DOUGLAS GORDON

ULTRASOUND

AS A DIAGNOSTIC AND SURGICAL TOOL

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Based on the
International Symposium
held at the Royal College of Surgeons, London
on December 5th and 6th, 1962

Edited by

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E & S LIVINGSTONE LTD EDINBURGH & LONDON

Printed in Great Britain

Preface

THOUGH ultrasonic rays have been used in medicine as a form of physiotherapy for over 20 years particularly in Germany, the other medical uses of ultrasound have been much slower in arousing interest amongst doctors.

Though the University of Illinois arranged a Symposium on Ultrasound in Biology and Medicine in 1955 and the American Institute of Ultrasonics in Medicine held an International Conference of Ultrasonics in Medicine in Los Angeles in 1957, the first meeting in Europe appears to have been a Research Forum on the Biological Uses of Ultrasound organized by Prof. Roger Warwick of Guy's Hospital on July 22nd, 1960 through the help of the Ciba Foundation, London.

This meeting was so successful that the writer, who had the honour to preside on that occasion, decided to arrange further meetings for groups of workers in both diagnostic and surgical applications. Each group met twice a year usually in London but sometimes at other centres.

When the British Radiological Societies decided to devote a session to the Diagnostic Uses of Ultrasound at their Joint Meeting in December, 1962, it seemed an obvious step to arrange for the two discussion groups to meet in the same week and so encourage the attendance of workers in other countries. As soon as the proposal was made known the response was quite overwhelming.

It was clearly impossible to restrict the numbers to the usual limit of 25 which had been chosen to keep the meetings informal. So at very short notice the meeting was thrown open to all interested and became the First International Symposium on Ultrasound as a Diagnostic and Surgical Tool.

Though an exceptionally severe fog prevented many of the foreign workers from attending, it proved extremely popular with those present and a list of the actual papers read is included as Appendix 1 of this book.

It was originally intended to publish the papers read at the Symposium in book form. On further consideration, however, it was decided that the time was ripe for the production of a textbook suitable for the use of clinicians who were ignorant of ultrasonic physics but would like to find out if ultrasonic techniques could be applied in their particular field.

The task of writing the preliminary chapters has proved much larger than was realized and even now the writer fears that some subjects are not covered sufficiently fully to make the contributions in the later chapters fully comprehensible to those with no claim to being physicists. A list of books is however included in the bibliography (Appendix 7).

For those with no previous experience it is suggested that Chapters 1, 5, 6, 12 and 21 should be read first and then the Chapter or Chapters from 13 to 28 which seems most appropriate to their own sphere.

If this procedure suggests that ultrasound is a possible answer to their problems then a second systematic reading of the whole book and a careful study of the bibliography are the next steps advised.

As textbooks of any new subject inevitably become rapidly out of date to some extent, it is advised that anyone entering the field should take two steps to maintain contact with the other workers. The first is to subscribe to the quarterly journal " Ultrasonics " published by Iliffe Industrial Publications Ltd., London S.E.1. The other is to notify the writer that they wish to receive the periodical ultrasonic bulletins that are sent out to announce meetings and report progress of one sort or another. It is particularly requested that all who publish work in the field will send reprints, two for preference, as the writer is trying to compile a complete library for the benefit of all interested.

The British Institute of Radiology, 32 Welbeck Street, London W.1 is giving a measure of support to the organizing of the Second International Symposium to be held in London on May 27th and 28th, 1964 and it is likely that the discussion groups will eventually become formally associated with the Institute.

The field covered by this book is so wide that no editor can hope to be fully conversant with all aspects. Readers are asked to report any faults of omission or commission so that when the time comes for a second edition it will be less open to criticism.

DOUGLAS GORDON.

25 Church Road,
Richmond, Surrey, England.
February, 1964.

Editor's Acknowledgments

The Editor gratefully acknowledges permission from:—

The Editor of the Journal of Physiology to reprint Chapters 18 and 19.

The Editor of Acta Oto-laryngologica to reprint Chapter 23.

The Editor of the Transactions of the Ophthalmological Society to use the blocks for Figures **12,** 8 and **A5,** 2.

The Editor gratefully acknowledges the provision of photographs by the following:—

Physics Department, Bristol General Hospital (Fig. **11,** 3).

Prof. A. Sjoberg, Uppsala (Fig. **11,** 5).

Smiths Industrial Division (Figs. **12,** 1, **13,** 4 and **13,** 5).

Prof. R. Warwick, Guy's Hospital (Fig. **20,** 6).

The Ferens Institute, Middlesex Hospital (Figs. **25,** 3 A, B, C and D).

Smith, Kline-Precision Inc., Philadelphia (Fig. **27,** 1).

Prof. P. A. Lindstrom, Salt Lake City, Utah (Fig. **28,** 1).

The Editor expresses also his personal thanks to the following who have collaborated in the work described in Chapters 13, 20 and 25:—

Dr. H. C. Grant, West End Hospital for Neurology and Neurosurgery, for undertaking the histology.

Dr. A. Beck, Paddington General Hospital, for providing facilities for animal experiment.

Messrs. Dancol Engineering Co. Ltd., Hanworth, Middlesex, for the great interest taken in the design and manufacture of the apparatus.

Miss B. Murphy for computing the table on page 363.

Miss B. K. Gordon for help in compiling the index.

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APPENDICES

CHAPTER 1

What are Ultrasonic Waves?

AS the human ear cannot detect frequencies above about 16,000 cycles per second any sound of a frequency above this is described as ultrasonic. This simple statement is in fact extremely misleading as it implies that the sound is transmitted through air and that the frequency is not greatly above the auditory limit. In actual fact it is extremely difficult to propagate a very high frequency through air and it is even more difficult to pass ultrasonic waves from air into liquid or solid or vice versa.

It is therefore better to consider ultrasonic waves as confined to liquids and solids and as having frequencies measured by millions of cycles rather than by thousands. However, like sound, the ultrasonic waves require a transmission medium of some sort and unlike wireless waves they are unable to travel across a vacuum.

Taking examples from everyday experience, let us consider what happens when a stone is thrown into a pond. No matter whether the stone is dropping vertically or travelling almost horizontally, ripples go out from the point of entrance in ever increasing circles, each ripple separated from its neighbour by a matter of a few inches. If a finger is moved about in a bath of water the ripples always move in all directions and it is impossible to produce any directional effect. On the other hand on the coast of a large ocean it is possible to see regular waves of very great length proceeding in an orderly direction propelled only by the force of the wind. The only way in which it is possible to produce surface waves similar to that seen in the ocean, is by moving a plank or similar long object backwards and forwards at right angles to its length. It will rapidly be discovered that the distance between the waves must be considerably less than the length of the plank before any directional effect can be obtained.

The wave lengths of audible sounds in air vary from a few inches to many feet. As the human larynx is much smaller than the wave length it is impossible to obtain a directional effect.

Ultrasonic waves having a frequency of a million cycles per second have a wave length of $1\frac{1}{2}$ mm. in water. It is therefore quite easy to have generators of ultrasound which are many wave lengths across.

Electrical oscillations of the order of a million cycles are known as radio frequency and it is important at an early stage to obtain a clear picture of the difference between radio waves, radio frequency potentials and ultrasonic waves. Radio frequency electrical power, usually generated by radio valves or by transistors, can produce both radio waves and ultrasonic waves, according to the way in which the power is used. This may seem confusing, but an internal combustion engine if used to drive a dynamo will produce electricity while if installed in a car or a ship it will produce motion. Similarly if the radio frequency power is conveyed to an aerial or antenna it seems to disappear as it is converted into energy in the " ether ". On the other hand if the radio frequency power is supplied to a device known as a transducer which is in contact with a suitable conducting material, the energy will appear as vibrations of that material.

Wave Types

It is necessary now to consider in more detail the nature of these vibrations. To do this we must therefore consider the structure of matter. Liquids and solids may be thought of as consisting of a very large number of atoms which repel one another. These repulsions being equal, the atoms arrange themselves so that the distance between adjacent atoms is more or less uniform. If as a result of pressure from one direction an atom is displaced towards its neighbour, the neighbouring atom will tend to move away and thus increase the pressure on the atom beyond and so on down the line (Fig. **1,** 1).

If, however, the direction of movement of the first atom is reversed, its neighbour will tend to return to its normal place and this motion too will pass down the line. If a whole row of atoms move in the same direction at the same time they will move the whole of the next row and so the waves will propagate in a uniform manner. In actual practice all the atoms in one plane will move together as the atoms are arranged in three dimensions. Though each individual atom only travels through a very small distance by being subjected to compression and stretching alternately, the zone of compression appears to travel through the material followed by a zone of stretching and followed in its turn by another zone of compression. The distance between the centre of one compressed zone to the centre of the next compressed zone is the wave length.

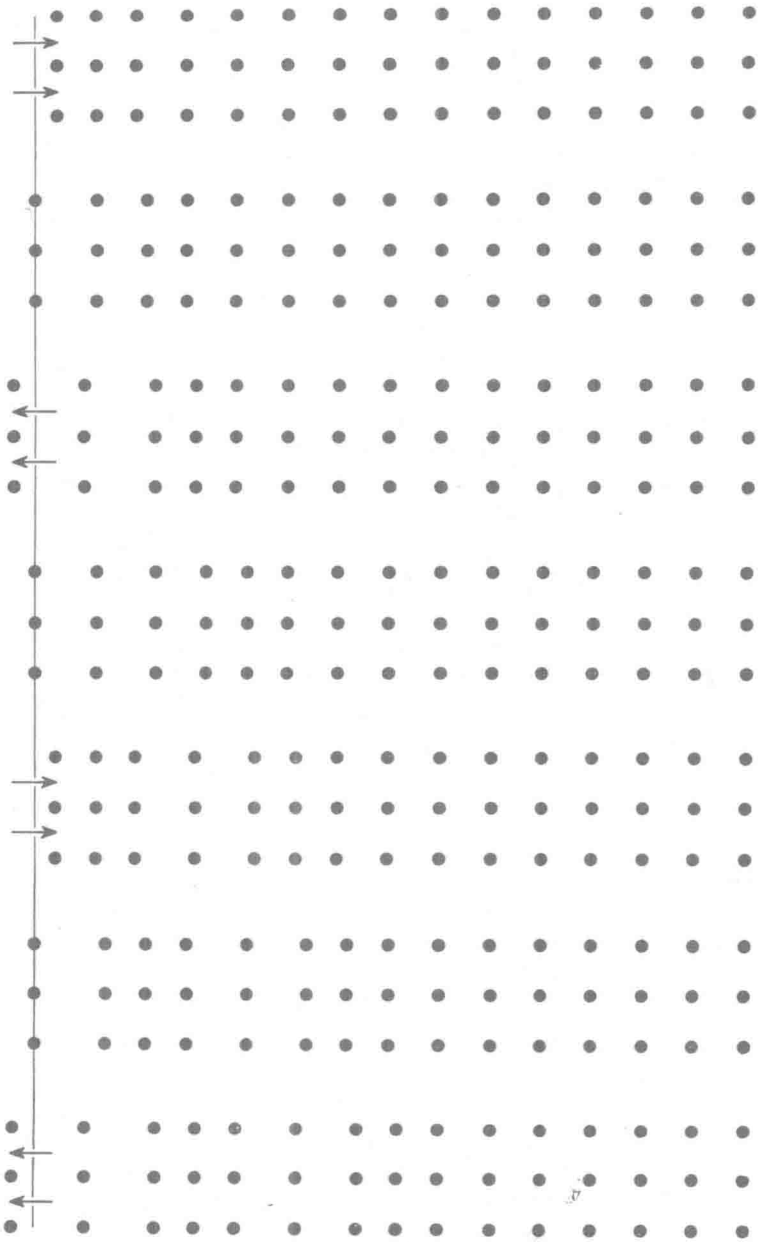

FIG. 1, 1
Diagram to illustrate the propagation of waves by the movement of atoms.

Vibrations of the type described are known as *longitudinal waves* and this is the only type of vibration that can occur in liquids. In the case of solids, however, two other forms of waves are possible. If a child takes a long rope and then rapidly raises and lowers the other end it is possible to produce complicated wave patterns in which the wave length can quite easily be seen but the movements of the rope are at right angles to the direction in which the waves appear to move. These are known as *transverse waves* or *shear waves*. These waves are of very slight importance in the medical field.

Of even less importance are the *surface waves* where the propagation is confined to the surface of a material in the same way as the ripples on the surface of a pond.

Throughout this book it must be assumed that the ultrasonic waves are of the longitudinal type unless shear or surface waves are specifically mentioned. A considerable source of confusion arises from the fact that though the waves are in fact sequences of compressions and rarefactions with the particles moving in the axis of propagation of the wave, they are for reasons of convenience nearly always represented by wavy lines following a sine curve which gives the misleading impression that the particle movement is at right angles to the direction of propagation. The reason for this is that ultrasound is nearly always produced or detected by electrical potentials which are most readily studied by means of the cathode ray oscilloscope in which the potential is displayed as a series of sine curves.

Pendulums

If one imagines a pendulum with a pencil projecting downwards to touch a large sheet of paper that moves steadily along at right angles to the direction of swing (Fig. 1, 2) it will be found that the pencil will write a sine curve. The movement of the pendulum represents the particle movement during ultrasonic activity while the mark on the paper corresponds to the appearance on a cathode ray oscilloscope.

So far the oscillations have been assumed to be repeated uniformly. Now one must consider what happens when a pendulum such as a swing starts from rest. Imagine, for example, the effect of a single strong push. The swing rapidly gains speed at first, then slows, stops, reverses, and accelerates past the starting point to reverse direction again after a shorter swing than the first. The oscillations die away until the swing becomes stationary. It will be seen that the line drawn on the paper (Fig. **1,** 3A) gives a very misleading indication of the form in which the energy was applied to the swing all of which was delivered in a fraction of the first swing.

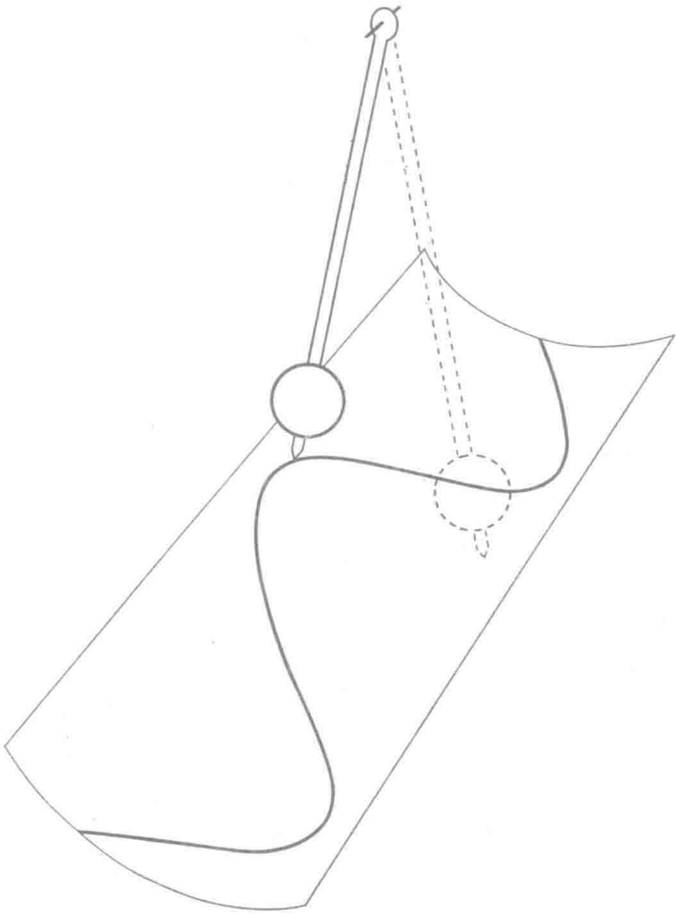

FIG. **1,** 2
The Path of a Pendulum.

On the other hand if a series of small pushes are given it will be found that the swing will gradually increase in amplitude until a maximum is reached. When the pushes cease the oscillations die away very much as in the first example (Fig. **1,** 3B).

It is common knowledge that to obtain a large amplitude of swing it is essential to push it at exactly the same point in each oscillation. As soon as the pushes are made at a different rate from the natural rate " chosen " by the swing, they will tend to stop the swing rather than to help it. On the other hand if the swing is pushed every other oscillation, it will continue to function almost as well as with a push every time.

To alter the rate of the swing's natural oscillations it is necessary to alter the lengths of the rope or chain that suspends it. The shorter the swing the higher the rate of swinging and conversely.

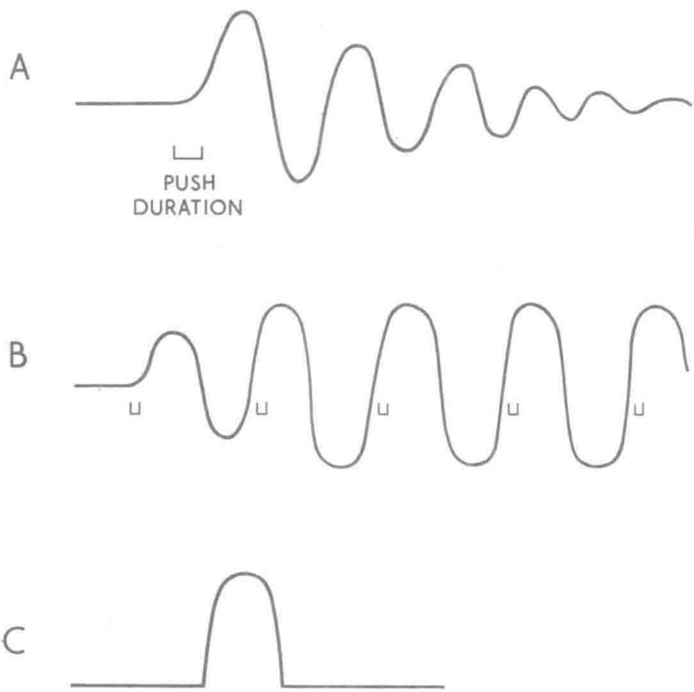

FIG. 1, 3
Wavetrains. A. A Single Push. B. Rhythmic Small Pushes.
C. The Unobtainable Ideal Pulse.

On the other hand a swing with a lead weight will behave differently from a swing with a passenger of equal weight and wearing a voluminous dress that acts as a sail. The friction of the dress as it passes through the air acts as a brake and the same effort will produce a much smaller oscillation than with the compact weight that produces less friction. Even more striking will be the difference when the pushes cease. The lead weight will oscillate for a long time while the passenger will find herself stationary in a few seconds.

Gongs

These childish examples may seem far removed from ultrasonic research, but they illustrate very well some of the fundamental problems that arise throughout the rest of the book.

As a transition stage one may take a gong or bell that is rung by being hit with a hammer. Just as with the swing there is a natural rate of oscillation which cannot be varied without altering the size of the swing, so with a gong or bell there is a natural pitch which can only be altered by altering the size or shape of the gong or bell. This corresponds to the natural frequency of the transducer crystal that generates or detects ultrasound. This too is determined by the physical size and shape of the crystal.

A gong struck once rings for a long time getting gradually softer in the same way as the swing given a single push continues to swing backwards and forwards through diminishing arcs. Later it will be seen that a crystal continues to vibrate after electrical excitation ceases.

If a gong is struck sharply while a hand presses flat on another part of its flat surface it will not only make a much quieter sound but the sound will be much shorter. This is the analagous condition to the passenger with the large dress on the swing. In acoustics instead of referring to friction one talks of damping and this corresponds to the dampers in the piano that stop the strings from vibrating as soon as the keys rise. This problem of damping plays a very important part in transducer design.

If one wished to use a gong as a means of signalling over considerable distances one would at once discover one of the major problems of ultrasound. In order to be heard over long distances one would hit the gong hard while it was freely suspended with its flat surface perpendicular to the direction of the person listening. The problem would arise as soon as one wanted to convey information. With the undamped gong it might take some seconds before the sound had diminished enough for a second blow on the gong to be detectable by the listener. The rate at which Morse code could be transmitted would be intolerably slow. On the other hand if the gong were damped by having most of its surface pressed on by hands or similar sound-absorbing matter, it would be possible to transmit a message quite quickly but the range of transmission would be very much reduced. As is easily felt, most of the energy from the hammer blow is absorbed by the hands leaving very little to enter the air and reach the listener.

An improved arrangement is that in the piano where the hammer strikes the undamped string and damping is applied later under control of the player. Unfortunately in ultrasonic transducers it is hardly ever possible to alter the damping in this way. One can vary the damping through wide limits but one cannot vary the damping without major alterations to its construction.

Wave Trains

The pattern drawn by the pencil on the pendulum, the recording made of the noise made by a gong or a photograph made of the trace on a cathode ray oscilloscope provide a record of what is called a wave train. This is the whole of the activity that occurs from the end of a period of complete inactivity to the beginning of the next period of inactivity. Such wave trains may vary widely.

At one end of the range is what is known as *Continuous Wave* (nearly always abbreviated to CW). In this the oscillations rise rapidly to a steady level which is maintained for long periods and terminate abruptly.

Another common type of wave train is a simple modification of this. It consists of a period of CW followed by a roughly equal period of rest then a period of CW followed by another period of rest and so on. This pulsed CW usually is produced by operating a radio-frequency generator from alternating voltages derived from the mains. The pulses therefore tend to have durations of 1/100 sec. in Europe, and 1/120 sec. in America corresponding to half a cycle of the respective 50 and 60 cycles per second mains supplies.

When pulses are referred to however, they usually refer to much shorter wave trains where the intervals of inactivity greatly exceed the length of each pulse. As these pulses are being used to convey information rather than power they are kept as short as possible. In theory the ideal wave train would consist of a single half cycle or one half of a sine wave (Fig. **1,** 3c).

Going back to the swing analogy this would represent making the swing move from its resting position to full excursion and then stopping it without any bounce as it reached its original position. This would prove such a difficult exercise for swings weighing more than a pound or two that it gives a very fair indication of the virtual impossibility of obtaining an ideal wave train in practical ultrasonic work.