the fractured bone approaches that of intact bone. In cases of delayed union, the character of the wave does not improve sufficiently with time. The authors are convinced that this is a promising new method for the early diagnosis of delayed union.

Key words: delayed union; fractures; fracture healing; percussion-note; vibration

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Lippmann (1932) reported on the usefulness of a percussion-auscultation method as an indicator of displacement in femoral fractures. McGaw (1942) used percussion-auscultation in the assessment of fracture healing in the femoral neck, femoral shaft and tibia. Jernberger (1967) introduced vibrations at frequencies from 20 to 10,000 Hz into the fractured tibia, investigated the propagation of vibration and suggested the possibility of assessment of fracture healing by vibrations. Dencker & Moberg (1967, 1968) tested soft tissue interposition between the fragments by the diminution of propagation using vibration at a frequency of 1,000 Hz.

It appears, however, from the reports above that the use of vibration to study the process of fracture healing is very complicated and reliable diagnostic criteria have not yet been established.

The purpose of the present investigation was to establish a new method of estimation

of fracture healing using vibrations within the audible range. It was hypothesized that the vibration properties of bones change when the bone is fractured and as healing of the fracture progresses. If we could record the note for each stage as a signal waveform, it could be used as an objective measure of the condition of the fracture and by measuring the changes in the signal waves we could follow the healing process. We carried out a series of experiments to check this theory.

MATERIALS AND METHODS

At each stage of this study, intact bone of the uninjured extremity was compared with fractured bone. Forty-one cases of fracture of the tibial shaft were followed from the time of injury. Twenty-two of these cases were treated conservatively and 19 were operated upon. The age distribution is shown in Figure 1. Eight cases of delayed union, in each of which cancellous bone grafting was performed, were similarly investigated.

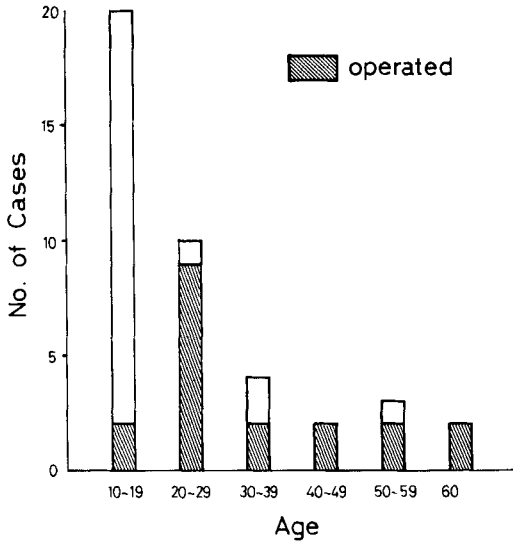


Figure 1. Age distribution in 41 cases of fresh fracture of the tibia.

A diagram of the tapper is shown in Figure 2 and the vibration signal measurement system in Figure 3. The wave signals produced when intact bones are tapped with this tapper all have the same pattern (Figure 4). Therefore using this tapper we can obtain a uniform percussion-note (p-note). The medial malleolus is struck with the tapper and the vibration is picked up at the medial region of the tibial tuberosity and transmitted to the synchroscope. The resulting

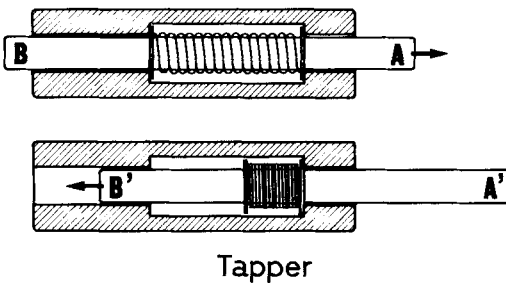


Figure 2. The structure of the tapper. Draw A to A' and release. Then B' returns to B and taps the bone.

	Cylinder	Spring
Material	wood	piano wire
Diameter	15 mm	0.6 mm
Length	170 mm	60 mm
	plane ends	coil interval 60/16mm

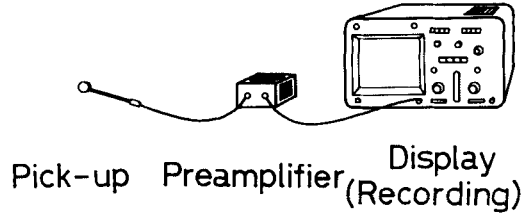


Figure 3. The vibration signal measurement diagram.

Pick-up: Matsushita (National) EFP-P600
Piezoelectric sensor

Preamplifier: transistorized amp.

power source: dry battery

frequency band: 10 Hz~100 KHz.

Display (recording): Iwasaki SS5100 CRT synchroscope.

waveform is photographed with a polaroid camera for later evaluation.

The p-note induced by the tapper may also be picked up at the medial region of the tibial tuberosity with a stethoscope bell and recorded on tape. It is played back to a wave analyser and analyzed. Simultaneously each p-note is transmitted to the wave analyser and the waveform corresponding to it recorded and studied.

Initial X-ray findings were classified as follows:

Group A. Only a crack or a slight displacement

Group B. A transverse fracture or an oblique fracture with moderate displacement

Group C. A free fragment

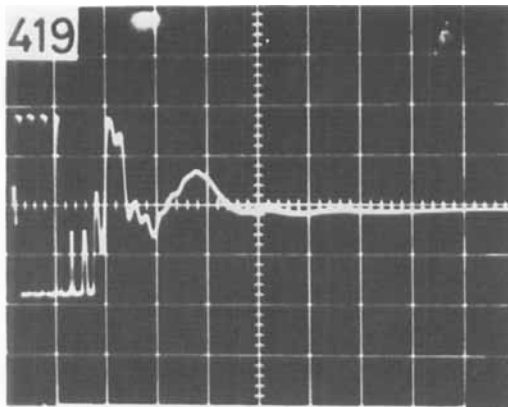
Group D. A comminuted fracture

The relationship of these X-ray findings to the distribution pattern of the waveforms of the p-note was evaluated.

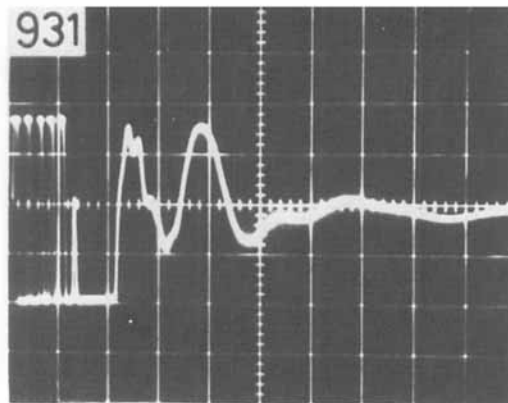
RESULTS

The signal waveform of the p-note of an intact bone has a nearly constant pattern. Figure 4 shows two such signal waveforms for intact bones. The horizontal axis is a time scale, 2 ms per cm. The vertical scale is the output signal 2 V per cm. The waveforms exhibit the standard envelope pattern of an attenuated curve. Note that in the first 2~3 ms after the build-up time the intact bone has a superimposed 4~5 cycle wave.

Figure 5 compares the p-note of fractured bones (on the right) and intact ones (on the



Type 3 (intact)



Type 3 (intact)

Figure 4. The signal waveform of the p-note of an intact bone.

left). For the fractured bones, in the first 2 ms there is a one cycle wave in Figure 5A and a two cycle one in Figure 5B.

Though there is variation between the waveforms obtained in our investigation, both in the intact bone and in the fractured bone, we are able to classify the signal waveforms as follows:

Type 1 is a one cycle wave (the right side of Figure 5A)

Type 2 is a two or three cycle wave (the right side of Figure 5B)

Type 3 is a four or five cycle wave (the left side of Figure 5A and B)

Type 1 and 2 are pathological and Type 3 is normal.

The distribution of the different waveforms in 41 cases of fresh fracture is shown in Table 1. Pathological waveforms are seen in 40 out of the 41 cases. The one case showing Type 3 will be discussed later.

Figure 7 shows the frequency spectra and p-note waveforms corresponding to the Type 1 and Type 3 results of Figure 6. In the range 700 to 4800 Hz, there is a remarkable difference between the intact and the affected parts. The spectra at low frequencies are nearly equal but at high frequencies there is remarkable attenuation for the fractured bone. This difference at high frequencies explains both the differences in waveform seen in Figure 7B and the changes in p-note waveform and in the p-note itself.

Figure 8 illustrates that the signal wave of the fractured bone tends to improve gradually to finally equal that of the intact bone. Just after injury the waveform of the fractured bone is Type 1. At the stage of clinical and roentgenographic union it is Type 2 and 1 month later it is Type 3.

The distribution of the different waveforms at the stage of clinical and roentgenographic union and weight-bearing is shown in Table 2. The original number of Type 1 cases is reduced to two. The majority exhibit Type 2 waves.

Following complete union there is almost no difference in the signal waves of the intact

Table 1. Waveform types in fresh fractures

Waveform type	No. of cases
Type 1	25
Type 2	15
Type 3	1
Total	41

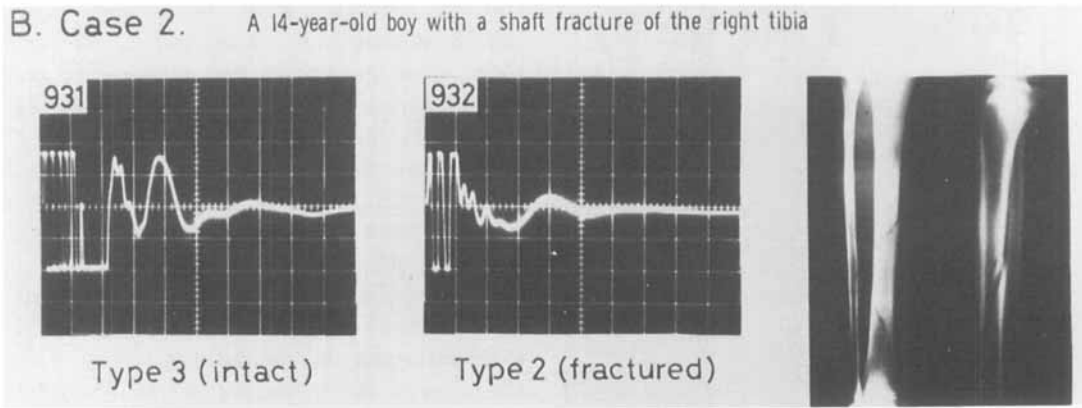
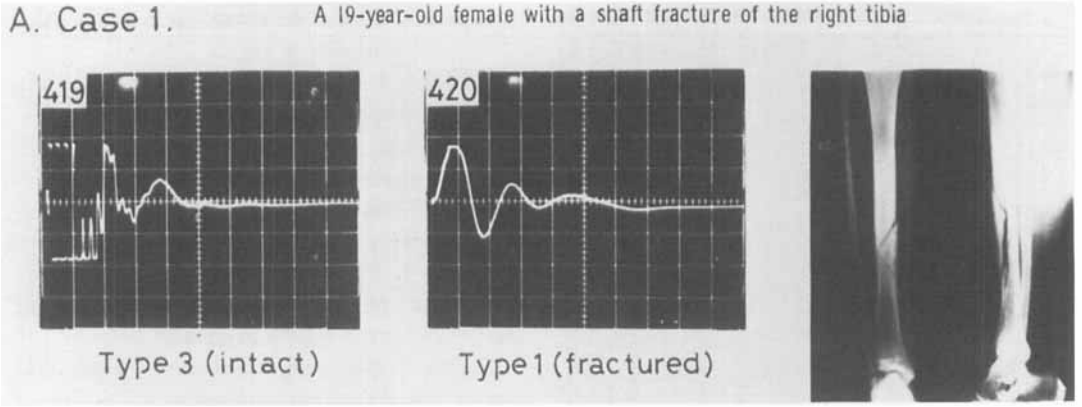


Figure 5. The signal waveform of the p-note of fresh fractures and their corresponding X-rays.

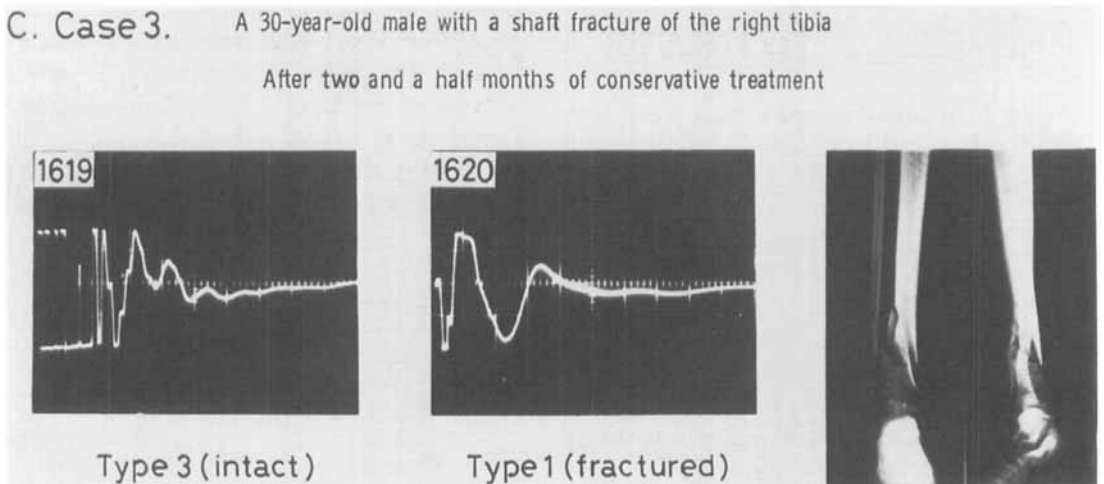
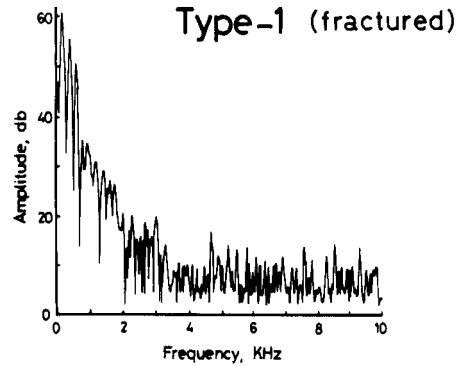
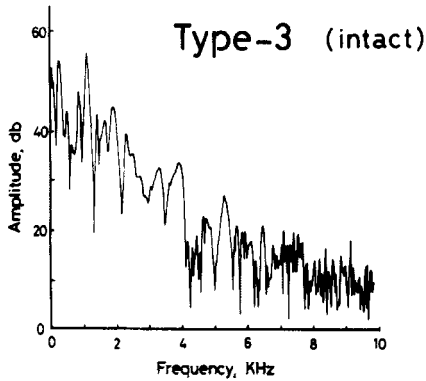


Figure 6. Fracture of the tibial shaft in which wave analysis was performed.

A. Spectrum of the p-note



B. Wave form of the p-note measured by wave analyser

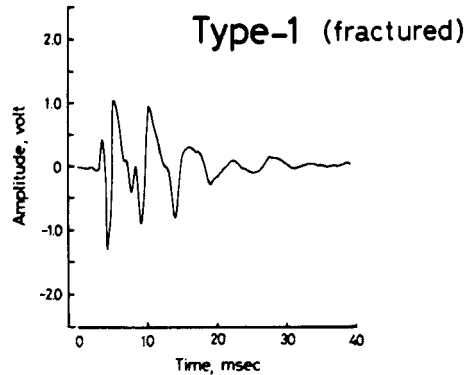
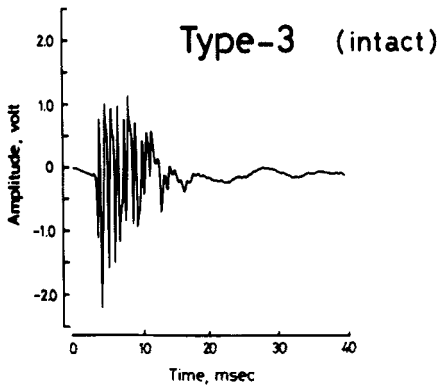


Figure 7. The frequency spectra and p-note waveform corresponding to Figure 6, and obtained using the wave analyser.

and the fractured bone. The period necessary for normalization of the signal wave is shown in Table 3. The shortest time is 2 months and

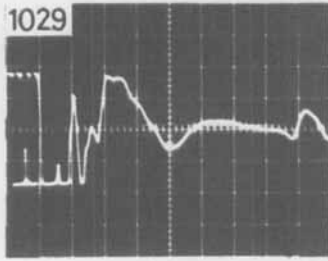
the longest 1 year, and the average period is 4.4 months. This average period is 1.9 months longer than the average period (2.5 months) for clinical and roentgenographic union.

Table 2. Waveform types at the stage of clinical and roentgenographic union

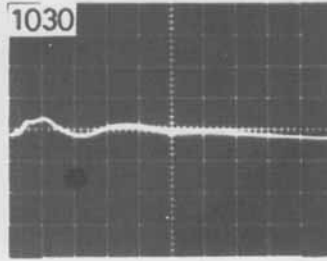
Waveform type	No. of cases
Type 1	2
Type 2	37
Type 3	2
Total	41

In delayed union the signal waveform shows no improvement with time. In each case abnormal mobility was confirmed by operation. Cancellous bone grafting was performed. The distribution of the waveforms is shown in Table 4. There were two Type 1 cases, five Type 2 cases and one Type 3. The periods necessary for normalization of the p-note signal waves varied from 4

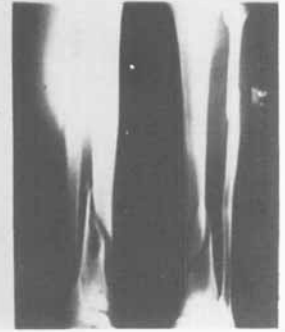
A. Two days after injury



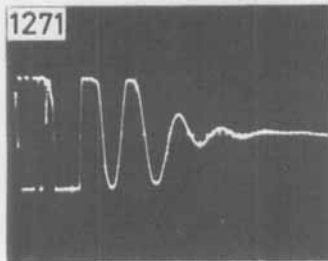
Type 3 (intact)



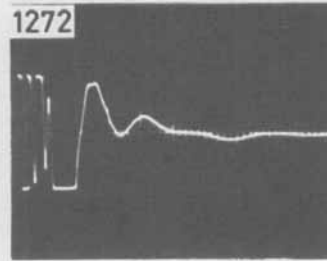
Type 1 (fractured)



B. Three months after operation (the stage of weight bearing)



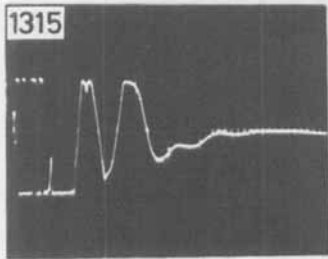
Type 3 (intact)



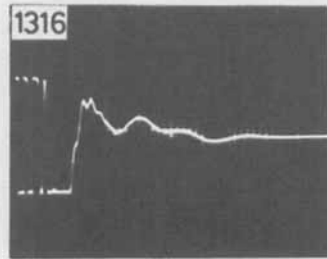
Type 2 (fractured)



C. Four months after operation



Type 3 (intact)



Type 3 (fractured)



Figure 8. Changes in the signal waveforms of p-notes corresponding to fracture healing. A 26-year-old male with a shaft fracture of the left tibia.

Table 3. Period necessary for the normalization of the signal wave

Period necessary for the normalization of signal wave	No. of cases
2 months	2
3 months	5
4 months	4
5 months	7
6 months	6
6 months~1 year	5
Total	29

delayed union received primary treatment in other hospitals, we could not investigate the process of p-note before our operation.

The distribution of the signal waveforms corresponding to the initial X-ray findings are shown in Table 5. In Group A four out of 14 cases are of Type 1, and nine are of Type 2. In Group B 15 out of 21 cases are of Type 1 and six are of Type 2. In this group the majority exhibit Type 1. In Group C all six cases are of Type 1. In other words, the more noticeable the displacement on the X-ray, the higher the number of cases exhibiting Type 1.

Table 4. Cases of delayed union

Case no.	Age	Time elapsing before operation	Waveform before operation	Waveform at the stage of clinical and roentgenographic union	Period necessary for normalization of the p-note
1	44 years	1 year 6 months	Type 2	Type 2	—————
2	41	1 year	2	2	1 year
3	23	5 months	1	2	1 year
4	19	11 months	3	2	5 months
5	59	1 year	1	2	1 year
6	56	4 months	2	2	6 months
7	42	1 year 10 months	2	2	7 months
8	25	4 months	2	2	4 months

Table 5. Waveform type corresponding to the X-ray findings for fresh fractures (see text for X-ray classification)

X-ray	No. of cases	Waveform type		
		Type 1	Type 2	Type 3
Group A	14	4	9	1
Group B	21	15	6	
Group C	6	6		
Group D	0			
Total	41	25	15	1

months to 1 year. In case 4 the initial waveform was Type 3 and at the stage of weight-bearing the waveform was Type 2. This will be discussed later. Because all of the cases of

Cases in Group D were not seen in this study. The unusual case showing the signal wave of Type 3 at the stage of injury cited earlier was in Group A. In this case (and in the similar one with delayed union) we believe that the instrumentation amplification was inadequate to reveal any abnormality.

If there is edematous swelling at the medial malleolus, the input is unstable and the correct p-note cannot be obtained. Therefore edematous swelling in the malleolar region makes the bone unsuitable for this kind of investigation.

In our experiment, it was shown that the p-note, if it passes through one joint, loses the high frequency spectrum. For example, if we tap at the lateral condyle of an intact

humerus and pick up the p-note at the acromion, the signal wave is Type 1. Similarly, if we tap the lateral malleolus of an intact fibula, the signal wave of the p-note picked up at the medial region of the tibial tuberosity is Type 1. On the other hand with greater amplification, we can observe a p-note exhibiting the signal waveform of Type 3 at the acromion.

DISCUSSION

Thirty-seven out of the 41 cases of fresh fracture exhibited a signal waveform of Type 2 at the stage of clinical and roentgenographic union and weight-bearing so that the period necessary for normalization of the p-note waveform is longer than the period necessary for clinical and roentgenographic union, i.e., this test may be more sensitive to pathological changes in bones than X-rays. The results led us to conclude that, by following changes in the p-note with time, it should be possible to tell when the fracture is healing satisfactorily and to get an early indication of a delayed union.

The lower leg consists of the tibia and the fibula. Therefore, we have to check the influence of propagation of the vibration through the fibula as well. But the results of

our investigation indicate that the influence of the fibula is negligible.

Our study has been limited to fractures of the tibia because the tests are easily performed in this area. But in future we hope to extend our procedure to the femur and the humerus.

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