Ultrasound applications in humans
Recommendation by the German Commission on Radiological Protection

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**Ultraschallanwendungen am Menschen**

Empfehlung der Strahlenschutzkommission

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Recommendations

Owing to the increasing use of high intensity ultrasound on humans, especially for non-medical applications, e.g. ultrasound lipolysis\(^1\), combined with an associated lack of operative staff training, health risks to those individuals undergoing treatment cannot be excluded.

This recommendation issued by the Commission on Radiological Protection (SSK) supplements the commission’s recommendations on patient safety (SSK 1997) with reference to new forms of application and the on-going technological development of devices, while also making recommendations on the safety classification of equipment and the training requirements, graded according to intensity category, for medical and non-medical ultrasound applications.

To be in a position to apply ultrasound safely, it is essential that users have a basic knowledge of physics, ultrasonic propagation behaviour, and anatomy to ensure correct use, as well as preventing damage or any adverse effects. Furthermore they also need to possess additional medical knowledge to ensure critical areas of the body are protected and any contraindications are recognised and observed. Owing to the considerable risk potential, regulation of the production, marketing, use and maintenance of high intensity ultrasound devices is urgently needed.

The Commission on Radiological Protection therefore recommends:

I. **Devices**

Classing ultrasound devices for human application with ultrasonic intensities\(^2\) of over 50 mW/cm\(^2\) for eyes, or over 100 mW/cm\(^2\) for the rest of the body, or with an MI (mechanical index) > 0.4 or a TI (thermal index) > 0.7 as medical devices (Class IIb), thus making them subject to the Act on Medical Devices, e.g. with regard to design, production, marketing, application, maintenance, quality controls and inspections, the obligation to report, active market monitoring, and the documentation of complaints.

II. **Medical applications in a medical context**

1. Restricting the use of diagnostic and therapeutic ultrasound\(^3\) on humans to medically justified cases.

2. Only licensing the use of ultrasonic intensities of up to 50 mW/cm\(^2\) for eyes, up to 100 mW/cm\(^2\) for the rest of the body, or with an MI (mechanical index) < 0.4 and simultaneously a TI (thermal index) < 0.7 on humans for medical diagnosis by a licensed physician, or under the supervision of a licensed physician (e.g. for training purposes).

3. Only licensing the use of ultrasonic intensities of over 50 mW/cm\(^2\) for eyes, over 100 mW/cm\(^2\) for the rest of the body, or with an MI (mechanical index) > 0.4 or TI (thermal index) > 0.7 on humans for medical diagnosis by a licensed physician with the relevant certificate (see IV), or by residents or other individuals with medical

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\(^1\) Among scientists lipolysis is generally understood as being the hydrolytic splitting of saponifiable lipids. The term is nevertheless increasingly being applied - as here - to mean the “liquefaction of fat cells”.

\(^2\) Hereafter ultrasonic intensity is to be understood as the intensity spatial and time average \(I_{\text{SATA}}\) (SATA: spatial average + time average), see also DIN EN 61689; VDE 0754-3:2008-07.

\(^3\) The difference between diagnostic and therapeutic ultrasound is generally a question of the frequency range used.
training, under the supervision of a licensed physician with the relevant certificate (see IV).

4. Requiring users possess a certificate covering treatment applications (see IV) for the use of ultrasonic intensities from 50 mW/cm² to 3 W/cm² for eyes, or 100 mW/cm² to 3 W/cm² for the rest of the body, or with an MI (mechanical index) > 0.4 or a TI (thermal index) > 0.7 on humans for the purpose of medical treatment. Only licensed physicians or individuals with medical training may apply this technology. During medical training, any application should be monitored by an individual with the relevant certificate.

5. Requiring users possess a certificate covering treatment applications (see IV) for the use of ultrasonic intensities over 3 W/cm² on humans for the purpose of medical treatment. Only licensed physicians or individuals with specialist medical training may apply this technology. During medical training, any application should be directly supervised by an individual with the relevant certificate.

6. Informing patients receiving treatment using ultrasound applications about possible adverse effects and complications, recording the occurrence of adverse effects and complications, and reporting serious incidents pursuant to the Act on Medical Devices (MPG 2011).

7. Requiring that the medical application of ultrasound on humans be subject to an ongoing system of quality control aimed at monitoring key parameters of the equipment used.

III. Non-medical applications

1. Assessing the use - without medical justification - of ultrasonic diagnostic and treatment applications on humans according to the risks associated with them, and either prohibiting them, or imposing conditions and/or warnings respectively.

2. Only licensing the application - without medical justification - of ultrasonic intensities of over 50 mW/cm² for eyes, over 100 mW/cm² for the rest of the body, or with an MI (mechanical index) > 0.4 or TI (thermal index) > 0.7 on humans by a licensed physician, or under the supervision of a licensed physician, and requiring both the physician and the operator to be holders of the relevant certificate (see IV).

3. In view of the associated risks, prohibiting the use - without medical justification - of high intensity focused ultrasound (HIFU⁴) on humans, e. g. for cosmetic/aesthetic reasons, such as “lipolysis”.

4. Requiring special certification (see IV) for all occupational categories/users respectively.

⁴HIFU high intensity focused ultrasound
IV. Certification

Guaranteeing and verifying the necessary certification by means of suitable specialist training in theory and practice (expert knowledge) and application-specific instruction and further training (record of practical experience, training certificate, and proof of qualification), e.g. due to successful course attendance at a (state) recognised or accredited body or training institute.

Different courses should be available for different application areas. Special courses should be required for non-medical applications.

To be able to conduct such procedures safely and avoid and/or minimise any existing risks respectively, individuals claiming to be ultrasound professionals must demonstrate basic knowledge of physical ultrasonic properties, ultrasound propagation, the technical design of ultrasound devices, the specific rules concerning use, as well as of basic anatomy, physiology, and any contraindications or exclusion criteria.
Scientific reasoning

1 Introduction

In recent years the range of ultrasound applications open to humans has expanded considerably. These are no longer confined to medical indications, but instead are also finding increasing use in non-medical contexts. New applications for highly focused ultrasound in particular have been found in the latter. The associated adverse effects and complications, not to mention the increasing use of high intensity ultrasound by medical laymen, have led to new risks and by extension, the emergence of some major safety concerns. For this reason, the Federal Ministry for the Environment and Reactor Safety has commissioned the Commission on Radiological Protection, on the basis of the commission’s Recommendations for Patient Safety in Medical Ultrasonic Diagnosis (SSK 1997), to analyse ultrasound applications currently being used in diagnostics, treatment, and cosmetic surgery with the purpose of establishing which ultrasound applications should only be conducted by a physician, and which applications on humans may be permitted outside medical and dental practice, e.g. for cosmetic or other purposes. Furthermore a recommendation should also be issued concerning the qualifications required for individuals using ultrasound applications on in humans.

1.1 The basic physics

Ultrasound consists of mechanical oscillations at frequencies imperceptible to the human ear, i.e. in excess of 20 kHz. In biological soft tissue ultrasound propagates in the form of longitudinal waves. In the process particles move in the direction of wave propagation, leading to alternating phases of positive and negative pressure.

In solid objects, e.g. in ultrasonically oscillating surgical instruments, propagation also occurs in the form of transverse and surface waves, which are characterised by different speeds, wavelengths, and rates of ultrasonic attenuation.

Frequencies ranging from 20 kHz to several 100 kHz (low-frequency ultrasound) and approx. 0.8 MHz to 4 MHz (high-frequency ultrasound) are used in medical treatment; in addition there are broadband signals associated with pulsed ultrasound applications.

When seeking to establish a conclusive medical diagnosis using ultrasound and in selecting the frequency to be used, there is always a degree of compromise between spatial resolution and penetration depth, owing to the level of ultrasonic attenuation and the properties and reflectivity of the structures being examined. To achieve good spatial resolution it is necessary to use frequencies that are considerably higher than those used in treatment applications; for diagnosis this ranges from 1 MHz (e.g. transcranial ultrasound) to approx. 100 MHz (e.g. dermatology). Ultrasonic microscopes use even higher frequencies (GHz) in vitro.

Ultrasonic propagation can be described in similar terms to the law of optics. At boundaries where there is a change in acoustic impedance (determined by the speed of propagation and structure density) reflection occurs. At boundaries to bone, for instance, the rate of reflection is very high; at gas boundaries there is near total reflection. That is why ultrasound gel is needed to create an air-free bond between the body and the transducer. The superimposition of incident and reflected waves at highly reflective boundaries can produce super-elevated intensities and painful thermal effects.

Using a suitably sized and shaped transducer, high intensity therapeutic ultrasound (HITU) can be produced which generates a local increase in intensity relative to the transducer
surface/focal region ratio. Even higher intensities can be produced using focused ultrasound (HIFU)\(^5\), applied during procedures such as extracorporeal shockwave lithotripsy (ESWL)\(^6\).

In diagnostic terms, focusing allows improvements in lateral resolution (e.g. using adjustable transmit focus). During the imaging process, ultrasound frequency is varied to improve depth resolution.

Propagation is described using the following parameters: particle velocity (the speed at which the particles are moving) in m/s, ultrasonic pressure in Pa, ultrasonic intensity in W/m\(^2\), and wavelength speed (ultrasonic propagation speed) in m/s.

Piezoelectric (piezoceramic) transducers are used in diagnostics to generate ultrasonic energy and to detect echo signals; they convert mechanical oscillations into electrical energy (direct piezo effect), and electrical energy into mechanical oscillations (inverse piezo effect). Highly focused ultrasound applications also use other types of transducers.

The ultrasound beam created by the transducer can be divided into two regions, namely the area directly in front of the transducer (near field), and the more distant area (far field). In the near field, the differences in path length of partial waves being emitted by the transducer are sufficient to generate constructive and destructive interference. In this zone it is possible to focus. In the process the range of the interference field depends on the size of the transducer in relation to the ultrasound frequency. In the more distant area (far field), interference is negligible and the ultrasound beam uniform in shape. Intensity here decreases proportionally to the square of the distance from the transducer.

### 1.2 Working mechanisms

In biological tissue, ultrasound waves cause particles to move in a longitudinal direction. The kinetic energy that is absorbed may be released as warmth, thus enabling thermal treatment to take place. In the process the attenuation coefficient is directly proportional to frequency; the level found in muscle tissue is almost double that of adipose tissue. Since the attenuation coefficient in air is approximately one whole order of magnitude greater, any air pockets in the bonding gel or inside the body can lead to overheating.

The thermal index (TI) is used to describe the anticipated thermal reaction, while the mechanical index (MI) is used to measure mechanical impact pursuant to DIN EN 62359. Owing to the range of attenuation coefficients, the TI must refer to tissue type (e.g. soft tissue, brain or bones).

As well as this warming effect, the alternating positive and negative pressure of the longitudinal waves causes cyclical encroachment, which can lead to "micro-massage", thereby promoting improved circulation or the healing of wounds, for instance. If the intensity is too high or the duration of treatment too long, however, this mechanical impact can lead to cell membrane and/or tissue structure damage, which may either be viewed as an adverse side effect or a therapeutic benefit (e.g. liquefaction of glass bodies or ocular lenses).

The mechanical shock impact generated by transient high intensity ultrasound impulses can lead to the ablation or comminution of calcifications (e.g. bladder or gall-bladder stones).

During the negative pressure phase of the ultrasound wave, microscopically small short-lived vapour or gas bubbles may occur in fluids, causing cavitation. These tiny bubbles demonstrate resonant behaviour and may develop into larger bubbles. Depending on the type of

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\(^5\) HIFU: High intensity focused ultrasound  
\(^6\) ESWL: Extracorporeal shockwave lithotripsy
microbubble two basic forms of cavitation exist; there are also transitional forms which may occur between these two.

1. Transient (“inertial”) cavitation occurs in the case of vapour bubbles created during the negative pressure phase; these continue to grow until they reach critical size and then implode. At a local level this can cause high temperatures (estimated between 5000 K and 10000 K), high (implosive) pressure equal to several thousand MPa, and high energy jet pulses (micro-streaming) reaching speeds of 50-150 m/s; in water the latter briefly generate pressure of over 110 MPa, sufficient to ablate calcifications and perforate cell membranes (SSK 1997). This process has also been proven to promote the formation of free radicals. Transient cavitation therefore has the potential to cause significant damage.

For cavitation bubbles to implode they must have reached a critical size (e.g. in water 3.3 µm at 1 MHz); the relevant equation involving the tissue-specific constants \( k \), frequency \( f \), and the resonant bubble radius \( r_{res} \) is as follows:

\[ r_{res} \cdot f = k \]

The threshold for transient cavitation depends on the viscosity, prevailing pressure, temperature, and gas content of the material in question. Cavitation can occur in bodily fluids (e.g. urine, blood, interstitial fluid), causing potential damage e.g. to the kidneys, efferent urinary conduits, and blood cells. Ultrasound contrast agents (intravenously administered gas-filled bubbles of diameters between approx.1 µm and 10 µm) can serve to promote cavitation. The administration of such an artificial “cavitation-promoting” agent can considerably reduce the ultrasound intensity threshold for transient cavitation. In such instances the cavitation threshold will therefore vary from ultrasound unit to ultrasound unit, thus potentially increasing any risks to health. There remains disagreement, however, as to whether transient cavitation can occur in tissue that does not contain gas, since the relevant thresholds are approximately one whole order of magnitude greater than those for fluids (Church and Yang 2005).

Ultrasound devices (e.g. colour Doppler systems) are already capable of generating sufficient ultrasonic pressure within the diagnostic range of frequencies as to make it impossible to rule out transient cavitation. This is all the more applicable to ultrasound treatment equipments which operate at much higher intensities.

2. Non-inertial cavitation can occur in fluids and tissues that contain gas. An ultrasonic field generates oscillating gas bubbles. The latter however are not subject to high-energy implosion; the gas present dampens the oscillations, thus preventing implosion from taking place.

1.3 Biological effects

The biological effects of ultrasound vary according to the ultrasound parameters, the tissue involved, and its temperature. Adverse health effects only occur if the characteristic parameters are exceeded (threshold effect).

- The movement of particles induced by the ultrasound and other facilitating effects (heating and cavitation) may help to promote the administration of substances through the skin (e.g. the application of medicines) (phonophoresis/sonophoresis). This is achieved either by using frequencies between 20 kHz and 100 kHz (low-frequency sonophoresis) for substances with a higher molecular weight, or over 700 kHz for substances with a lower molecular weight (high-frequency sonophoresis) (Polat et al. 2011).
The intentional generation of heat is created by continuous (sinusoidal) sonic waves and finds application, for instance, in conventional ultrasound physiotherapy. The DIN EN 60601-2-5 safety standard limits ultrasound intensity for such procedures to 3 W/cm². Nevertheless the hand-held transducer must be kept in constant motion to prevent pain or thermal/mechanical tissue damage.

Intense heating of the skin can lead to biological tissue changes, tightening the subcutaneous trabeculae (both elastic and collagen fibres) (Wall et al. 1999). Tissue inflammation is another potentially adverse effect of heating. This can also occur if cells (e.g. fat cells) have been damaged mechanically. The inflammation leads to changes which are comparable with those associated with normal wound healing. The increase in collagen production thus effected can therefore lead, as a further consequence, to a tightening of tissue.

Cyclical mechanical encroachment may cause mechanical cell membrane damage and cell and structural tissue damage to occur, especially in the case of high ultrasonic pressure amplitudes and ultrasonic intensities, such as those required by high intensity focused ultrasound (HIFU), e.g. extracorporeal shockwave lithotripsy (ESWL). This effect is intentionally used in treatment, and yet it may also be exploited for cosmetic purposes. To this end, ultrasound is emitted either as a constant stream or in pulsed form. Adverse side effects may include cell damage, structural damage and internal bleeding, especially if the area to which ultrasound is being applied (owing to its extreme size, excessive penetration depth, or imprecise localisation) includes tissue and/or structures that do not require treatment.

The cyclical mechanical encroachment caused by transient high intensity ultrasound pulses can be used for the mechanical ablation or destruction of calcifications (ultrasound lithotripsy) and deposits, as well as for the destruction of tissue (tumour destruction, ultrasound vitrectomy).

Transient cavitation enables cell membranes to be opened (sonophoresis) and/or damaged, cells and tissue structures to be destroyed, and cells to be killed. In the process, tissues in the gaseous exchange system are particularly at risk, such as the lungs, gastrointestinal tract and capillaries, as well as gaseous liquids. Tiny gas bubbles at the lung margins and in the intestines may serve as cavitation nuclei, making the occurrence of cavitation possible even at diagnostic ultrasonic pressures, and causing damage to small vessels and capillaries, with the potential for (micro-) bleeds. Furthermore ultrasound contrast agents in the form of encapsulated gas-filled microbubbles may also promote cavitation.

Adverse effects of ultrasound-induced tissue damage include inflammation, the formation of (fatty) cysts, damage to blood vessels resulting in haematomas, damage to nerves, as well as any side effects associated with the heating process.

2 Applications in Humans

2.1 Diagnostic applications

Sonography is based on the principle of sonar; it provides a visual display of the echo as it bounces off tissue boundaries, determining spatial positions according to the distances travelled. The range of frequencies used depends on the depth of examination required and the spatial resolution; it typically lies between approx. 2 MHz and 20 MHz, but it may also be
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considerably higher in the case of special applications, e.g. pachymetry\(^7\). By displaying sequential alterations over a period of time (A-scan, T-M scan), the echo can for instance be used to analyse heart valve movements; by displaying the echo’s spatial distribution, created by moving the ultrasound beam mechanically or electronically, the sequence can be pieced together to form a two-dimensional cross-section (B-scan). This allows ultrasound echo images to be presented in real time (real time scanner), thus enabling examinations to be conducted interactively. The safety standards for ultrasound B-scan units limit ultrasound intensities to 50 mW/cm\(^2\) (ocular applications) and 720 mW/cm\(^2\) (other applications) (DIN EN 60601-2-37). It is possible to generate three dimensional images (e.g. of a foetus) using successive volume scan images. Ultrasound imaging is a popular obstetrics tool. Nevertheless, there is an increasing trend in examinations that are not medically justified, e.g. for souvenirs (photos including so-called “keepsakes”, videos: “baby cinema”).

Additional diagnostic information can be obtained by analysing changes in ultrasound signal frequency associated with moving particle reflection, especially that of blood erythrocytes (Doppler effect). This can be relayed as an audible ultrasonic signal, or displayed in the form of colour-coded B-scan cross-sections. Using this one- or two-dimensional Doppler procedure, it is possible to examine the flow properties in blood-carrying vessels including the heart, and quantify the speed of blood flow, volume, and impedance indices, for instance, without the need for a contrast agent. Since the echoes produced by such tiny reflectors are necessarily of low amplitude, the ultrasound intensities required for Doppler scans are higher, which also means a risk of cell damage cannot be excluded.

It is possible to boost the signal by administering a contrast agent in form of encapsulated microbubbles intravenously (echo contrast sonography). Using a contrast agent, echo contrast sonography provides a clearer picture of blood vessels and tumours. It is vastly superior to other imaging techniques when it comes to scanning the tiniest vessels (microvascular imaging), since it is able to trace the path of a single gas bubble measuring just 2 µm - 3 µm in diameter.

Sonographic contrast agents differ from those used for other imaging techniques in that they are simply gas bubbles encapsulated in a phospholipid, albumin or galactose shell, designed to prevent the formation of clusters, and thus lower the risk of thrombosis. Moreover, only the blood vessels are imaged, since the intact microbubbles are confined to the vessel space and are unable to penetrate tissue. This produces extremely clear images, for instance, of hepatic and pancreatic tumours. Compared with the heavy metal-based contrast agents used in radiology, the side effects are negligible. In rare instances (approx. 1 in every 1,000 - 10,000 cases) acute anaphylactic shock can occur, which in the worst case scenario may lead to patient death.

By applying the transducer, the ultrasound may be conducted from outside the body using mechanically moving (rotating or oscillating) or electronically segment- or phase-controlled linear arrays. Rigid and flexible ultrasound probes also exist which allow higher frequency ultrasound images of the inner body to be produced (e.g. transrectally, transvaginally and transoesophageally) for the examination of areas such as the intestines, pancreas, amniotic sac, or heart (endosonography). In the case of protracted surgical procedures, endosonography may be used to monitor heart function and anaesthetic depth. Moreover it is also applied as a supplementary surgical procedure in cases where no direct view is possible, e.g. when determining fine needle biopsy locations or obliterating tumours.

\(^{7}\)Measuring the cornea
Intraductal and intravascular sonography are special forms of endosonography for which the ultrasound transducer is integrated in the tip of a catheter. These techniques are applied in the diagnosis of plaques in the coronary and major arteries, for instance, with the aim of deciding whether a stent needs to be inserted, or if blood flow could be improved by dilating the vessel. It also allows the degree of risk posed by wall thickening and structures in the bile ducts to be assessed.

Other diagnostic ultrasound procedures are elastography and shear wave elastography, e.g. HistoScanning, with which the quality and quantity of tissue can be analysed, e.g. when diagnosing or monitoring prostate and liver diseases – here as an alternative to repeated liver biopsies (e.g. in cases of hepatitis C). Tissue rigidity is thus determined by measuring the degree of tissue deformation and/or sonic conduction resulting from the application of mechanical vibrations or ultrasonic pulses. The reason for this approach is that progressive liver disease is accompanied by fibrosis, i.e. a gradual hardening of the liver. A quantitative assessment of liver fibrosis helps determine the most suitable time for treatment.

2.2 Therapeutic applications

The thermal, mechanical, and cavitation-related effects of ultrasound are also used for treatment purposes. The most well-known are applications in the area of physiotherapy and in the treatment of chronic wounds, as well as HIFU e.g. in tumour therapy.

Ultrasound is generally used in physiotherapy and orthopaedic contexts for the treatment of musculoskeletal pain (e.g. chronic back pain, arthrosis, tendinopathy, musculopathy, arthritis). Ultrasonic energy is emitted by piezoelectric transducers with diameters measuring up to several cm, with typical frequencies ranging from 1 MHz to 3 MHz. The relevant safety standard (DIN EN 60601-2-5) limits ultrasonic intensity to 3 W/cm². Owing to the super-elevation of intensity at bony interfaces, the hand-held transducer must be kept in constant motion at higher intensity settings in order to prevent pain and thermal tissue damage.

As well as the high-frequency transducers already mentioned, low-frequency ultrasound (approx. 25 kHz - 150 kHz) is also used, specifically in the treatment of chronic wounds (ulcus cruris, decubitus). Low-frequency ultrasound is also used in dentistry (calculus removal), in ophthalmology (phacoemulsification), and in various experimental treatment approaches (e.g. intravascular thrombolysis).

Sonophoresis is the term given to an increase in the transdermal or cellular absorption of substances (e.g. medicine) under the influence of ultrasound. Here different ultrasound frequencies may be applied; these are generally low frequency, with intensities ranging from 0.1 W/cm² to 0.5 W/cm², but higher frequencies are also used (1 MHz to 16 MHz), with intensities ranging from 0.2 W/cm² to 3 W/cm² (Polat et al. 2011).

HIFU is used to concentrate ultrasound generated outside the body with wide angle transducers - penetrating the skin with moderate intensity (thus keeping pain at a bearable level at the point of connection) - on a tiny focal point measuring just a few mm². High intensities in the region of 5000 W/cm² may occur; these lead to transient cavitation and temporary increases in temperature to approx. 100 °C, thus causing mechanical cell damage and thermal necroses. Positioned with imaging technology (e.g. MRI8), HIFU can be used in this way to treat tumours (e.g. prostate carcinomas) while enabling temperature readings to be taken at the same time. This treatment procedure, which is currently not subject to any guidelines, requires fundamental justification and a system of quality assurance.

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Ultrasonic waves of even greater intensity are used in extracorporeal shockwave lithotripsy to destroy calcifications e.g. in the gall bladder, kidneys, bladder or pancreas. In this instance repetitive short ultrasonic pulses (e.g. 3000 - 6000) are emitted until the calcification can no longer be detected by X-ray. Orthogonal X-ray projection images are used to aid positioning of the applicator; this may result in radiation exposure of several millisieverts per treatment (Schwab et al. 2010).

Microbubbles are not only used as contrast agents, but also for focused biochemical treatment. Exposing the filled microbubbles in the target area to ultrasound with high MI values causes them to implode through cavitation. Within the context of gene therapy (Friming et al. 1998, Hernot and Klibanov 2008), this facilitates the controlled administration of medically active agents (DNA release). The jet stream generated by transient cavitation produces (transient) cell membrane poration, which in turn facilitates the introduction of active agents into cells.

During surgical procedures, variously shaped sonotrodes (scalpel, saw) tuned to vibrate at resonant frequency (e.g. ranging from 22 kHz - 60 kHz) are used to perform treatment. Ultrasound tools are used in periodontology, for instance, for certain dental procedures and the removal of calculus.

2.3 Non-medical applications

The main non-medical application of ultrasound is the ultrasound-assisted transcutaneous (cosmetic) introduction of substances (sonophoresis), which is also performed in critical areas such as around the eyes.

Another application is the destruction of subcutaneous fatty tissue (“lipolysis”) or connective tissue using high intensity focused ultrasound (HIFU). This merits critical attention since intensities amounting to several kW/cm² can be reached in the focal zone without any kind of visual monitoring system being in place. Some special dermatological applications focus the beam at a shallow depth to create a grid of small scale thermal lesions. Although the focal dimensions amount to several millimetres, the ultrasound generated is inaccurately described as “micro-focused”. The cosmetic procedure principally relies on thermal effects. In addition low-intensity ultrasound units (< 3 W/cm²) are also used for cosmetic applications, despite the fact that their action mechanism has yet to be scientifically explained. Many manufacturers assert that cavitation is responsible for the destruction of fat cells. Others explain the modus operandi as being the local generation of high temperatures which “burn off” the fat cells.

What the devices have in common is the blind, not image controlled application of high intensities and the fixation of the focus at a particular depth, e.g. several centimetres.

HIFU cancer treatment has revealed that high ultrasound intensities can produce significant adverse effects, such as blood vessel and nerve damage. Furthermore, a general lack of localisation and a failure to adjust focal depth to suit the area intended for treatment bears a considerable risk of damage to healthy tissue. The critical nature of the situation is heightened by the fact that the official purpose given for most of these ultrasound units is “body contouring”. This is seen as justification by the manufacturers for classing the units as cosmetic rather than medical devices.

Were they to be classed as medical devices, they would fall into the IIb⁹ conformance class for high-risk medical devices which, pursuant to European Council Directive 93/42/EEC.

⁹ The German Medical Devices Act categorises devices in conformance classes I, IIa, IIb and III according to increasing product risk and the increasingly complex marketing authorisation process that accompanies the former. Manufacturers take direct responsibility for launching Class I products, those of Class IIa must be produced in a certified, quality assured environment, (only as of) Class IIb must products pass an additional
(MPR 2007) concerning medical devices and the German Medical Devices Act (MPG 2011), are subject to a risk/benefit analysis, the maintenance of a risk management systems, as well as a certified EC-type examination and certified quality-assured production processes. As yet no generally binding regulations exist, neither at a national nor international level, concerning the classification of ultrasound lipolysis units - whether as medical or cosmetic devices. Their classification as a medical device would nevertheless be justifiable according to the terms used to define a medical device pursuant to Council Directive 93/42/EEC, Article 1, § 2a (MPR 2007). Accordingly medical devices are (also) those designed by manufacturers for use on human beings with the purpose of “… changing anatomical structures”. This argument has already been used, for instance, by the Austrian Ministry of Health in a statement released on the subject (BMG 2010).

One basic requirement of medical devices is that their use is associated with an acceptable ratio of risk to benefit (MPR 2007, Appendix I, § 1 and § 6). Since HIFU applications which are not medically justified are not only associated with a comparably low degree of benefit (altering body shape), but also with significant health risks, the risk/benefit ratio of cosmetic “lipolysis” using focused ultrasound would seem to be untenable. France has already reached this conclusion and has issued a governmental decree prohibiting “lipolysis” for cosmetic purposes “using external physical agents” (MTLS 2011).

The classification of ultrasound body-contouring devices as non-medical devices is inappropriate and poses some serious risks. Not only are they not subject to the design testing and safety assessment process by a notified body, they are also not subject to the obligatory routine safety tests, as specified for commissioned medical devices, nor are they covered by the provisions for mandatory reporting of serious incidents. Of particular concern, moreover, is that these ultrasound devices are being used by laymen, whose knowledge of anatomy is insufficient, and who are neither able to recognise the specific risks and numerous contraindications, nor to follow the detailed instructions concerning the use of high intensity ultrasound reliably.

With the high risk potential of focused ultrasound devices and their indiscriminate application by operators, there is danger down the line, especially in view of current practice. This irresponsibility of attitude is further emphasised by the fact that manufacturers are not shy of promoting the method for correcting bags under the eyes, despite such treatment being subject to particularly restrictive regulations.

### 3 Health risk assessment parameters

In addition to the physical device parameters, health risks are mainly assessed by the mechanical index ($MI$), used to evaluate the risk of cavitation, and the thermal index ($TI$), which rates the risk of heating (see DIN EN 62359 for definition). The thermal index is broken down into values for soft tissue (TIS) and bones (TIB). The declaration of $TI$ and $MI$ values is specified by the DIN EN 60601-2-37 device standard. In the process, particular attention is given to assessing any health risks to the unborn child. According to a recommendation issued by the British Medical Ultrasound Society (BMUS 2007), the following $MI$ values are to be regarded as upper limits:

\[ MI = 0.3 \quad \text{for capillary bleeding} \]
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\[ MI = 0.3 \] for mechanical risks associated with gaseous exchange tissue or the existence of gas bubbles (contrast agents)

\[ MI = 0.7 \] for risks associated with cavitation

\[ TI = 0.7 \] for risks of foetal overheating

Furthermore reference is made to the high ultrasound intensities associated with A-scans, TM-scans and especially Doppler scans, with a justifying indication being considered necessary. The World Federation of Ultrasound in Medicine and Biology (WFUMB 2010) recommends that a \( TI \) of 0.5 and an \( MI \) of 0.3 should not be exceeded for non-medical applications, while the US National Council on Radiation Protection and Measurements (NCRP 2002) requires a justifying indication for ultrasound exposures with an \( MI > 0.5 \) and a \( TI > 1 \).

Bearing in mind the lack of information about possible subtle biological effects and their effect - even at diagnostic ultrasound intensities - on the developing foetus and its brain, with potentially alarming effects on the development of the unborn child, the concept of extending the medical examination beyond the necessary medical scope merely to produce souvenirs in the form of photos and videos is regarded as untenable (BMUS 2007, WFUMB 2010).

Safety regulations, based on water tank readings, governing the intensity limits of diagnostic and physiotherapy ultrasound devices (3 W/cm²) do exist; the values are given as the spatial peak and time average (SPTA).

Please note: To reflect the spatially uneven distribution of ultrasound intensity and the pulsing ultrasound beam accurately, various values were defined when drafting the regulations:

- **SPTA** (spatial peak + time average): the peak value occurring in a space (e.g. focus), calculated over time
- **SATA** (spatial average + time average): the average value calculated across a space (e.g. the transducer surface) over time
- **SPTP** (spatial peak + time peak): the peak time value occurring in a space
- **SATP** (spatial average + time peak): the peak time value occurring across a space

In the DIN EN 60601-2-37 standard, it is no longer considered harmless if the mechanical index exceeds 0.4 (for water) and/or the thermal index exceeds 1.0 respectively\(^{10}\) during adult ultrasound scans; careful handling is therefore required. An intensity of 100 mW/cm² (SPTA) is deemed to equate to a thermal index of 1.0. The values given must remain lower, however, if so indicated by the risk analysis. Furthermore the EN 60601-1-11 standard on medical devices also requires that laymen using such units confine their activities to output values that are within safe limits. Were the units to be classified by manufacturers as medical devices, untrained staff would naturally be eliminated from conducting ultrasound lipolysis.

Ultrasound treatment units are currently subject to the technical requirements pursuant to EN 60601-2-5 (physiotherapy units) with an upper limit of 3 W/cm². In addition there is the DIN EN 60601-2-36 (ESWL) standard and the DIN EN 60601-2-62 (HITU) draft standard. Furthermore, the general "basic requirements" for medical devices as specified in the Medical Devices Act (MPG 2011) also apply: in particular, the requirement to adhere to an acceptable risk/benefit ratio for the patient, as well as the safety regulations governing electrical medical devices (DIN EN 60601-1), and a commitment to maintain an on-going process of risk

\(^{10}\) A thermal index for soft tissue, brain and bones of 0.4 is no longer regarded as harmless for transcranial or neonatal applications.
management with continuous risk analysis and risk assessment, including an undertaking by the manufacturer to engage in the active observation of market changes and application innovations (DIN EN 14971). Such regulations do not apply to non-medical devices.

In view of the quantity and severe nature of adverse effects associated with high intensity focused ultrasound, the following contraindications, among others, exist (HC 2006):

- pregnant women
- pacemaker patients (around the implantation zone)
- individuals with poor blood vessel condition (e.g. arteriosclerosis or aneurysm)
- individuals with microcirculatory disorders
- individuals with reduced pain sensation
- individuals with impeded reflexes
- cardiac patients
- patients with thromboses or peripheral vein inflammations
- areas with reduced pain sensation
- areas with restricted circulation
- brain
- spinal cord and spine
- major peripheral nerves
- eye and eye lenses
- neoplastic tissue
- epiphyseal lines in children.
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