Ultrasound Therapy

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Ultrasound therapy

by
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1 Preface

This therapy manual is intended primarily to give background information in connection with the use of Enraf-Nonius ultrasound equipment.
With a view of the demand for more information about ultrasound, we felt obliged to provide a more detailed explanation of this subject.

We thank R. Hoogland for this description of the theory and the practical application.

2 Basic information

2.1 Definitions

Definition: 'Sound waves' are mechanical vibrations in an elastic medium.

These longitudinal waves can cause the tympanic membrane to vibrate. The are sound vibrations. Frequencies below about 20 Hz are subsonic, frequencies above 20.000 Hz are ultrasonic. This ultrasound frequency range is related to the *human* ear. It is subjective and arbitrary. This is evident from the fact that the range of audible sounds decreases with age.

Definition: 'Ultrasound therapy' is medical treatment by means of mechanical vibrations with a frequency above 20 kHz.

In practice, the frequencies used for treatment range between 0.7 and 3 MHz. However, some equipment exists for diagnosis and therapy which uses frequencies between 5 kHz and 10 MHz.

Definition: 'Ultrasonophorsis therapy' is medical treatment with medical substances introduced into the body by means of ultrasound energy.

Definition: 'Ultrasound diagnosis' is scanning of a portion of the body by means of ultrasound for pathological changes.

If desired, this can be combined with various electrical currents. The sensitive zones in the tissues, which are quite easily found in this manner, can be used as application points for treatment. The technique will be described in Chapter 3.

2.2 Physical fundamentals

This book refers to standard manuals on the physics of ultrasound. The results only will be given. For the derivation of the formulae and background information, the relevant physics literature should be consulted.

2.2.1 Generation of Ultrasound

Modes of generating ultrasound
Any vibrating object is a source of sound. Sound waves can also be generated in different ways, e.g. mechanically by a tuning-fork or in medicine by means of electro-acoustic transducers.

The piezo-electric effect
If pressure is applied to crystals (quartz), and to some polycrystalline materials such as lead-zirconate-titanate (PZT) or barium titanate, electric charges develop on the outer surface of the material. This is called the piezo-electric effect.
Piezo-electric effects are also seen in the human body, especially in bony tissue, collagen fibers and body proteins. Possibly, these piezo-electric phenomena are involved in the biologic effects of ultrasound.

The reverse piezo-electric effect

The piezo-electric effect is reversible. Thus, if the substances mentioned above are exposed to an alternating electric current, they will undergo changes in shape in the frequency of the alternating electric field. The material then becomes a source of sound. Currently, quartz, barium titanate and lead-zirconate-titanate (PZT) are used for generation of ultrasound via the reverse piezo-electric effect. The last two materials have the advantage that, because of their ferro-electric properties, only a small voltage is required to induce the acoustic energy. This, for instance, makes a transformer in the sound head superfluous, making it much smaller. Quartz requires a high voltage (several kV). On account of the necessary transformer, the treatment head becomes relatively large. PZT is preferable to barium titanate because it retains its marked piezo-electric properties up to much higher temperature thresholds. PZT is also less sensitive to mechanical shocks.

2.2.2   Equipment

The instrument consists of a high-frequency generator. This is connected to a piezo-electric crystal (the treatment head).
The resonant frequency of the crystal is partly determined by the thickness of the piezo-electric material (PZT) and consequently the frequency of the ultrasound is so determined as well. Moreover, this implies that the sound head and the equipment must be mutually adjusted, so that the treatment head cannot be used with another piece of ultrasound equipment unless calibration is performed.

Technical innovation has solved this problem in the Sonopuls® apparatus, where the treatment heads are fully interchangeable between different instruments of the same type and proper adjustment is automatically performed.

As a result of the alternating current applied to the piezo-electric material, this generates sound waves. These will propagate in the neighboring media (e.g. tissues). Because the piezo-electric material generates sound waves bi-directional, ultrasound will also enter the treatment head (rebound effect). This is of little significance because of the air present in the treatment head.
The transducer also vibrates laterally, consequently ultrasound energy in transferred to the sidewall of the treatment head via the transducer mounting (sidewall radiation).

Picture 1: Sonopuls 492

In the treatment heads of the Sonopuls® apparatus the sidewall radiation has been reduced to < 10mW/cm². Various authorities quote < 10mW/cm² as an acceptable value. On protracted use of ultrasound sidewall radiation development of these symptoms depends on excessive intensity of this sidewall radiation.
Therefore its value should be measured and specified for the equipment.

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Continuous and pulsed ultrasound
Most ultrasound equipment can generate both continuous and pulsed ultrasound energy. The maximum intensity that can be set for continuous ultrasound is 3W/cm²

Picture 2: Sonopuls 190

The Sonopuls® 190 permits adjustments of the intensity between 0 and 2 W/cm² for continuous and 3 W/cm² for pulsed ultrasound.
Pulsed ultrasound has the advantage that thermal sensations are suppressed. In addition, this mode permits a higher intensity, which for application of continuous ultrasound can cause undesirable effects. The higher intensity is probably the explanation for the nonthermal effects occurring in pulsed ultrasound therapy. Also due to the pulsation of the ultrasound beam the mechanical effects are more pronounced.

Ratio	(= 'Duty cycle')	Pulse time (ms)	Pulse pause (ms)	Pulse repetition period (ms)
1 : 5	(= 20%)	2	8	10
1 : 10	(= 10%)	1	9	10
1 : 20	(= 5%)	0,5	9,5	10

Table 1.1: Example of the parameters for pulsed ultrasound with a pulse repetition frequency of 100 Hz.
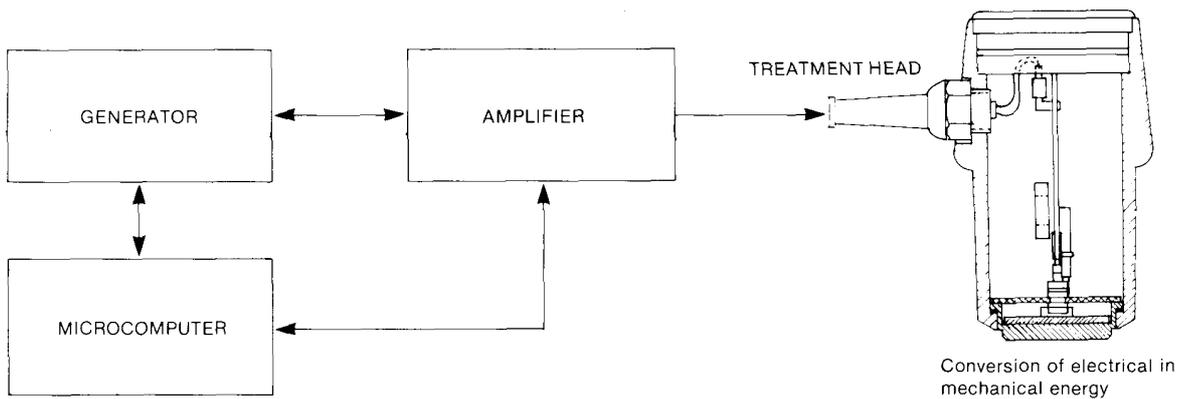
Fig. 1.1: Principle of ultrasound equipment

The effective radiating area (ERA)

The effective radiating area of the treatment head (ERA) is an important parameter determining the intensity. Because the piezo-electric element does not vibrate uniformly, the ERA is always smaller than the geometric area f the treatment head.

To permit a true indication of the intensity on the instrument, determination of the ERA is essential because the effective intensity depends on this. Correct ultrasound dosage depends partly on the area to be treated and ERA, reason why the ERA should be known. Therefore the ERA should be measured and specified (see fig. 1.2).
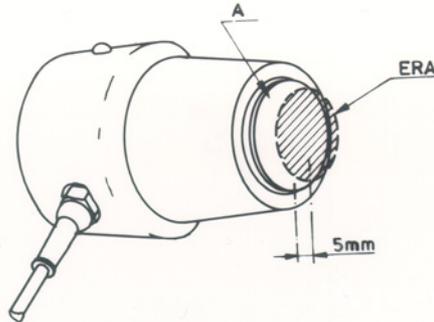
Fig. 1.2: Impression of a geometric area (A) and an effective radiating area (ERA).

1- and 5-serie US heads	ERA	Geometric area
1 MHz	5,0 cm² 0,8 cm²	6,2 cm² 1,4 cm²
3 MHz	5,0 cm² 0,5 cm²	6,2 cm² 0,7 cm²
9-serie US heads	ERA	Geometric area
1 MHz and 3 MHz	5,0 cm² 0,8 cm²	6,3 cm² 1,3 cm²

Table 1.2: Table of ERA for the Sonopuls® apparatus

2.3   Properties of the ultrasound beam

In the ultrasound beam two areas can be distinguished (see fig. 1.3):
- **the near field   : the Fresnel zone**
- **the distant field   : the Fraunhofer zone.**
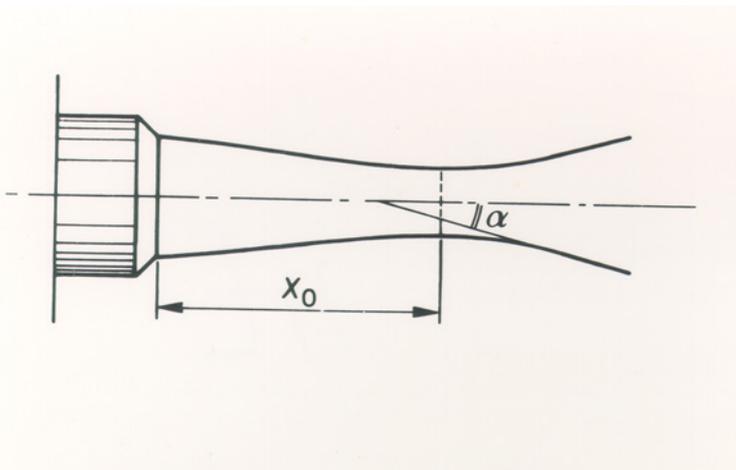
Fig. 1.3: Longitudinal cross-section of the ultrasound beam.

2.3.1 The near field

The **near field** is characterized by:
- interference phenomena in the ultrasound beam, which may lead to marked variations in intensity
- the absence of divergence, in fact here is slight convergence of the ultrasound beam

2.3.2 The distant field

The **distant field** is characterized by:
- the near-absence of interference phenomena, so that the sound beam is uniform and the intensity gradually decreases with increasing distance to the transducer;
- the ultrasound beam has a larger diameter. This size depends on the type of sound beam (divergent or collimating);
- a wider spread of the sound energy due to both the divergence and the fact that the intensity distribution perpendicular to the longitudinal axis of the sound beam becomes increasingly bell-shaped (see fig. 1.4).
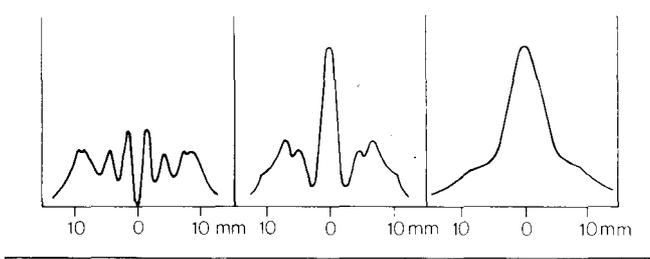
Fig. 1.4: Transverse cross-section of the ultrasound beam.

The length of the near field depends on the diameter of the treatment head and the wavelength. With the usual treatment head of 5 cm² the near field is about 10 cm long. For a sound head of 1 cm² the near field is about 2 cm long at 1 MHz.
At 3 MHz the near field is 3 times as long, because the wavelength is proportionally shorter.
Because the depth effect of ultrasound is limited, the therapeutic effects occur mainly in the near field. It should be remembered that in the Fresnel zone interference phenomena occur in the ultrasound beam, resulting in its being non-homogeneous. These interference phenomena may cause intensity peaks 5-10 times higher than the set value – in some cases even 30 times higher.
This non-homogeneous behavior of the sound bundle is expresses as the **Beam Non-uniformity Ratio (BNR).**

2.3.3 The BNR value

Theoretically, the BNR cannot be smaller than 4, i.e. one should always allow for intensity peaks of at least 4 times the set value. For well-manufactured treatment heads the BNR lies between 5 and 6, depending on construction. The BNR value should be specified on the treatment head.

1- and 5-serie US heads		BNR
1 MHz	Treatment head 6.2 cm²	6.0 max.
	Treatment head 1.4 cm²	6.0 max.
3 MHz	Treatment head 6.2 cm²	6.0 max.
	Treatment head 0.7 cm²	6.0 max.

9-serie US heads		BNR
1 & 3 MHZ	Treatment head 6.3 cm²	6.0 max.
	Treatment head 1.3 cm²	6.0 max.

Table 1.3: BNR values for the Sonopuls® treatment heads

See fig. 1.5.

For safe treatment the head must always be kept in motion so that the ultrasound energy is properly spread.
Rotation of the head in **one** position must be rejected because the intensity peaks in the sound beam are usually positioned symmetrical to the longitudinal axis of the treatment head (so-called rotation symmetry). Rotation of the treatment head causes intensity peaks in the same location, resulting in over-dosage.

By means of the underwater method the near field can be avoided by maintaining a sufficient distance to the body (viz. The length of the near field), depending on the size of the treatment head. The interference phenomena of the near field will then occur in the water. A disadvantage is the larger diameter of the ultrasound beam in the distant field, causing a reduction of the energy per cm². These aspects should be taken into account for dosage calculations. With the usual application of ultrasound therapy total reflection will not occur because the boundary angle is so large as not to be exceeded under normal conditions.
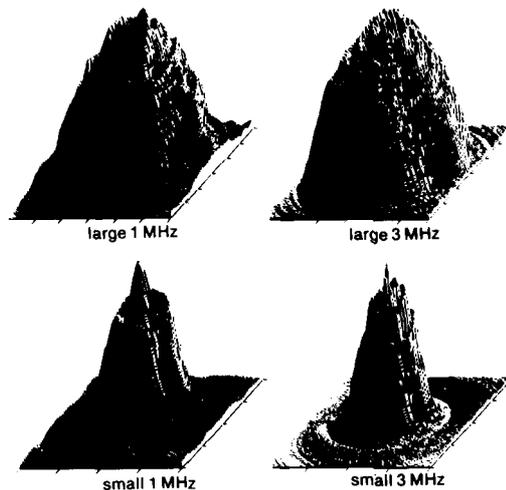
Fig. 1.5:   Beam diagram large head 1 MHz
*   Beam diagram large head 3 MHz*
*   Beam diagram small head 1 MHz*
*   Beam diagram small head 3 MHz*

Divergence of the ultrasound beam
Divergence of the ultrasound beam occurs only in the distant field.
The divergence is determined by the angle of spread (α) (see fig. 1.3) according to the formula:

$$\text{Sin } \alpha = 1.22\ \lambda/D, \text{ where}$$

λ = wavelength of the ultrasound
D = diameter of the treatment head

	5 cm²	1 cm²
1 MHz	4.2º	9.3º
3 MHz	4.4º	3.1º

Table 1.4: Angles of spread at 1 and 3 MHz for various treatment heads

It has been said earlier that the near field is shorter for a small treatment head, so that divergence occurs earlier and the ultrasound energy is spread over a large area. It will be clear that divergence of the ultrasound beam is markedly less at 3 MHz.

2.4 Physical phenomena occurring in the medium

2.4.1 The nature of the (ultra)sound wave

The ultrasound wave is of a longitudinal nature, i.e. the direction of propagation is the same as the direction of oscillation. Longitudinal waves require an elastic medium for propagation. In principle, every medium is elastic with the exception of a vacuum. The longitudinal elastic waves (sound waves) cause compression and expansion of the medium at half a wavelength's distance, leading to pressure variations of the medium (see fig. 1.6).
In this context the medium is the contact substance and the tissues of the body in which the ultrasound energy propagates.
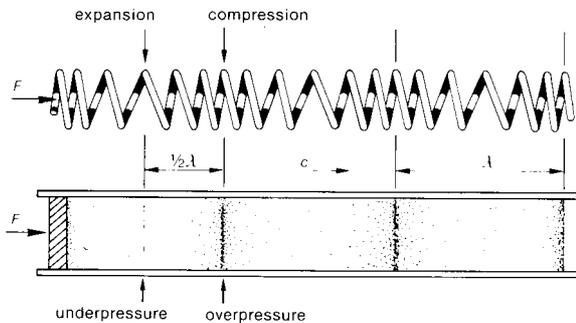
Fig. 1.6: Elastic waves in a spring and a liquid.

2.4.2 The wavelength of ultrasound

This is expressed by the relationship:

$$\lambda * f = c, \text{ where:}$$

λ = the wavelength (m)
f = the frequency (Hz)
c = the speed of propagation (metres/second)

Because the frequency of the equipment is set and the speed of propagation is determined by the medium, the wavelength also depends on the latter.
In soft tissue and in water the wavelength at 1 MHz is approximately 1.5 mm and in bony tissue about 3 mm. The effect on the speed of propagation in the tissues at 3 MHz is small. Thus there is a linear reduction of the wavelength, which is about 0.5 mm in soft tissues and about 1 mm in bony tissue.

Medium	c (m/s)	ρ (kg/m³	λ (mm) 1 MHz	λ (mm) 3 MHz
Aluminium	5100	2.7×10^3	5,10	1,70
Blood	1566	1.0×10^3	1,57	0,52
Blood-vessel	1530	1.1×10^3	1,53	0,51
Bony tissue	3445	1.8×10^3	3,44	1,14
Skin	1519	-----	1,51	0,50
Cartilage	1665	-----	1,75	0,58
Air at 20 °C	343	0.0012×10^3	0,34	0,11
Tendon tissue	1750	-----	1,75	0,58
Muscle tissue	1552	1.0×10^3	1,55	0,52
Fatty tissue	1478	$0,9 \times 10^3$	1,48	0,49
Water at 20 °C	1492	$1,0 \times 10^3$	1,49	0,50

Table 1.5   Survey of media and their speed of propagation (c), mass density (ρ) and wavelength (λ) for ultrasound at a frequency of 1 MHz and 3 MHz.

2.4.3   The mass density of the medium

The mass density of the medium (ρ) is a parameter expressed in kg/m³. Together with the specific acoustic impedance (Z_s), this determines the resistance of the tissues to sound waves. The mass density also partly determines the speed of propagation (*c*). The higher the mass density, the higher the speed of propagation (see Table 1.5). the value of the mass density is required for determination of the specific acoustic impedance and consequently for the reflection.

2.4.4   The specific acoustic impedance (Z_s)

Because the specific acoustic impedance is a material parameter it depends on the mass density and the speed of propagation: $Z_s = \rho * c$.

Medium		Z_s (Kg/m²s)	
Aluminium		13,8	$- 10^6$
Blood		1,6	$- 10^6$
Bone		6,3	$- 10^6$
Blood-vessel		1,7	$- 10^6$
Gel	circa	1,8	$- 10^6$
Skin	circa	1,6	$- 10^6$
Air		0,0004	$- 10^6$
Muscle tissue		1,6	$- 10^6$
Fatty tissue		1,4	$- 10^6$
Water (20 ºC)		1,5	$- 10^6$

Table 1.6   The specific acoustic impedance

2.4.5   Compression and expansion of the media

The medium (tissue) is a compressed and expanded at the same frequency as that of the ultrasound, i.e approximately $1 . 10^6$ times per second. The resultant pressure changes are fairly large. For instance, at an intensity of 1 W-cm² the pressure variation is about 1.7 bar (at 1 MHz and *c* = 1500 m/s).
At a wavelength of 1.5 mm this implies a pressure gradient of 3.4 bar over a distance of 0.75 mm in view of the fact that the points of high and low pressure are half a wavelength apart. At 3 MHz the pressure variation is greater; it increases as the square law. Therefore it may be assumed that the pressure variation increases by a factor of 9! Due to attenuation of the sound beam the pressure variation decreases with depth. However, due to interference in the near field and reflection at the various boundaries a large increase in pressure can develop.

2.4.6   Reflection and refraction of sound

Reflection of ultrasound
Reflection occurs at the boundaries between different tissues. The amount of reflected energy depends on the specific acoustic impedance (Z_s) of various media according to the formula:
R = the amount of reflected energy

This formula applies to a sound beam with perpendicular incidence where $Z_s 1$ is the specific acoustic impedance of medium 1 and Z_s that of medium 2 at a boundary surface measured from the treatment head.
In practice this means that the reflection decreases as the difference between the two specific acoustic impedances becomes smaller. In the body, significant reflection occurs for transitions between tissue and bone (30%).
The specific acoustic impedance of the sound head is practically identical to that of the contact medium (gel). Consequently there is hardly any reflection between these media. Theoretically reflection between aluminium and contact medium would be about 60%.

Aluminium – air	100,0%
Aluminium – contact medium	60,0%
Treatment head – contact medium	Nil
Contact medium – skin	0,1%
Skin – fatty tissue	0,9%
Water – fatty tissue	0,2%
Fatty tissue – muscle tissue	0,8%
Muscle tissue – bone tissue	34,5%
Skin - air	100,0%

Table 1.7   Survey of reflection at some medium boundaries.

Refraction of sound
In addition to reflection, a non-perpendicular incidence of the sound waves causes refraction of the sound beam according to the formula:
c_1 = speed of sound in medium 1
c^2 = speed of sound in medium 2

In $n > 1$, refraction takes place towards the perpendicular;
If $n < 1$, then refraction is away from the perpendicular.
Only the latter is significant because of the deflection of the ultrasound beam when the critical angle is reached and the ultrasound beam begins to run parallel to the boundary between the two media. The speed of sound in the various body tissues is such that for normal applications of ultrasound the critical angle will not be exceeded.
Reflection and refraction will not be appreciably different at 1 and 3 MHz, because the mass density of the various tissues is constant and the effect of the sound frequency on the speed of propagation is small.

2.4.7   Scattering of ultrasound

Scattering of ultrasound in the body occurs due to two phenomena:
- divergence in the far field
- reflection

Especially because of reflection, the ultrasound beam may spread in the body, so that effects can develop not only in the direction of the sound beam, but also outside it (see fig. 1.7). as pointed out before, reflection needs to be taken into account only if highly reflective materials and/or substances such as metals, air and bony tissue are placed in the ultrasound beam. In addition, it should be remembered that ultrasound can hardly leave the body as a result of the reflection form air, which is virtually 100% (see table 1.7). the total dosage of ultrasound applied to the body is converted to other forms of energy. An exception is the underwater method, where the ultrasound energy can leave the body.
If the sound beam hits bony tissue, reflection amounts to about 30%. Then the ultrasound beam is attenuated by absorption of energy, depending on the thickness of the surrounding tissue layers (e.g. muscle tissue).
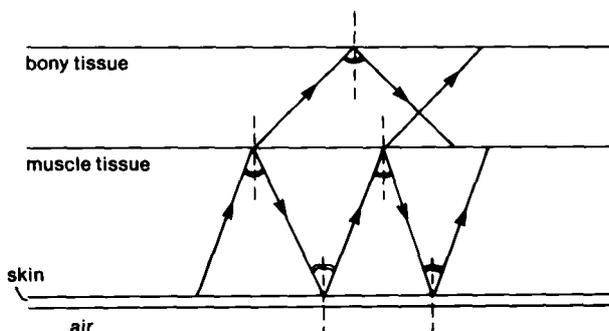

Fig. 1.7 Scattering of the ultrasound beam by reflection.

The reflected energy again enters the original tissue layer and will again enters the original tissue layer and will again be attenuated by absorption. At the boundary between skin and air almost complete reflection occurs, and so over again. The ultrasound beam rebounds between bony tissue and air.
The same is possibly true for the 70% of sound energy propagated in the bony tissue. The sound beam will be markedly attenuated in this tissue on account of the very high absorption of the ultrasound energy. (see fig. 1.7)

2.4.8   Interference of ultrasound

Interference of ultrasound waves occurs due to two phenomena:

a. Interference in the ultrasound beam in the near field leading to at least a four-fold local increase in intensity compared to the value set on the instrument (see BNR value).

b. Interference phenomena as a result of reflection. The incident and reflected sound beams can overlap, leading the two wave motions which may attenuate or enhance each other.
    Interference resulting in enhancement leads to an increase in the intensity of the sound beam. (see fig. 1.8)
    In practice, problems result only if the tissue layer extending down to the bone is thin or absorbs little sound energy. This is the case for treatment near the wrist area, the ankles, patella and similar locations. Especially with application of continuous ultrasound, this phenomenon causes irritation of the periostium with a sensation of heat and/or pain. This once more illustrates the importance of motion of the treatment head.
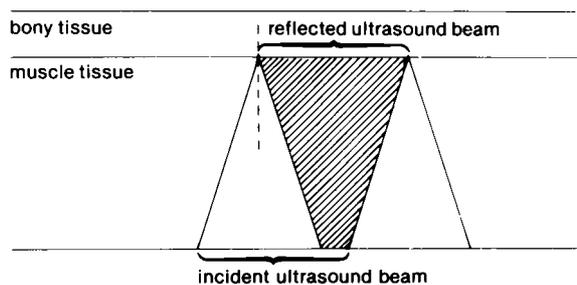
Fig. 1.8 Interference by reflection

2.4.9   Absorption and penetration of ultrasound

As the (mechanical) ultrasound energy penetrates into the body tissues, biologic effects can be expected to occur only if the energy is absorbed by the tissues. Due to the absorption the intensity of the sound waves will decrease as they penetrate further into the tissues. The absorption of ultrasound energy by biologic tissues varies. The **absorption coefficient** (*a*) is used as a measure of the absorption in various tissues. The absorption in the tissues is lower than for high frequencies. This relation ship is linear for all tissues except bone between the frequency, absorption and action at depth of ultrasound. In effect, the absorption coefficient together with reflection determines the spread of ultrasound in the body.
For ultrasound, among other things, the following formula applies. This formula is true for ultrasound consisting of longitudinal waves with perpendicular incidence on homogeneous tissues:

$I(x) = I_0 * e_{-ax}$ where:

$I(x)$ = the intensity in W/cm² at a depth x in cm
I_0 = the intensity in W/cm² at the surface of the body, but **IN** the body tissue
e = 2.7 (base of natural logarithms)
a = absorption coefficient (cm -1).

From this formula it emerges that the intensity of ultrasound at a certain depth depends on the absorption coefficient (*a*).

Medium	Absorption coefficient (a)	
	1 MHz	3 MHz
Blood	0,028	0,084
Blood-vessel	0,4	1,2
Bony tissue	3,22	
Skin	0,62	1,86
Cartilage	1,16	3,48
Air (20 ºC)	2,76	8,28
Tendon tissue	1,12	3,36
Muscle tissue	0,76	2,28*
	0,28	0,84**
Fatty tissue	0,14	0,42
Water (20 ºC)	0,0006	0,0018
Nerve tissue	0,2	0,6

 * sound beam perpendicular to fibers
** sound beam parallel to fibers

Table 1.8   Absorption coefficient (a) at 1 and 3 MHz

From the table it appears that two values are used for the absorption in muscle tissue. The marked difference is caused by the direction of the sound beam in relation to the muscle fibers. The former value applies if the sound beam is perpendicular to the muscle fibers. This is by far the most usual situation in the practical application of ultrasound. The latter value applies if the sound beam runs parallel to the muscle fibers. In the latter case the absorption is almost a factor 3 smaller.
A more practical value relating to absorption is the half-value depth (D1/2).

Definition: the 'half-value depth' in the distance in the direction of the sound beam in which the intensity in a certain medium decreases by half.

The half-value depth (D1/2) as determined by the absorption coefficient can be calculated with the formula:

Half-value depth (D1/2) ≈ 0,69/*a*

	1 MHz	3 MHz
Bone tissue	2,1 mm	----
Skin	11,1 mm	4,0 mm
Cartilage	6,0 mm	2,0 mm
Air	2,5 mm	0,8 mm
Tendon tissue	6,2 mm	2,0 mm
Muscle tissue	9,0 mm	3,0 mm *
	24,6 mm	8,0 mm**
Fatty tissue	50,0 mm	16,5 mm
Water	11500,0 mm	3833,3 mm

*   sound beam perpendicular to fibers
**   sound beam parallel to fibers

Table 1.9   Half-value depth (D1/2) of various media

Only the most practically significant values have been included in the table.

Until now it has been generally assumed that the half-value depth for muscle tissue is about 3 cm. This is correct if the sound beam runs parallel to the muscle fibers, which in practice will hardly ever be the case. If the sound beam is perpendicular to the muscle fibers – as is mostly the case during treatment – the half-value depth is found to be 0.9 cm.
The consequence of the greater absorption is that the action in depth decreases.
In addition it is seen that much ultrasound energy is absorbed in tendon tissue and cartilage. Possibly this is an explanation for the favorable therapeutic results of treatment of these tissues.

The greatest depth at which a therapeutic effect can still be expected is called the **penetration depth** (*p*). this is the point where 10% of the applied sound intensity remains. It should be noted that this value only specifies the depth, not the local intensity of the ultrasound. The intensity of the ultrasound at the penetration depth determines whether a therapeutic effect will really no longer result at this depth. The value of *p* is approximated by:

p ≈ 2.3/a

	1 MHz	3 MHz
Bone tissue	7 mm	----
Skin	37 mm	12 mm
Cartilage	20 mm	7 mm
Air	8 mm	3 mm
Tendon tissue	21 mm	7 mm
Muscle tissue	30 mm	10 mm *
	82 mm	27 mm**
Fatty tissue	165 mm	55 mm
Water	38330 mm	12770 mm

 * sound beam perpendicular to fibres
** sound beam parallel to fibres

Table 1.10 Penetration depths of some media

2.5   The contact medium

As appears from chapter 3, it is necessary to use a contact medium between the treatment head and the body in order to transfer the ultrasound energy to the body. Air is wholly unsuitable as a contact medium because of the almost complete reflection of the ultrasound. Water, however, is a good contact medium and is also cheap. If water is used as a contact medium it must have been degassed by boiling as far as possible and in some cases it must be sterile, e.g. for treatment of open wounds. By degassing, deposition of air bubbles on the treatment head and the treated part of the body is prevented. In practice gel, oil and ointment – sometimes with other substances added (ultrasonophoresis) – are used in addition to water.
In random order, the following requirements can be specified for the contact medium.

The contact medium must be:
- sterile, if there is a risk of (cross) infection
- not too liquid (except for the underwater method)
- not too quickly absorbed by the skin
- incapable of causing marked staining
- free from a marked cooling or irritant effect on the skin
- chemically inert
- cheap
- endowed with good propagation properties
- free from (micro) gas bubbles
- transparent
- free from micro-organisms or fungi.

2.6   Propagation properties of contact media

In propagation of ultrasound energy to the body various media and boundary surfaces are encountered, viz. from transducer plate to contact medium and from contact medium to the body. For the transition between two media a so-called **transmission factor** is specified, which indicates the fraction of the energy transmitted.
The intensity of the ultrasound indicated on the equipment is specified for water at 5 mm from the treatment head.
As a rule of thumb one may assume 100% transmission of ultrasound in the body tissues.
According to current data on transmission losses in the contact substances, the gels in present use as contact medium do not have a significant effect on the amount of energy that reaches the body.

3 Biophysical effects of ultrasound

3.1 Introduction

The effects of ultrasound are not yet completely clear. It is clear, however, that application of ultrasound to biologic tissues has a number of effects. The primary consideration with ultrasound is that it is a form of mechanical therapy. It is also evident that mechanical energy can be converted to thermal energy, for instance, but this is a consequence of the mechanical effect of ultrasound.
The effects of 1 MHz and 3 MHz are probably not different, however, certain effects may be more emphasized at the respective frequencies.
As far back as the fifties, Pohlman stated that no other effects are observed for ultrasound between 1 and 10 MHz. The special nature of ultrasound at 3 MHz is therefore rather the much greater mechanical effect and the markedly higher absorption of the ultrasound energy in the superficial tissue layers (see table 1.7 and 1.8). This also spares the deeper tissues, because the intensity greatly decreases as a consequence of the greater absorption.

3.2 Mechanical effect

The first effect to occur in body tissue as a result of ultrasound is of a mechanical nature. Sound vibrations require an elastically deformable medium for their propagation. In principle, any medium except a vacuum is deformable. The ultrasound vibrations cause compression and expansion in the tissues at the same frequency as the ultrasound, leading to pressure variations in the tissue.
Therefore the mechanical effect is also called **micro-massage**.
At 3 MHz the pressure maxima and minima are closer together than at 1 MHz because the wavelength decreases to 0.5 mm approximately.
Due to reflection in the sound beam and at the boundaries between the tissues the intensity in W/cm² may increase, so that the greatest pressure variations occur at the boundary between two different media. Therefore one may assume the most pronounced therapeutic effects to occur at the boundaries. *Ultrasound therapy is therefore also called a therapy of boundary surfaces.*

These pressure differences have the following consequences:

- changes in volume of the body cells of the order of 0.02%
- changes in permeability of the cell and tissue membranes
- an improved exchange of metabolic products.

Micro massage is of great therapeutic importance. All effects of ultrasound therapy are caused by it. These effects occur with both continuous and pulsed ultrasound energy. Depending on the intensity used for treatment, these effects may have a favorable or unfavorable influence on the tissues. The unfavorable effects will be discussed in paragraph 2.5.

3.3 Thermal effect

Micro massage of the tissues leads to generation of frictional heat. This thermal effect has been frequently described in the literature and is the best-known effect of ultrasound.

The amount of heat generated differs for the various tissues. It depends on a number of factors, some of which can be adjusted, e.g. the form of ultrasound (continuous or pulsed), the intensity and the duration of treatment. In addition, the absorption coefficient plays an important part (see table 1.8). Lehmann states that the temperature in muscle tissues increases by 0.07°C per second for continuous ultrasound of 1 W/cm². This value has been calculated for a muscle phantom, i.e. without the regulating effects of the bloodstream. Therefore this appears to indicate the value of the maximum increase in temperature in muscle tissue. In a therapeutic situation involving ischemia such a marked rise in temperature might increase and lead to unfavorable effects. In a study on the medial side of the knee of pigs this author showed that the increase in temperature in the soft parts is relatively small in comparison with the deeper articular structures. For continuous ultrasound at 1.5W/cm² for 5 minutes with a transducer plate of 12.5 cm² the average increase in temperature of the capsule is 6.3°C, that of the soft tissues 3.3°C. The medial part of the meniscus shows an average increase of 8.2°C, whereas in the bony tissue an increase in temperature of 9.3°C occurs.
Measurements in dogs have shown that the temperature in the bone-marrow increase by 0.4°C at a dosage of 0.5 W/cm² continuous ultrasound and by 5°C for 2.5 W/cm² continuous ultrasound, in both cases applied for 5 minutes (Payton et al. 1975).

Heat is especially generated at sites of reflection of ultrasound. This reflection occurs particularly at boundaries between tissues with different specific acoustic impedance. Because of this reflection, interference phenomena may result that lead to an increase in intensity. Reflection takes place mainly at bony tissue (35%). The generation of heat as a result of this increase in intensity is marked in the periostium and may lead to periostial pain. This problem is much less marked when pulsed ultrasound energy is used because the generated heat is wholly or partly dissipated between the pulses. Thus the thermal effect is low.

To summarize:
because of differences in absorption coefficient,
- as a result of reflection on tissue boundaries, and
- as a consequence of interference peaks and troughs, generation of heat in the ultrasound field will be non-uniform.
By keeping the treatment head in motion an effort is made to minimize this non-uniformity. The distribution of the heat in the various tissues is unique in comparison with other forms of treatment such as short-wave therapy and thermo therapy.
Heat is especially generated in bony tissue, cartilage, tendons, muscle tissue and skin.

Because the ultrasound beam is almost parallel, the area where the thermal effect occurs will approximate that of the treatment head (ERA). If heat is expected to have a favorable effect on the healing of lesions in the tissues mentioned above, ultrasound therapy in continuous form is indicated. It is important to ensure that the patient at most senses a small thermal effect. At a high intensity (more than 2 W/cm²) and with the continuous form of ultrasound, a marked increase in the blood circulation results in order to keep the body temperature as constant as possible. It has been noted that a lower intensity can also promote circulation. The mechanisms involved will be dealt with later. The significance of heat as a part of ultrasound therapy has been variously assessed. Many diseases are accompanied by disturbed circulation. The body is often incapable of dissipating the heat generated by ultrasound. This leads to an increase in temperature that may have an adverse effect on the disease. In the case of an acute injury, e.g. a sprain of the ankle, the heat generated (in combination with the mechanical irritation) may have an adverse effect on the recovering blood-vessels. Bleeding may easily recur. Therefore it is advisable to wait a couple of days before local ultrasound therapy is started in such cases. From the rheumatologic angle a warning has also been issued about the consequences of raised intra-articular temperatures.

The heat generated in arthritis is found to have a noxious effect on the internal articular structure, especially the articular cartilage. The collagen fibers in hyaline cartilage are destroyed and are replaced by inferior collagen fibers. The enzyme collagenase initiates this process, other enzymes becoming involved in the destruction of the joint.
Articular disorders in which this process in particularly manifest are inflammations of the joints (including rheumatoid arthritis and arthorosis, often characterized by synovitis).

The conclusion from these findings is that ultrasound therapy resulting in an increase in intra-articular temperature is contraindicated, especially in disorders where this temperature is already higher than normal. The interesting question now arises whether anything is known about the effect of heat on collagen fibers other than in hyaline cartilage. Viidik et al. Have shown that under the influence of heat a softening of collagen fibers in tendons and articular capsules can occur, leading to hyper mobility. The loading of the newly formed fibers only becomes optimum if specific kinesio-therapy is also given.

Yet it is incorrect to deny that heat generation is of any value. Lehmann has shown that a rise in temperature is an important factor in the development of some physiologic processes.

3.4 Biologic effects

As stated, the effects of ultrasound therapy are all the result of micromassage (mechanical effect). Depending on the form, continuous or pulsed, this micromassage results in a predominance of either thermal or other effects. The following biologic effects can be seen as a physiologic response to the mechanical and thermal effects mentioned.

```
┌─────────────────────────┐
│ Ultrasound energy       │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐                    ┌─────────────────────────┐
│ Micromassage            │ ─────────────────▶ │ heat                    │
│ (mechanical effect)     │                    │ (thermal effect)        │
└─────────────────────────┘                    └─────────────────────────┘
            │                                              │
            └──────────────────────┬───────────────────────┘
                                   ▼
```
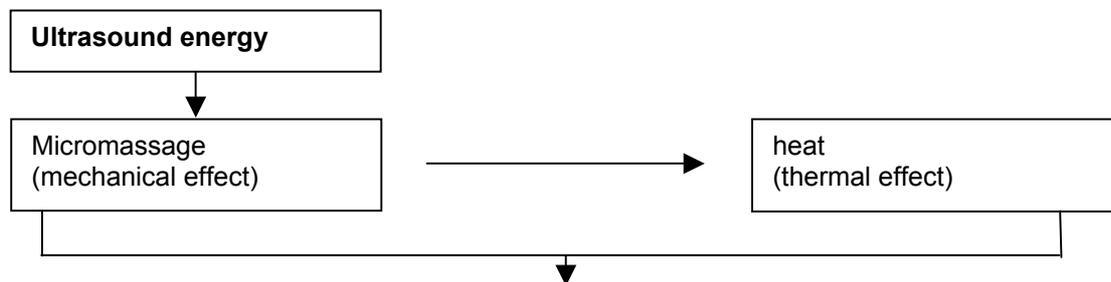
- promotion of blood-circulation
- muscle relaxation
- increased membrane permeability
- increased regenerative power of tissues
- effect on peripheral nerves
- reduction of pain
- other effects

3.4.1 Promotion of blood-circulation

The possibility of promoting the blood-circulation by means of ultrasound is mentioned in many publications. The absorption of ultrasound energy results in a thermal effect, to which the body responds by vasodilation. It is important to remember that the thermal effect is not limited to the continuous form of ultrasound. With pulsed ultrasound there is also a thermal effect, although much smaller. The vasodilation occurring as a result of treatment with ultrasound can be partly regarded as a protective measure aimed at keeping the body temperature within the narrowest possible limit.

The vasodilation is caused by:
a. The release of **tissue stimulants**. This is the consequence of cellular damage resulting from mechanical vibration.
b. Stimulation – possibly direct – of (thick myelinated?) afferent nerve-fibers. This leads to a post-excitatory depression of orthosympathetic activity.
c. Reduction of muscle tone as a result of the mechanism mentioned above.

Although several authors have demonstrated a reflex effect of ultrasound, it is not yet clear what afferent fibers are being stimulated.

An increased muscle tone leads to an impeded blood circulation, with a simultaneous increase in the energy demands of the hypertonic tissue. Thus the concentration of tissue stimulants increases fairly rapidly, leading to an increased nociceptive afferent activity of thin nerve-fibers.
The consequences of this are: increased pain, increased muscle (tissue) tone and a further disturbance of the circulation.

To break this vicious circle, promotion of the circulation will be an important step towards recovery. The possibility of promoting the blood-circulation via the reflex route, using ultrasound, has been demonstrated by Becker and others. He described an improved circulation, especially in the acral blood vessels of patients with vascular disorders, as a consequence of segmentally applied ultrasound therapy. Pohlmann recommends routine inclusion of segmental therapy in the therapeutic plan, in addition to local treatment of disorders.

In the literature, this refers almost exclusively to **Para vertebral** application, although other localizations may also be useful. Lota described the effect of ultrasound at low intensity (0.5-1 W/cm²) on the peripheral blood-circulation and on the temperature of the skin and muscles. The effects of both local and segmental (Para vertebral) treatment were recorded.

The conclusion was reached that continuous application of only 1 W/cm² resulted in both an improvement of the blood-circulation and a rise in temperature of the skin and muscles on local application. Para vertebral application resulted in improvement of the circulation in the skin.

Otherwise, the effect of ultrasound on the blood-vessels has been a subject of controversy. Some authors observed vasodilation while others described vasoconstriction. In a remarkable study by Hogan et al. more light was shed on the significance of these apparently controversial results given by different authors. It is pointed out that the effect of ultrasound (on arterioli in the skeletal muscle) usually leads to vascoconstriction. One phenomenon described by these authors is highly interesting.
In most tissues the arterioli are not at rest under normal physiologic conditions, but show slow peristaltic movements (2 or 3 per minute). On application of pulsed ultrasound the frequency of this vascular mobility is seen to increase enormously (to 31 per minute). An interesting finding is that the frequency of these vascular motions hardly increases (7 to 8 per minute) on ordinary heating of the tissue.
The authors point out that such movements of the arteriolar walls are more important for nutrition of the tissues than arteriolar dilation alone.

3.4.2 Muscle relaxation

In the preceding paragraph it has been pointed out how improvement in the blood-circulation can lead to muscle relaxation because tissue irritants can be carried away.
In addition, it may be possible that the ultrasound directly stimulates afferent nerve fibers and that the muscle relaxation is the consequence of post-excitatory depression of orthosympathetic activity.

3.4.3 Increased membrane permeability

Ultrasound vibrations have been found to increase the permeability of membranes. This effect is seen for both continuous and pulsed application of ultrasound. As a result of the mechanical vibrations, tissue fluid is forced through the cell membrane. This may have an altered ion concentration as a consequence, which might result in altered cell excitability. In the cells the protoplasmic flow is seen to increase so that processes of physiologic exchange are promoted. Due to the circulation of tissue fluid the pH becomes less acidic. This is called the anti-acidotic effect of ultrasound and is useful for the treatment of rheumatoid inflammation (soft tissue rheumatism) in which there is acidosis of the tissues (see paragraph 2.2).

3.4.4 Promotion of tissue regenerative power

Ultrasound has been shown to promote the process of regeneration in various tissues. Dyson and Pond described the effect of ultrasound on artificially-induced small wounds of the ears of rabbits. The favorable effect of ultrasound was equaled only by that of drugs. The most effective intensity was found to be 0.5 W/cm² with pulsed application (1:5) at a frequency of 3.5 MHz. Electron microscope studies showed that the mechanical forces produced a stream of freely mobile particles. The thermal effect plays a subordinate role in this process.

3.4.5 Effect on peripheral nerves

Some authors postulate that ultrasound can depolarize afferent nerve fibers. If the intensity is so chosen as to result in mild stimulation this is evidently the case. How, and to what extent ultrasound can also directly act on nerve fibers at lower intensities, and what afferent nerve fibers are then excited, is not yet clear. The sound pressure is probably not responsible for this because the net pressure is almost zero and the frequency of the pressure changes is so high that mechanosensors cannot react to it.
Once more it must be pointed out that depolarization of many afferent nerve fibers is an obscure phenomenon and that the function of many of these fibers is not yet known.

Continuous ultrasound at an intensity of 0.5-3 W/cm² has been shown to affect the conduction velocity of peripheral nerves. Both an increase and a decrease of conduction velocity have been described. Almost without exception, the thermal effect has been regarded as responsible for this alteration. In this connection the mechanical aspect is not thought to be significant.
At higher intensities a conduction block can occur. Although this is not specifically evident from Table 1.8, nerve tissue is especially sensitive to the effect of ultrasound. In a study of the effect of continuous ultrasound for 5-10 minutes at an intensity of 2-3 W/cm²on the sciatic nerve, swelling of the axon cylinders to total severance of the nerve were found. At a lower intensity (0.25-0.5 W/cm²) the myelin sheath showed minimal changes that became more serious on repeated application.
In the central nervous system an effect of ultrasound can also be demonstrated. An increased serotonin release has been found, the significance of which is as yet unclear.

3.4.6   Reduction of pain

Experience shows that ultrasound therapy results in a reduction of pain which is difficult to explain. The complexity of the processes leading to a sensation of pain is responsible for this difficulty. In addition, little is known about the effect of ultrasound energy on pain sensation. However, some factors can be distinguished that contribute to reduction of pain. These are:

-   **Improvement of tissue circulation**
    The favorable effect of improved blood-circulation has already been discussed in paragraph 2.4. An improved circulation leads to a better drainage of tissue irritants (pain mediators), so that fewer nociceptive nerve fibers are excited.

-   **Normalization of muscle tone**
    Because there is less chemical excitation of muscle afferents, a reduction of reflexly raised tone occurs.

-   **Reduction of tissue tension**
    An improved circulation of the blood (an lymph) has a favorable effect on the resorption of oedema fluid.
    Reduction of the oedema leads to a fall in tissue tension, which in turn results in a reduction of pain and promotion of tissue circulation.

-   **Reduction of pH**
    The improvement in circulation results in an increase of the tissue pH. It is not exactly known how this results in a reduction of pain.

-   **Stimulation of afferent nerve fibers**
    Possibly ultrasound can directly depolarize (thick?) afferent nerve fibers. As with electrotherapy, this can result in a reduction of pain.

3.5   Other effects

Other effects have been observed as a consequence of ultrasound application. At present their therapeutic significance is not clear, while many of the effects in this category are known to have a negative influence.

Tissue damage
Although the use of pulsed ultrasound has reduced the thermal effect it should be remembered that high intensity causes a marked mechanical peak loading of the tissue. This may even lead to tissue damage. The extreme pressure differences developing as a consequence of exposure to ultrasound may cause cavitation in the tissues. Although the output of equipment in current use is such that this phenomenon can hardly occur or not at all, it is wise to adjust the intensity such that the patient *does not sense a painful excitation.*

Stasis of blood-cells
Dyson and Pond described stasis of blood-cells in the blood vessels running parallel to the ultrasound beam after application of ultrasound to chick embryos. The minimum energy at which this phenomenon still occurred was 0.5 W/cm² of continuous ultrasound. This phenomenon was generally reversible. After conclusion of the experiment the circulation was undisturbed.
Continuous movement of the treatment head certainly appears sufficient to eliminate this phenomenon.

Other side-effects described:
-       reduction of the blood-sugar level
-       fatigue
-       nervousness
-       irritation
-       anorexia
-       constipation
-       tendency to catch cold

These side-effects are all thought to result from over-dosage.

4 Technique

4.1   Modes of energy transfer and manipulation of the treatment head

Transfer of energy can in principle be applied in two ways:

4.1.1   Direct contact between treatment head and body

This mode of energy transfer is the most frequently used.
The treatment head is applied directly to the skin. It is known that air reflects ultrasound almost completely. Therefore it is absolutely necessary to ensure application of a highly conductive medium between the treatment head and the skin.
For the requirements in relation to this medium see paragraph 1.5.

In principle, water is an excellent and cheap medium meeting the requirements. However, application often encounters practical difficulties. Underwater treatment is therefore limited to some specific fields and indications, as will become clear later. The many types of contact media currently available for ultrasound transmission can be broadly classified as follows:
-        oils
-        water-oil emulsions
-        aqueous gels
-        ointments

For transmission of ultrasound, gels are the most suitable. The gel must be somewhat dissolved by the skin salts, so that it can be rubbed effectively into the skin (pores). Some manufacturers add a medicament to the contact medium, often a substance that promotes blood-circulation (hyperemia-inducing gels).

The Sonopuls® units include a normal treatment head and a small head. The advantage of this small head is that body parts of irregular shape such as the joints of the hand, wrist, foot and ankle, and structures such as the Achilles tendon, can be properly treated because the small head is in full contact with the part of the body involved.
The treatment head has an (optical) monitoring system that gives a warning indication if the ultrasound energy differs too much from the set value. If the amount of ultrasound energy reaching the tissue becomes less than 80% of the set intensity the intensity is automatically reduced to 0.05 W/cm².
The clock stops if the energy transfer is insufficient and starts again when transfer of energy is resumed. Then the intensity initially set will be automatically supplied by the instrument. In this manner the set time for treatment is effectively used.

4.1.2   Treatment under water

If the surface of the body is very irregularly shaped, and good contact between the treatment head and the skin is complicated in consequence, the so-called *underwater method* can be chosen as well as treatment with the small treatment head mentioned above. Underwater treatment can also be chosen if direct contact is not possible, e.g. because of pain.

The part of the body in question is submerged in a trough filled with water at a pleasant temperature. The treatment head is also submerged and positioned at some distance from the part to be treated. Preferably, the water should have been boiled previously because otherwise any air present may be deposited in the form of bubbles on the transducer plate and the skin of the treated area. As is known, air greatly impedes the transfer of energy; therefore air-bubbles must always be removed. Some areas of the body are difficult to reach, e.g. the under surface of the toes. In such cases a *metal plate* can be used, placed on the bottom of the trough, which will reflect the ultrasound to reach the body area from below. Some sense of geometry is desirable for this technique. Although the literature often mentions a mirror as a reflecting surface, it is better to use a metal plat in view of the higher reflectivity of metal.
A third technique for the treatment of irregularly shaped surfaces is the so-called *water pillow*. This is a plastic or rubber bag three-quarters filled with boiled and cooled water. The bag closely conforms to the area to be treated. The treatment head and the side of the bag in contact with the skin are covered with a sufficient quantity of contact medium and the treatment head is then applied to the bag. However, an appreciable loss of energy is involved. The introduction of the small treatment head has rendered the above-mentioned technique essentially superfluous.

4.1.3   Manipulation of the treatment head

In the ultrasound beam two areas are distinguished (see Chapter 1). The reduction in intensity as a result of absorption in the body is such that most effects are assumed to take place in the near field. This region is characterized by marked differences in intensity. The resulting peaks in intensity may cause thermal and mechanical tissue lesions. This is more marked for 3 MHz than for 1 MHz. Although the energy distribution in the distant field shows intensity peaks to a lesser extent, the highest intensity is still measured in the center of the ultrasound beam. The energy peaks occurring at membranes separating different tissue layers may cause excessive heating of relatively small areas (hot spots).

To ensure treatment of an area as evenly as possible *it is necessary to keep the treatment head in continuous motion, at an even rate*. In this way the position of the intensity variations is continuously altered. Movement of the treatment head – sometimes called the *dynamic method* – is also necessary to avoid changes in the blood-circulation. Ultrasound may cause stasis of the blood cells in the blood-vessels running parallel to the ultrasound beam.

With the underwater method the treatment head can be kept at a distance from the body corresponding to at least the length of the near field. The greater variations in intensity then occur in the water rather than in the body. This suggests that this technique deserves more widespread application than has so far been the case. It must be noted, however, that as a result of reflection at the walls of the water-trough the ultrasound may return to the body. This also implies that it is unwise for the therapist to keep his hand in the trough.

The treatment head can be moved in two ways:
1.   by means of *short, stroking movements* of a few centimeters that always overlap to ensure even treatment of the area.
2.   by means of small *circular motions*. These should also overlap, resulting in an essentially spiral movement.

In both cases the rate of movement is very slow.

Even if relatively small areas are treated, such as trigger points, portions of scars and portions of tendons, continuous movement is necessary although the movement may be very small.
From the above it may be evident that treatment with a stationary treatment head (formerly called the *static method*) should be abandoned. At present the expression *semi-stationary method* is used in this context.

4.2   Points of application

As in the case with all other forms of physiotherapy, ultrasound can be used with the aim of treating tissues. These can be situated at the point of application itself (i.e.: direct effect) or at other sites within the segment (i.e.: indirect effect). In the literature the indirect effect is often called 'segmental treatment', mostly referring to *Para vertebral* application. Other localizations within the same segment are also suitable for segmental treatment. For instance, the trigger-points of the ribs (periostium) occurring in patients with gastric and intestinal ulcers are also typical points of application for segmental treatment.

Ultrasound can only have a therapeutic effect if it is absorbed. From the above it may be clear that the points of application for treatment are especially situated in tissues which receive a sufficient amount of energy and have a fair absorption coefficient (see table 1.8). Important points of application are therefore bony tissue, cartilage, tendons, muscles and skin.
The tissues mentioned above therefore constitute points of application for ultrasound therapy, in view of their favorable absorption coefficient. Although *nerve tissue* absorbs relatively little energy it is found to be highly sensitive to ultrasound energy. The aim can be a direct as well as an indirect effect.

Some authors recommend a combination of local and Para vertebral application in all cases. This is the old 'somatic' line of reasoning, which postulates that in a patient with symptoms at the elbow, for instance, local treatment should be combined with treatment at the Para vertebral levels C6-T1. This has been supplanted by the 'autonomic' philosophy. For Para vertebral application, this implies that the levels C8-T9 are also (or exclusively) treated.
An effect on sites of linkage found at these levels may lead to a post-excitatory depression of orthosympathetic activity. In addition to the more or less specific localizations of the trigger points, other localizations are detectable by periostial massage which are candidates for an indirect effect.

4.3 Dosage

4.3.1 Introduction

Dosage is the product of stimulus strength (intensity) and duration of treatment.
In the application of ultrasound energy the following should be taken into account, however:

a. The possibility of treatment with two frequencies: the higher the frequency, the higher its energy.
b. The possibility of periodic interruption of the oscillation. Within the same period, pulsed ultrasound leads to a lower dosage than continuous ultrasound.
c. The fact that the intensity is given as power per surface are (W/cm²) on most instruments.
d. The use of treatment heads of different size. The dosage is then also different.

The factors of intensity and duration of treatment will now be discussed successively.

4.3.2 Intensity

The intensity is expressed in W/cm².
The Sonopuls® 590 permits the use of continuous ultrasound up to 2 W/cm² and pulsed ultrasound up to 3 W/cm². When the large treatment head with an area (ERA) of 5 cm² is used, the maximum power generation of these instruments is therefore 15W. With the small treatment head (ERA of 0.8 cm²) the maximum power released is 2.4W. The area of the treatment head should always be taken to mean the **effective radiating area (ERA)**, not the geometric area of the treatment head (see chapter 1).

Opinions differ widely on the intensity to be used. Lehmann advocated high-power production, while Edel and Lange claim that a low power yields better effects. Conradi considers and intensity of 0.6 W/cm² as high for continuous ultrasound under some circumstances.
This is taken to mean the intensity *at the site of the affected tissue*. This implies that the energy applied to the body-surface must often be considerably higher. The question arises whether the superficial tissue layers may not be exposed to an unacceptably high intensity.

The values mentioned have been found empirically over the years, an experience gained mainly with ultrasound frequencies between 800 kHz and 1 MHz. On theoretic grounds it is assumed that the therapeutic intensity is lower at 3 MHz than at 1 MHz. This conclusion is based mainly on the greater absorption and greater mechanical effect of ultrasound at 3 MHz.

In any case, during treatment the patient may not feel unpleasant sensations amounting to pain. A *mild* sensation of excitation is permissible.
If, as a result of treatment, headache, vertigo, fatigue and/or other (autonomic nervous) reactions develop, subsequent treatment should be given at a lower intensity. With continuous and pulsed ultrasound at high intensity a sensation of heat may be felt. Only a mild sensation of warmth is acceptable. If the Arndt-Schultz rule is kept in mind it will be clear that in general the intensity of the ultrasound energy applied should be low.

The following guidelines are given for continuous ultrasound:
< 0.3   W/cm²
  0.3 – 1.2 W/cm² is a medium intensity
  1.2 – 3   W/cm² is a high intensity.

For pulsed ultrasound the mean value must be considered. For instance, an intensity of 1 W/cm² in position 1:5 pulsed ultrasound is equivalent to 0.2 W/cm² continuous ultrasound. This is approximately the case for the thermal effect of ultrasound. However, the peak intensity of the pulse must also be considered because of the mechanical effect.

4.3.3 Energy release

The release of energy can be either continuous or pulsed. The reason for treatment with pulsed ultrasound is to avoid the effects of heat generation. For the physical aspect reference may be made to chapter 1. Besides elimination of the thermal effect, enhancement of the mechanical effect is sought. Summer and Patric, as well as Edel, refer to the specific sensitivity of nerve fibres to pulsed energy. Edel also points out that pulsed ultrasound has a greater muscle relaxant effect than the continuous form. At a frequency of 3 MHz these specific effects of pulsed application are even greater.

Some instruments permit a variation of the ratio of pulse time and pulse pause (see chapter 1). A reduction of the dosage – and consequently of the heat generated – for the pulsed form of ultrasound permits an increase in intensity at the body surface and thus an enhanced effect of ultrasound in more deeply located tissue structures.

However, one should remain aware of the adverse effects that may occur, as discussed in the previous chapters.

4.3.4   Duration of treatment

Opinions in the literature on the duration of treatment also vary. The duration of treatment depends on the size of the body area to be treated.

Lehmann fixes the maximum duration of treatment at 15 minutes. This refers to a treated area of 75-100 cm², which he considers the maximum area that can reasonably be treated (see chapter 5). Naturally the ERA of the treatment head is of importance in this respect.

Areas no larger than the treatment head are in general treated for a few minutes (3-5 minutes) by means of the semi-static method. Larger areas treated by the dynamic method require a longer duration of treatment.

4.3.5   Start and frequency of treatment

In fact, the frequency of treatment is not a part of the dosage but a consequence. The *start* of ultrasound therapy for acute trauma is usually set at 24-36 hours after injury.

The reason is that direct (local) treatment by means of ultrasound energy might damage the recovering blood vessels.

However, in addition to other physio-technical applications such as cryotherapy and pulsed shortwave therapy, indirect ultrasound application may be considered or treatment of the area around the lesion to promote the regional circulation.

The *acuteness* of the condition determines the dosage and the latter determines the frequency of treatment. Very acute disorders should be treated *at least daily*. The more chronic conditions, which are generally less severe, should be treated two or three times a week.

4.4   Methods

4.4.1   Before treatment

The therapist begins by taking the patient's history in relation to ultrasound therapy, and investigates absolute and relative contraindications.
- The patient is informed of the treatment and its purposes
- The site of the disorder is located as accurately as possible
- Then the therapist tests the thermal sensitivity
- In the meantime the therapist has chosen either:
  o the direct contact method, or
  o the underwater method
  and the contact medium or the water is brought to the correct temperature.
- The patient is placed in correct initial position, relaxed and free from pain as far as possible.
- The skin of the area in question is cleaned (removal of grease) with soap or 70% alcohol to permit optimal transmission of the ultrasound.
- If the skin is hairy shaving is best
- The parts of the body not treated are covered to avoid cooling.

4.4.2   During treatment

- The therapist sets the parameters on the instrument, for instance:
  o The frequency (1 or 3 MHz)
  o Pulsed ultrasound (incl. Pulse time/pulse pause ratio)
  o The intensity
- The contact medium is applied to the area to be treated. With the underwater method the part to be treated is submerged in water at a pleasant temperature. Air bubbles on the skin are removed.
- In the meantime the therapist has chosen the small or large treatment head and this is applied to the skin, or with the underwater method – at a distance from the body at least as large as the near field. This depends on the frequency and the size of the treatment head.
- The duration of treatment is set.
- The treatment head is kept in slow continuous motion, also for the semi-static method.

-   The patient is regularly asked to report any sensations felt. If necessary, the treatment is modified; the intensity can be reduced or a switch is made from continuous to pulsed ultrasound.
-   If there are indications of poor transfer of the ultrasound energy the contact medium can be reviewed if necessary, or it can be moved with the treatment head. Especially for patients with a dry (scaly) skin, contact medium must be regularly added.

4.4.3   After treatment

-   The equipment is switched off
-   The patient's skin and the treatment head are cleaned. The residual contact medium can be easily removed with a towel or tissue. The treatment head is also cleaned with 70% alcohol
-   The expected effects are checked (e.g. pain, circulation and mobility). Attention is given to the occurrence of side-effects
-   The patient is asked to comment subsequently on any reactions that may occur

5   Special applications of ultrasound

5.1   Combined therapy

In physiotherapy, combined therapy refers to simultaneous application of ultrasound and low- or medium-frequency electrical stimuli.

Combination of stimuli is only purposeful if:
-   The combination of stimuli has an effect different from those of the stimuli separately. These effects must have a diagnostic and/or therapeutic value
-   The combination of stimuli saves time, because otherwise they would have to be given separately in which case the effects of the separate stimuli remain the same

5.1.1   The combination of ultrasound with low-frequency electrotherapy

In general, the combination is with diadynamic currents. However, it is not at all necessary to use this form of current exclusively. Trabert's called 2-5 current is also suitable and, any low-frequency interrupted direct current.
Gierlich was the first to introduce this method. He had noted that sensitive points (e.g. trigger points, tender points and tendomyoses) react very strongly to this combination of stimuli. In analogy with Kahane's observations (galvanopalpation), it is noted that in addition to the hyper-esthesia a (circumscribed) skin rash also develops over the sensitive point.
Gierlich mentions the advantage – in contrast to galvanopalpation – that more deeply situated points can also be diagnosed. In this way, not only can sensitive points be discovered but larger hyper-esthetic areas, dermatomes or parts thereof (Head's zones) can also be tracked. They show an analogous reaction to trigger-points, with hyper-esthesia and rash. However, the rash is not as sharply outlined.
Hoogland (1980) reported that the combination of these stimuli yields effects different from those of the stimuli separately.

This is seen, for instance, from:

-   The fact that, for localization of application points for treatment by means of combined therapy, a very low current intensity is sufficient. With this low intensity, localization of such a point exclusively by electrical current is not possible.
-   The fact that ultrasound has a sensitizing effect on nerve fibers. In combined therapy this becomes evident because the intensity of the current must be repeatedly reduced during treatment; otherwise the excitatory sensation becomes excessive for the patient.
-   The fact that switching off the ultrasound equipment leads to a reduced current sensation. This often occurs immediately, or after a short interval, because adaptation of the nerve-fiber occurs. This leads to the conclusion that combined therapy is especially suitable for diagnosis. Certainly, this is true in those cases where the disorder is not very acute and the application points are not immediately traceable.

Therapeutically, ultrasound complements the effect of electrotherapy because the ultrasound prevents or markedly reduces adaptation, so that the electrical stimulus becomes more effective and can be applied for a longer period without such unsiderable features as unacceptably high current and etching of the skin. It may be clear that, for various reasons, the intensity of the ultrasound must be low when this form of therapy is employed (Hoogland 1985).

The method as advocated by Gierlich has a number of major disadvantages. These can be summarized as follows:
- The method is very aggressive because of the galvanic effects of the diadynamic current. Therefore it is suitable almost exclusively for conditions which are not very acute
- Very soon, etching develops. This is probably the consequence of the very thin layer of contact medium used as a conductor
- The effect at depth is slight because use is made of rectified forms of current and in addition of a low frequency, so that application points for electrotherapy can be found only in the skin and superficial muscle layer
- The treatment head, which is also the active electrode, must be regularly lifted from the body surface to add contact medium. The same intensity must always be used in order to demonstrate differences in sensitivity, so that it is almost impossible to reduce the current to zero. Lifting and replacing the treatment head is unpleasant for the patient when the circuit is opened and, especially, closed

To eliminate or reduce a number of these 'negative' phenomena the Sonopuls® uses chopping of the electrical pulse of the low-frequency current (fig. 4.1b). This results in a current with a frequency of 4000 Hz and pulse pauses of 0.125 ms each.

This halves the galvanic effect of the direct current and in addition the action in depth of the current increases on account of the higher frequency. The electro-physiologic consequences of increasing the frequency will not be further considered in this connection.
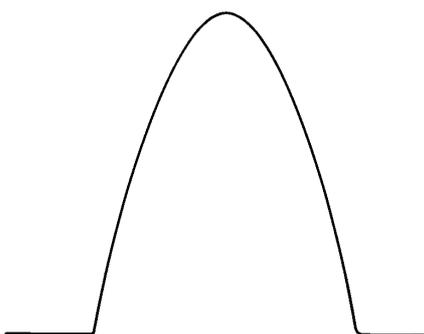

Fig. 4.1a Electric pulse of the low-frequency current   Fig. 4.1b Pulse shape from the 'chopper'
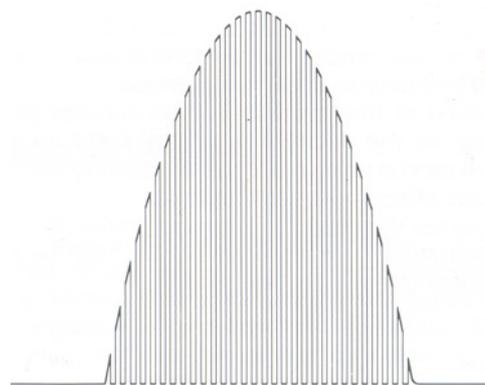
5.1.2   The combination of ultrasound and medium-frequency electrotherapy

- Suppression of the adverse effects of combined therapy has been obtained by combining ultrasound with medium-frequency alternating currents (Hoogland 1980). The advantages can be summarized as follows:
- There is no aggressive excitation
- With a sine shape alternating current etching is virtually excluded
- With correct electrode positioning the action in depth is greater, so that action points situated at a greater depth are also localized.
- Opening the electrical circuit does not cause unpleasant sensations for the patient. Closing the circuit is still unpleasant on account of the sudden electrical sensation, but is much less unpleasant than with interrupted direct current.

5.1.3 Technique of combined therapy

Any discussion of the technique can only be approximative because of individual differences. For instance, the current or frequency of the electrotherapy may e chosen differently as the situation changes.

Diagnosis

Ultrasound setting	: 0.5 W/cm² continuous
Diadynamic current	: current form DF or
Medium-frequency current	: AMF 100 Hz bipolar method.

For the localization of superficially situated structures, use is made of an indifferent electrode positioned in the same plane as the active electrode.
For more deeply situated application points the indifferent electrode must be positioned opposite the active electrode. The active electrode is formed by the metal plate of the treatment head (see fig. 4.2 and 4.3).
In combination with rectified forms of current the indifferent electrode is connected to the anode (+) and the treatment head with the cathode (-). Attention should always be given to supplying an ample amount of contact medium to minimize the risk of etching. The intensity of the current is so adjusted that the patient can just sense its passage. This intensity is determined in an area where pathologic excitability of the tissues may be assumed to be absent. With this combination of current and 0.5 W/cm² a search is made for points that:

- have a (markedly) increased sensitivity. (Beware of etching at sites of skin defects)
- radiate into the affected area
- radiate into an area at some distance from the point found (referred sensation).

Fig. 4.2 Diagnosis with combined therapy and treatment of deep structures.
Fig. 4.3 Combined therapy for superficial conditions.

Therapy
At the site found, therapy is given by means of the semi-stationary method. As a safety precaution, but also on account of the effect of pulsed ultrasound on nerve tissue (Edel) the pulsed mode of ultrasound is now chosen with the same intensity as used for diagnosis.
The duration of treatment is 5 to 10 minutes per point, depending on the excitability of the point involved.
In general, it can be said that if the excitability decreases a therapeutic effect has been obtained.
In some cases the excitation sensed markedly increases during treatment. The intensity should then be reduced until it is well tolerated by the patient.

5.2 Indications and contra-indications

5.2.1 Indications

As pointed out earlier, the combined therapy is unique on account of the sensitizing effect of ultrasound on nerve tissue. This is a complementary effect to that of the application of the electrotherapy. The range of indications for combined therapy therefore corresponds to that of low- and medium frequency electrotherapy.

5.2.2 Contra-indications

There are no specific contra-indications to combined therapy. Any contra-indications refer to the stimuli separately, i.e. both the ultrasound (see chapter 6) and the electrical current. A discussion of the latter is outside the scope of this book.

5.3 Ultrasonophoresis therapy

By ultrasonophoresis therapy is meant medical treatment with substances introduced into the body by means of ultrasound energy.
Ultrasonophoresis is a rational supplement to the classic method of introducing substances into the skin by means of massage. The possible disadvantages of massage are that hypersensitive tissue cannot be treated easily and that penetration of the active substances is not deep.
Iontophoresis therapy makes it possible to introduce the ions of certain active substance into the body by means of direct current. The penetration depth of the substances used with this method is distinctly greater than with massage.

It has been found that active substances can also be introduced into the body through the intact skin by means of ultrasound energy. Riffin and Touchstone demonstrated this for hydrocortisone ointment. They were able to demonstrate the presence of corticosteroid to a depth of 6 cm. It can be clearly shown that solid particles at the bottom of a glass vessel are vigorously agitated if the treatment head is aimed at them. In addition to the well-known oscillating motion of solid particles induced by ultrasound there is also a 'sound pressure' that pushes the particles away.

Ultrasound energy has the advantage that the particles to be introduced into the body need not be electrically charged and that etching cannot develop. In addition, the increased permeability of the various membranes under the influence of ultrasound makes it possible for the substances to penetrate rather deeply into the body. Because the substances in question (e.g. ointments) greatly absorb ultrasound a good contact medium should be employed. Some substances are soluble in water (or alcohol) and water is known to be an excellent contact medium. The viscosity of water can be increased by adding glycerol. In the resulting *thixotropic gel* the active substances are therefore present in solution. After conclusion of treatment the contact medium containing the active agents need not be removed, but can be covered with a bandage.

Substances not present in the contact medium can be rubbed into the skin (e.g. with a swab of cotton wool), after which the *contact medium* is applied to the area to be treated.

For determination of the dosage of the ultrasound no specific directions can be given. Reference may be made to Chapter 1 and Chapter 3, paragraph 3.3.

The active agent used in ultrasonophoresis can be classified according to their effect. The best-known and most frequently used are briefly summarized here.

Drugs affecting the circulation
These substances, such as histamine, methyl nicotinate, mecholyl etc., are known to be potent vasodilators and are used in cases of peripheral circulatory disorders, rheumatic conditions and aseptic inflammations.

Drugs promoting wound healing
Used are substances with a resorption promoting and fibrinolytic action. These substances are available under different trade-marks.

Anti-inflammatory drugs
These mostly contain corticosteroids and are used in (aseptic) inflammations such as (peri)tendinopathy, bursitis and other conditions of the soft tissues (soft tissue rheumatism).

The reports of two studies indicate that ultrasonophoresis is a valuable tool in physiotherapy.
Griffin (1967) treated 66 patients with ultrasound and hydrocortisone. 68% of the patients thereafter showed normal mobility without pain. In 36 patients treated with ultrasound and a placebo 55% showed no improvement. Moll (1979) treated various disorders and used the following forms of treatment:

Improvement
1.   lidocaine/decadron in combination with ultrasound 88.1%
2.   placebo in combination with ultrasound 56   %
3.   placebo with ultrasound of zero intensity 23.1%

6   Indications

6.1   Introduction

The Range of indications for ultrasound is very wide. It includes nearly all the conditions encountered in physiotherapy. The question arises as to the conditions for which ultrasound is the most suitable form of treatment. This becomes clearer when the factors restricting the use of ultrasound are considered. These factors are: *time and intensity.*

6.1.1   The time factor

The maximum duration of therapy is set at 15 minutes per treatment. It is improbable that (specific) effects will still occur with treatment of longer duration. However, the side-effects described in Chapter 2 will do so. Lehmann states that during the maximum period of treatment of 15 minutes the area treated can be at most 75-100 cm². This amounts to 1 to 1.3 minutes per cm². The present author fixes the *minimum duration of treatment at 1 min/cm².* This means that the *maximum treatable area is 75 cm²* (treatment head of 5 cm² and 15 minutes treatment). The ERA should be taken into account!

6.1.2 The intensity factor

In determining the intensity the essential question is: what intensity is desired at the site of the affected tissues? Then, bye means of the half/value depth an estimate can be made of the intensity to be applied to the body-surface. On the basis of the penetration depth it can be determined whether a therapeutic effect may be expected for the location in question.

The required intensity at the surface may then become so high that over dosage will occur for the superficial tissues – especially the skin, subcutaneous connective and fatty tissue and superficial muscle layers.

This policy leads to two criteria of importance for ultrasound therapy and thus for defining the indications:

a. the maximum area for treatment is small. This implies that for many disorders included in the range of indications for ultrasound therapy only partial treatment is possible. For instance, in anykylosing spondylitis the sacroiliac joints can be treated but not the entire vertebral column.
b. the action in depth of ultrasound is not great. Although it depends on the absorption in the surrounding layers of tissue, the action in depth of ultrasound is limited to 3-4 cm (at 1 MHz, see table 1.10).

Against this background the range of indications will now be described, with some comments.

6.2 Disorders

From the effects as described in Chapter 2 it might be determined *under what conditions* ultrasound is indicated in some pathological states. The indication is in fact independent of the medical diagnosis. A tissue-specific analysis for the *nature and position of the affected tissues* determines the choice of ultrasound, taking account of the position laid down in paragraph 5.1.
Example: in the diagnosis of a sprained ankle the indication for ultrasound is the swelling of the joint.

A specific classification of the range of indications is obtained by classification of pathological conditions:

6.2.1 Disorders of bony tissue, joints and muscles

Post-traumatic conditions after contusion, sprain, luxation, fracture.
In these cases there is a relative contra-indication for 24-36 hours after the injury. Treatment is mainly aimed at control of swelling and pain and also at the promotion of wound-healing internally and externally. Only small joints (surface < 75 cm²) are candidates for treatment.

Various effects of ultrasound have a favorable influence on fracture healing, including the resorption of calcium. In fractures, the piezo-electric effects may be important for healing. The indication depends on the location of the fracture.
A distal radial fracture can be more easily treated, because of the thin surrounding tissue layers, than a fracture of the femur where there is absorption in the surrounding tissues.

6.2.2 Rheumatoid arthritis in a quiescent stage

- **Arthrosis/arthritis**
  Here also it is true that if the condition is very acute, i.e. if the joint is hot, there is a relative contra-indication. A retropatellar chondropathy can be treated satisfactorily with ultrasound, whereas lumbar spondylarthrosis cannot, on account of the deep location of the facetal joints. Reflex muscular hypertonia is a good indication, however.
- **Ankylosing spondylitis**
  Local effect only. See paragraph 5.1.
- **Bursitis/capsulitis/tendonitis**
  Aspects mentioned previously are also of importance here. In addition, piezo-electric effects also appear to be involved, especially for the collagen tissue. Viidik indicates that the ordered arrangement of these fibers might be determined by piezo-electric phenomena. This might imply that in the application of ultrasound the direction of the sound beam is of importance. The direction should then be parallel to the arrangement of the collagen fibers.

6.2.3 Disorders of the peripheral nerves

- **Neuropathy**
  In many entrapment neuropathies a swelling around the nerve is assumed to exist. On account of the specific localization with a small area, the treatment of nerve fibers with ultrasound is a good indication. The high sensitivity of nerve fibers for ultrasound should be taken into account.
- **Phantom pain**
  The action is assumed to be based on the mechanical effect of ultrasound, leading to a 'numbing' of the nerve. However, it is not impossible that the neurinoma is damaged by ultrasound.
- **Intervertebral disc prolapse**
  In fact, this is a special form of entrapment neuropathy. The favorable effect of ultrasound has recently been demonstrated once more. However, the thermal effect may lead to swelling of the protrusion.

6.2.4 Disorders of the circulation

- Raynaud's disease
- Buerger's disease
- Sudeck's dystrophy
- Oedema

Various authors indicate that little improvement is obtained with local treatment of these diseases, segmental treatment being preferable. In this connection the application points are especially the trigger-points in the muscles.

6.2.5 Internal organic disorders

Much clinical experience has been gained on he influence of ultrasound on the internal organs. Local application of ultrasound to organs such as the stomach (anti-acidotic effect) is now hardly used. However, this field of indication should not be forgotten.
In suitable cases, ultrasound may be a substitute for chemotherapy. Typical application points for this indication are muscle and periosteal points in the corresponding segmental areas.

6.2.6 Disorders of the skin

- Scar tissue
  - o Surgical scars
  - o Traumatic scars

Both form a very good indication for ultrasound therapy. In dosage, the time factor is set at 1 to 1.5 min/cm² scar tissue. The intensity depends on the depth of the scar. Both the rate of healing and the quality of the scar are improved.
For scars of wounds that have not yet closed, sterility of the contact medium is an absolute prerequisite. The possibility of cross-infection from the treatment head may be a problem in such cases.

6.2.7 Dupuytren's contracture

Just as with scar tissue, Dupuytren's contracture is a good indication because of the effect of ultrasound on collagen fibres, leading to a reduction of the contracture. Sometimes the underwater method is necessary because of the marked flexion of the fingers.
Ultrasonophoresis with hyaluronidase is valueable in such cases, as in the treatment of scar tissue.

6.2.8 Open wounds

- Decubitus ulcers
- Post-traumatic

Accelerated wound-healing is a well known effect of ultrasound. The reasons have been described under the effects of ultrasound.

7   Contra-indications

7.1   Absolute specific contra-indications

Because ultrasound therapy, when the intensity is too high, can induce a potent thermal effect, all the contra-indications that apply to thermal therapy are also applicable here. For reasons of safety some tissues or organs are not treated, such as:

- Eyes
  Because cavitation in the ocular fluid may possibly lead to irreversible damage, the eyes should not be treated with ultrasound
- Heart
  With direct treatment, changes in the action potential have been described
- Pregnant uterus
  Although the intensity reaching the uterus is minimal, the abdomen of a pregnant woman should not be treated for reasons of safety. The effect of ultrasound on rapidly growing tissue (fetus) is uncertain. To avoid any disturbance the treatment of segmentally corresponding tissues is also inadvisable
- Epiphyseal plates
  These regions formerly ranked high among the contra-indications. With *pulsed application* of ultrasound (at low intensity) these areas *can now be treated* in patients younger than 18.
- Brain tissue
  No literature data known
- Testicles
  Because the influence of ultrasound on these organs is unpredictable, they are not treated.

7.2   Relative specific contra-indications

Status <u>after</u> laminectomy
Care is necessary in the case of patients who have undergone laminectomy for disc prolapse. Treatment of scar tissue or the facetal joints of the vertebral column – on insufficiently careful indications – can lead to damage to the nerve-roots within the spinal membranes.

Loss of sensitivity
Areas where loss of sensitivity exists should be treated carefully. This is especially true for the application of continuous ultrasound.

Endoprostheses
Bone cement (methyl methacrylate) has a high absorption coefficient. Plastic parts of prostheses may suffer from the thermal effects of continuous application of ultrasound.

Note: *osteosynthesis material* shows little increase in temperature, either on account of the good conduction of metals or because metal reflects ultrasound energy. In this case the surrounding tissues are hazardous.

Studies have shown that internal fixation by means of bolts does not form a contra-indication to ultrasound if this is applied at low intensity and by the dynamic method.

Tumors
After some initial success, ultrasound therapy of tumors has been discontinued.

Post-traumatic sequelae
As described previously, in these cases the circulation is often not capable of reacting adequately to the thermal input. As a result of both the thermal and mechanical effects the recovering blood-vessels may rupture, leading to recurrent bleeding. *Local* treatment of low intensity may be given only after 24-36 hours.

Thrombophlebitis and varices
The mechanical vibrations may cause an embolism.

ENRAF
NONIUS

Septic inflammations
In such cases there is the hazard of accelerated growth and dissemination of the bacteria throughout the body.

Diabetes mellitus
Ultrasound may lead to slight depression of the blood-sugar level. In patients with diabetes this may lead to symptoms such as fatigue. These usually disappear after reduction of the dosage.

8   Examples of treatment

8.1   Introduction

From the discussion of ultrasound therapy in this book it may be apparent that the therapist can determine whether ultrasound will be an effective therapeutic means or not, on the basis of the effects of ultrasound.
The nature and position – deep or superficial – of the tissues determine this, as do a large number of secondary and tertiary factors such as:

The actual temperature of a joint, which may alter from one session to another.
- A patient with diabetes mellitus where decompensation occurs, with sudden sensitivity to small variations in the blood-glucose level.
- Deterioration of the circulation.

These are a few examples, taken at random, where ultrasound is not suitable despite the fact that the indication, as such, is correct.
The choice of frequency – 1 or 3 MHz – is also determined by the localization of the tissues affected. As a consequence of the high absorption at 3 MHz, penetration into the tissue is relatively low. High intensities are required fairly soon if some ultrasound energy is to reach the affected tissue and produce a therapeutic effect.
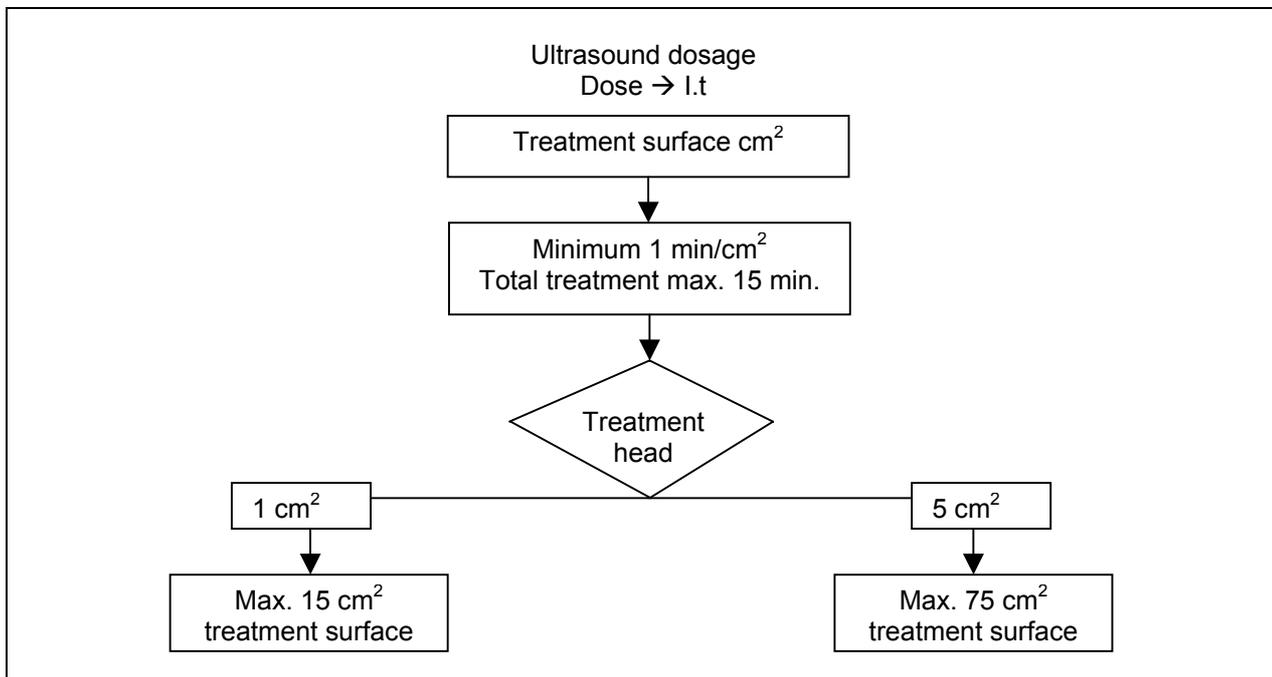

Diagram 7.1.   Determination of time factor
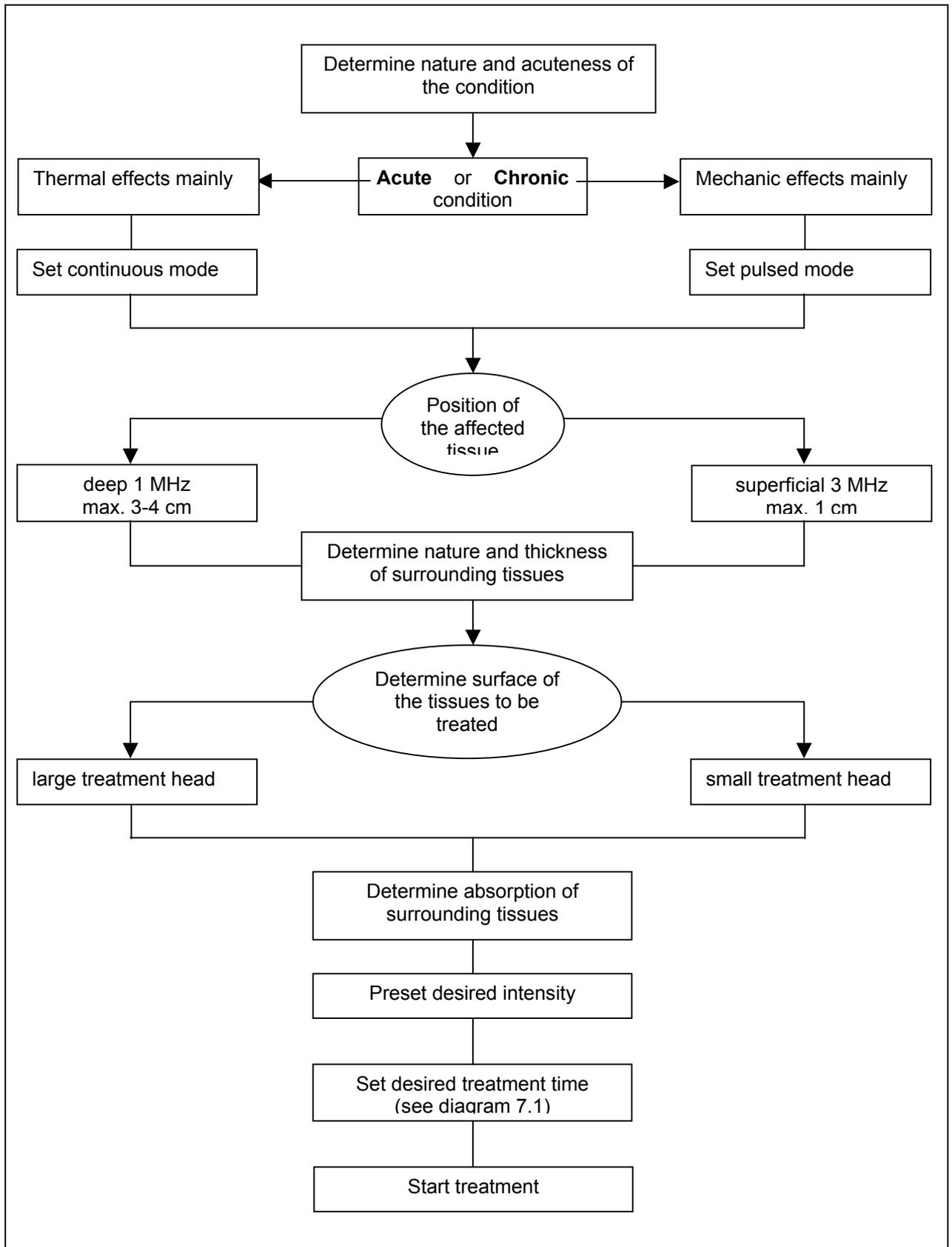
Diagram 7.2   Treatment scheme

N.B.   If the intensity is too high, it must be changed and/or the choice of thermal or mechanical
         effect must be reconsidered.

8.2   Some detailed examples of treatment

8.2.1   General

First, determine the intensity required at the site of the affected tissue. Then calculate – on the basis of the half-value depth (D1/2) – the intensity to be applied to the body-surface. The duration of treatment is referred to the area in cm² to be treated (see diagrams 7.1 and 7.2).

8.2.2   Specific

8.2.2.1 Subacromial bursitis

Duration of treatment
Surface area: say 15 cm².
For a large treatment head (5 cm²) a minimum treatment time of 3 minutes. For a treatment head of 1 cm² the corresponding minimum would be 15 minutes. A small treatment head is therefore excluded.

Intensity and frequency (1 or 3 MHz)
Assume a thickness of the deltoid muscle of 2 cm.
Half-value depth (D1/2): at 1 MHz 1   cm.
         At 3 MHz 0.3 cm.
Desired intensity at the location of the bursa:
0.5 W/cm² *pulsed* ultrasound for *acute* conditions
1   W/cm² *continuous* ultrasound for *chronic* conditions

Required intensity at the body surface:
  2 W/cm² for acute conditions (1 MHz)
  8 W/cm² for acute conditions (3 MHz)

  4 W/cm² for chronic conditions (1 MHz)
16 W/cm² for chronic conditions (3 MHz)

Conclusion
Under these circumstances subacromial bursitis can only be treated at a frequency of 1 MHz and only in the acute phase. Also note the contra-indication if the joint is hot.

8.2.2.2 Treatment of scar tissue after total hip surgery

Duration of treatment
Assume: length of scar 14 cm.
Time: 6 minutes minimum with the large treatment head (diameter 2.5 cm).

Frequency (1 or 3 MHz)
3 MHz is ideal on account of the high absorption in the skin and superficial tissue layers to a maximum of 1 cm depth in the muscle tissue (see table 1.10 of penetration depths). The advantage is that the prosthesis and the cement are spared, because the intensity at these sites is generally negligible.
If the deeper parts of the scar are also to be treated, this can be done at 1 MHz. A combination of both approaches is a logical consequence for deep scars.

8.2.2.3 Treatment of tendinitis of the extensor carpi radialis brevis muscle

Basic assumptions
Situation: just below the extensor carpi radialis longus muscle at the origin of the tendon from the muscle belly.
Thickness of tissue layer: < 1 cm
Area of pathological tissue:
the origin of the tendon is mostly involved (1-2 cm²).
Technique: semi-stationary

Duration of treatment
1 to 2 minutes (small treatment head of 1 cm²)

Intensity and frequency (1 or 3 MHz)
0.2 W/cm² pulsed ultrasound for an *acute* condition at the site of the lesion
- 1 W/cm² pulsed ultrasound for a *chronic* condition at the site of the lesion.

Required intensity at the body surface:
0.6 w/cm² for acute conditions (3 MHz)
0.4 W/cm² for acute conditions (1 MHz)

3 W/cm² for chronic conditions (3 MHz)
2 W/cm² for chronic conditions (1 MHz)

These high values are the results of absorption in the overlying tissue layers.

Conclusion
An acute disorder is a good indication for both 1 and 3 MHz and for application of the small treatment head. With decreasing acuteness the condition becomes less suitable for ultrasound. In addition, the question arises as to whether the required dosage of ultrasound for a chronic condition is permissible for the superficial tissues.

8.2.2.4 Treatment of synovitis of the knee

Basic assumptions
The area of the knee in one plane is 15 x 15 cm.
It is usual to treat 3 planes (anterior, medial, lateral).
The total area to be treated is therefore 675 cm².

The large treatment head has an area of 5 cm².
The duration of treatment for this area is at least 135 minutes. This is unacceptably high regardless of the intensity used. Even if a single plane is treated per session the duration of treatment is unacceptably long, viz. 45 minutes.

From the above examples two general postulations can be derived relating to ultrasound therapy.

- ultrasound therapy is mainly suitable for highly acute conditions
- ultrasound therapy is mainly suitable for localizations with a small area

*Figure 7.1 Treatment of arthritis of the finger joint*   *Figure 7.2 Treatment of supraspinal tendinitis*
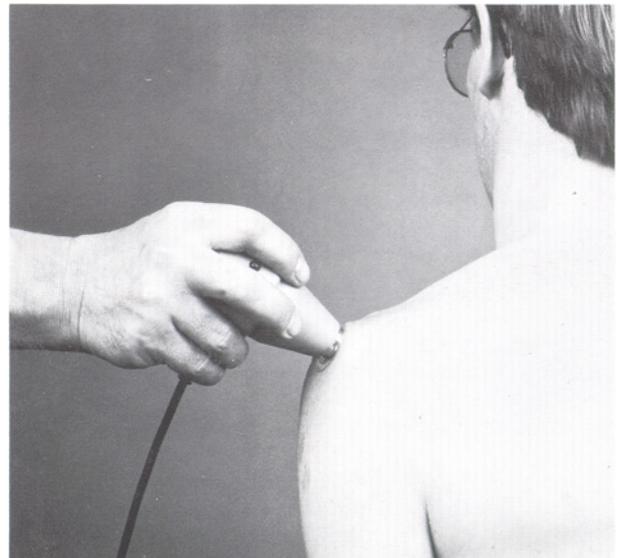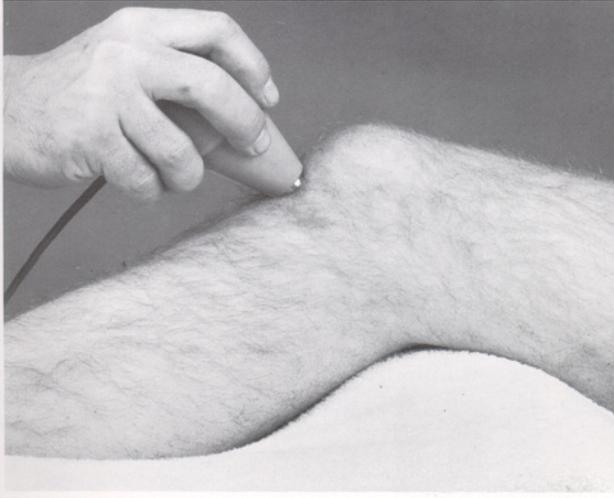
Figure 7.3 Treatment of an enthesopathy of the patellar ligament.

Figure 7.4 Treatment of the attachment of the extensor carpi radialis brevis muscle
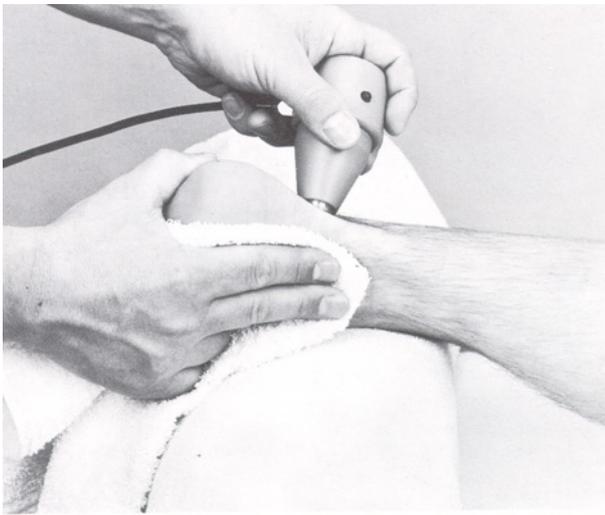
Figure 7.5 Treatment of tendonitis of the Achilles tendon.
**Notice the towel for the protection of the treater (layer of air)**
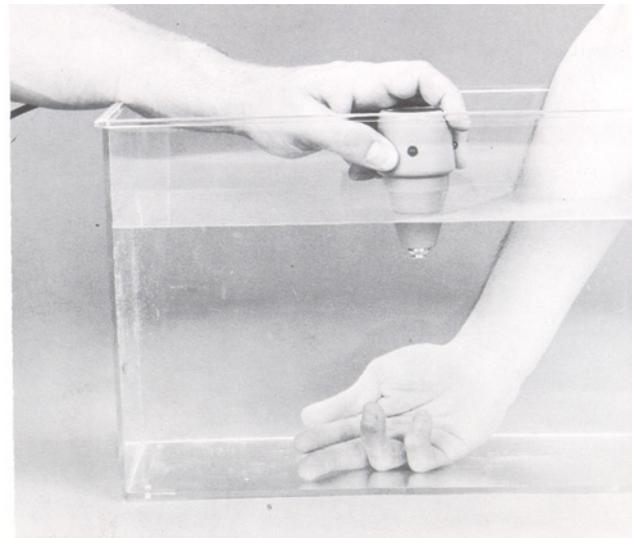
Figure 7.6 Underwater treatment of a Dupuytren's muscle.
A large distance has been chosen in order to avoid the near field of the small 3 MHz head as much as possible
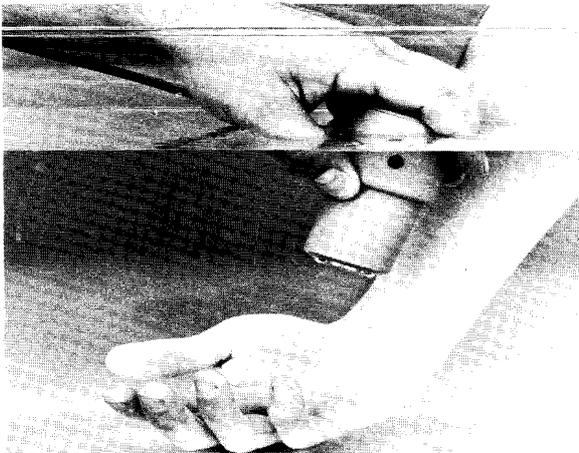

Figure 7.7 Underwater treatment of a Dupuytren's muscle
**Note the small distance of the large 1 MHz head**
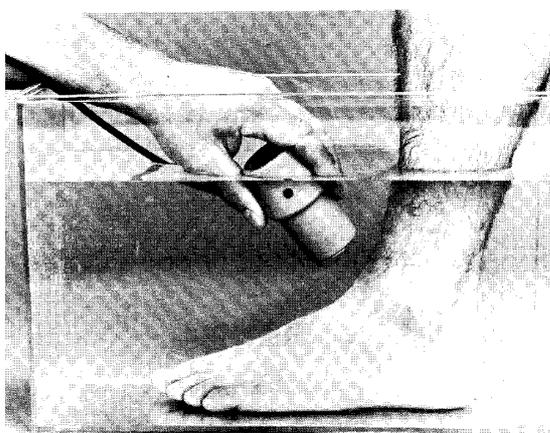
Figure 7.8 Underwater treatment of a frictionsyndrom of the tibialis anterior muscle

Note for the therapist: for underwater treatment it is advised to use a glove.

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