Ultrasound Dose Calculations

One of the advantages of ultrasound therapy remains the reasonably broad range of trials from which effective treatment doses can be established.

In principle, there is no need for the often used 'recipe book' in which a list of conditions is produced alongside the treatment dose. One of the reasons for this is that the 'best' recipe for all the conditions one might encounter does not exist, certainly not from the evidence base. Secondly, there is effectively no need to learn a whole list of such formulas for successful application, one needs to apply the principles to the particular tissue in question, taking into account the relevant parameters.

The following 'dose calculations' offer one method (by no means the only one) by which the most likely clinically effective dose can be established. There is no guarantee the resulting dose will work, but it does offer a mechanism by which the dose which is most likely to work can be estimated.

Dose Calculation Stages

The first steps involve the decision as to which machine settings are most appropriately applied to the patients particular problem. The second stage is to bring these into an effective treatment combination.

Machine settings :

There are effectively 4 things that you can change on your machine : ultrasound frequency, pulsing, power and time.

Machine Frequency

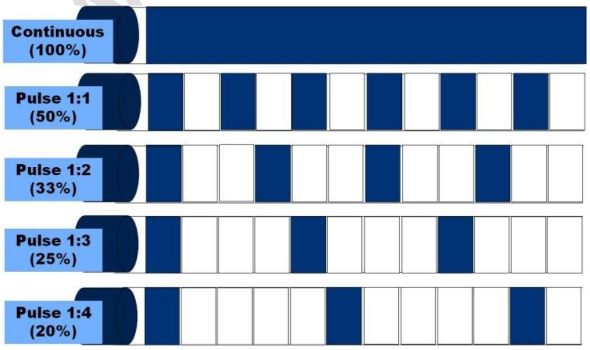
Taking into account that the most frequently available treatment frequencies are 1 and 3MHz, the option between them relates primarily to the effective treatment depth that is required.

3MHz ultrasound is absorbed more rapidly in the tissues, and therefore is considered to be most appropriate for superficial lesions, whilst the 1MHz energy is absorbed less rapidly with progression through the tissues, and can therefore be more effective at greater depth.

The boundary between superficial and deep lesions is in some ways arbitrary, but somewhere around the 2cm depth is often taken as a useful boundary. Hence, if the target tissue is within 2cm (or just under an inch) of the skin surface, 3MHz treatments will be most effective whilst treatments to deeper tissues (2cm+) will be more effectively achieved with 1MHz ultrasound.

Pulse Ratio

The pulse ratio determines the concentration of the energy on a time basis. The pulse ratio determines the proportion of time that the machine is ON compared with the OFF time. A pulse ratio of 1:1 for example means that the machine delivers one 'unit' of ultrasound followed by an equal duration during which no energy is delivered. The machine duty cycle is therefore 50%. A machine pulsed at a ratio of 1:4 will deliver one unit of ultrasound followed by 4 units of rest, therefore the machine is on for 20% of the time (some machines use ratios, and some percentages). The table overleaf shows their equivalence.



Mode	Pulse Ratio	Duty Cycle
Continuous	N/A	100%
Pulsed	1:1	50%
	1:2	33%
	1:3	25%
	1:4	20%
	1:9	10%

It is worthy of note that some machines offer pulse ratios for which no evidence can be identified to ascertain the effectiveness of the intervention. Pulse ratios of 1:9, 1:15 or 1:20 for example can be found on machines but with no trial evidence to support their use.

The selection of the most appropriate pulse ratio essentially depends on the **STATE** of the tissues. The more acute the tissue state, the more energy sensitive it is, and appears to respond more favourably to energy delivered with a larger pulse ratio (lower duty cycle). As the tissue moves away from its acute state, it appears to respond preferentially to a more 'concentrated' energy delivery, thus reducing the pulse ratio (or increasing the duty cycle).

It is suggested that pulse ratios of 1:4 are best suited to the treatment of acute lesions, reducing this as the tissue moves towards the chronic state moving through 1:3 and 1:2 to end up with 1:1 or continuous modes. Some machines are unable to deliver the most effective treatment modes and the therapist will need to compromise the treatment dose according to the facilities that are available.

Ideally try for 1:4 or 1:3 for the ACUTE lesions, 1:2 and 1:1 for the SUBACUTE lesions and 1:1 or Continuous for the CHRONIC lesions.

If it helps, imagine a CONTINUUM from the MOST ACUTE to the MOST CHRONIC and select pulse settings accordingly. If there are pulse settings which are not available on the device available, a compromise will need to be made, selecting the alternative which is as close as possible to the 'ideal'.

MOST ACUTE				MOST CHRONIC
PULSE 1:4 (20%)	PULSE 1:3 (25%)	PULSE 1:2 (33%)	PULSE 1:1 (50%)	CONTINUOUS (100%)

It is of note that it is the **state of the tissue** that determines the most appropriate pulse ratio rather than simply the duration since the onset of the lesion. In a similar way to the clinical decision making process in manual or other therapies, tissue reactivity is the key. If the tissue in question behaves in an acute manner on assessment, then the lesion is effectively treated with an 'acute' dose. If it behaves as a chronic, less responsive tissue, then treat with a 'chronic' dose. Some patients will present several weeks after an injury or lesion onset, yet the problem exhibits 'acute behaviour' and should treated accordingly. Similarly, some lesions appear to move swiftly into chronic behaviour mode, and these are best managed with a dose estimated for chronic lesions. The key here is to treat what you find at assessment, rather than what the timescale says should be there.

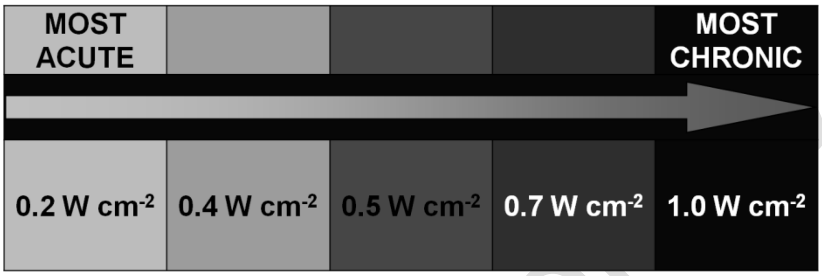
Ultrasound Treatment Intensity

In a similar way to the pulse ratio decision, the intensity of ultrasound required at the target tissue will vary with the tissue state. The more acute the lesion, the less strong the ultrasound needs to be in order to achieve/maintain the tissue excitement. The more chronic the tissue state, the less sensitive, and hence the greater the intensity required at the lesion in order to instigate a physiological response.

One important factor is that some of the ultrasound energy delivered to the tissue surface will/may be lost before the target tissue (i.e. in the normal or uninjured tissues which lie between the skin surface and the target). In order to account for this, it may be necessary to deliver more at the surface than is required, therefore allowing for some absorption before the lesion, and allowing sufficient remaining ultrasound to achieve the desired effect.

The intensity required (for non-thermal effects) at the lesion is summarised in the following table and in the sliding scale below:

Tissue State	**Intensity required at the lesion (W/cm^2)**
Acute	0.1 - 0.3
Sub Acute	0.2 - 0.5
Chronic	0.5 - 1.0



The rate at which ultrasound is absorbed in the tissues can be approximately determined by the half value depth - this is the tissue depth at which 50% of the ultrasound delivered at the surface has been absorbed. The figures used for these estimates are average values in that it absolute values will vary with the thickness of various tissues (e.g. skin, fat, muscle etc). The average 1/2 value depth of 3MHz ultrasound is taken at 2.5cm and that of 1MHz ultrasound as 4.0 cm though there are numerous debates that continue with regards the most appropriate half value depth for different frequencies.

The table below indicate the intensity required at the skin surface in order to achieve a particular intensity at depth. It is suggested that the intensity required at depth is established first, then the most appropriate frequency selected and these two factors are used to determine the surface intensity required.

If the intended treatment depth is less than 0.5cm, it is not considered necessary to use the table - i.e. not enough of the surface dose will be lost to make a (clinical) difference to the outcome.

	Depth of Lesion (cm)						
Intensity required at the lesion (W cm^{-2})	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**
	3MHz			**1 MHz**			
1.0	1.20	1.40	1.80	1.75	2.00	2.25	2.50
0.9	1.08	1.26	1.62	1.58	1.80	2.03	2.25
0.8	0.96	1.12	1.44	1.40	1.60	1.80	2.00
0.7	0.84	0.98	1.26	1.23	1.40	1.58	1.75
0.6	0.72	0.84	1.08	1.05	1.20	1.35	1.50
0.5	0.60	0.70	0.90	0.88	1.00	1.13	1.25
0.4	0.48	0.56	0.72	0.70	0.80	0.90	1.00
0.3	0.36	0.42	0.54	0.53	0.60	0.68	0.75
0.2	0.24	0.28	0.36	0.35	0.40	0.45	0.50
0.1	0.12	0.14	0.18	0.18	0.20	0.23	0.25

If, for example, the target lesion is at 1cm depth and the intended treatment intensity is 0.4W cm^{-2}, then from the table (a) use 3MHz (b) set the machine at 0.56 W cm^{-2} (or as near as your machine will allow). This means that at a 1cm tissue depth, there will be (approximately) 0.4 W cm^{-2} remaining.

Size of the Lesion

The greater the size of the lesion, the longer the duration of the ultrasound that will be required in order to achieve a particular effect. The most common method to take account of this factor is to estimate the number of times which the ultrasound treatment head to be utilised can be placed over the target tissue. Given that the intention is to apply 1 minutes worth of ultrasound energy per treatment head area covered (see below), there is a direct relationship between treatment area and treatment time.

For example, if the large treatment head is used to treat the anterior capsule of the shoulder, it can be estimated that it will fit twice over the target. Similarly, if the small treatment head is applied over the lateral ligament of the elbow, it may only fit once.

There is no need to measure the treatment head, it is a matter of estimating the number of time the head fits onto the target tissue rather than a millimetre by millimetre measurement.

Some people have suggested that it is 'wrong' to treat areas greater than 2 x the treatment head. Unless heating is your treatment priority, I can find no evidence that suggests this is the case. If you are using ultrasound to heat the tissue, it might be relevant in that isonating a larger area may result in insufficient development of heat in the tissue. If your intention is to generate 'non-thermal' effects, this is not an issue.

Compiling the treatment dose.

The final compilation of the treatment dose which is most likely to be effective is based on the principle that one needs to deliver **1 minutes worth of ultrasound energy (at an appropriate frequency and intensity) for every treatment head that needs to be covered**.

The size of the treatment area will influence the treatment time, as will the pulse ratio being used.

The larger the treatment area, the longer the treatment will take. The more pulsed the energy output from the machine, the longer it will take to deliver 1 minutes worth of ultrasound energy (there is a greater proportion of time during which the machine gives no output).

Using the tables above, it is possible to estimate the surface intensity required at a particular frequency to achieve sufficient ultrasound at the required depth to gain the desired effect.

Using the information in the previous sections, the following examples may serve to illustrate the point :

Example 1

Ultrasound treatment for a (very) acute lesion of the lateral ligament of the ankle

Assuming that on examination, the primary focus of the lesion is determined to be at the anterior portion of the ligament (anterior talo-fibular), the following clinical decisions are made :

- The lesion is superficial, hence a 3MHz frequency would be most appropriate
- The lesion is acute, thus an intensity of 0.2 W/cm^2 should be sufficient to treat the lesion
- There is no need to increase the surface dose to allow for loss of ultrasound at depth (<0.5cm depth to reach the tissue)

- The lesion is acute, therefore a pulse ratio of 1:4 will be most appropriate
- Using the large treatment head, it is estimated that the target tissue is approximately the same size as the treatment head (i.e. the head fits on to the tissue once)

Working on the principle of 1 minutes worth of ultrasound per treatment head area, the total time taken to treat the lesion will be (1 minute) x (number of times the treatment head fits over the lesion) x (the pulse ratio) which in this instance = (1) x (1) x (5) = 5 minutes.

[the factor to account of the pulsing can be easily worked out by adding together the two components of the pulse ratio thus, pulsing 1:4, adds up to 5, so multiply by 5. Pulse at 1:2, adds up to 3, so multiply by 3 etc]

The final treatment dose will therefore be
3MHz ; 0.2 W/cm^2 ; Pulsed 1:4 ; 5 minutes

There is no 'proof' that this dose is guaranteed to work, but given the available evidence, it is the dose that is most likely to achieve the intended effect (i.e. activation of the tissue repair process).

Example 2

Ultrasound treatment of a subacute lesion of the lateral ligament complex of the elbow and superior radioulnar joint

Assuming that on examination, the primary focus of the lesion is determined to be at the lateral ligament of the elbow joint itself together with the lateral portion of the annular ligament of the superior radioulnar joint, the following clinical decisions are made :

- The lesion is superficial, hence a 3MHz frequency would be most appropriate
- The lesion is sub-acute, thus an intensity of 0.4 W/cm^2 should be sufficient to treat the lesion
- There is no need to increase the surface dose to allow for loss of ultrasound at depth
- The lesion is sub-acute, therefore a pulse ratio of 1:2 will be most appropriate
- Using the small treatment head (due to the nature of the surface), it is estimated that the target tissue is approximately twice the size of the treatment head (i.e. the head fits on to the tissue twice)

Working on the principle of 1 minutes worth of ultrasound per treatment head area, the total time taken to treat the lesion will be (1 minute) x (number of times the treatment head fits over the lesion) x (the pulse ratio) which in this instance = (1) x (2) x (3) = 6 minutes.

The final treatment dose will therefore be
3MHz ; 0.4 W/cm^2 ; Pulsed 1:2 ; 6 minutes

Example 3

Ultrasound treatment of a chronic lesion of the anterior capsule of the shoulder (glenohumeral joint

Assuming that on examination, the primary focus of the lesion is determined to be at the anterior capsule of the glenohumeral joint, the following clinical decisions are made :

- The lesion is not superficial, hence a 1MHz frequency would be most appropriate
- The lesion is chronic, thus an intensity of 0.5 W/cm^2 should be sufficient to treat the lesion
- There IS a need to increase the surface dose to allow for loss of ultrasound at depth, and using the tables above, it is estimated that the required surface dose will need to be 0.88 W/cm^2 (this is assuming that the capsule is about 3cm below the skin surface. This will depend on the size of the patient – it is not a universal formula)
- The lesion is chronic, therefore a pulse ratio of 1:1 will be most appropriate

- Using the large treatment head, it is estimated that the target tissue is approximately twice the size of the treatment head (i.e. the head fits on to the tissue twice)

Working on the principle of 1 minutes worth of ultrasound per treatment head area, the total time taken to treat the lesion will be (1 minute) x (number of times the treatment head fits over the lesion) x (the pulse ratio) which in this instance = (1) x (2) x (2) = 4 minutes.

The final treatment dose will therefore be
1MHz ; 0.88 W/cm^2 ; Pulsed 1:1 ; 4 minutes

Example 4

Ultrasound treatment of a very chronic lesion of the gastrocnemius/TA musculotendinous junction

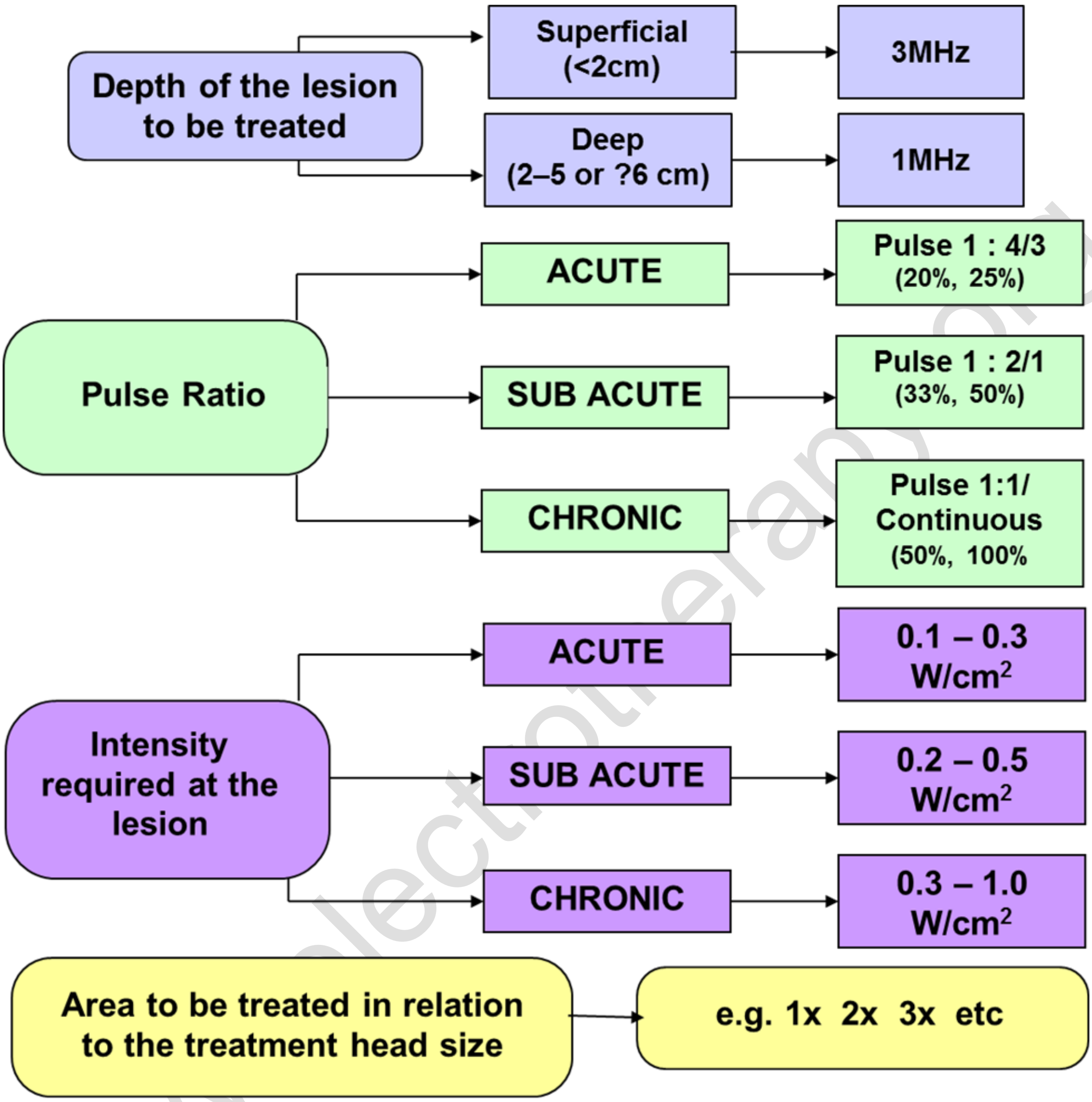
Assuming that on examination, the primary focus of the lesion is determined to be at a reasonably well defined area of the MT junction, the following clinical decisions are made :

- The lesion is relatively superficial, hence a 3MHz frequency would be most appropriate (this may not be true for some patients)
- The lesion is very chronic, thus an intensity of at least 0.6 W/cm^2 will probably be required to treat the lesion
- There IS a need to increase the surface dose to allow for loss of ultrasound at depth, and using the tables above, and assuming the MT junction is estimated at 1cm depth, using 3MHz, the intensity will need to be set at 0.84 W/cm^2 to achieve the 0.6 W/cm^2 required at the lesion
- The lesion is particularly chronic, therefore a continuous mode will be most appropriate
- Using the large treatment head, it is estimated that the target tissue is approximately three times the size of the treatment head.

Working on the principle of 1 minutes worth of ultrasound per treatment head area, the total time taken to treat the lesion will be (1 minute) x (number of times the treatment head fits over the lesion) x (the pulse ratio) which in this instance = (1) x (3) x (1) = 3 minutes.

The final treatment dose will therefore be
3MHz ; 0.84 W/cm^2 ; Continuous; 3 minutes

Ultrasound Dose Calculation Summary Chart



Ultrasound treatment : AIM for **1 minutes worth of ultrasound per treatment head area**

Therefore longer if **PULSED** and longer for **LARGER TREATMENT AREAS**

Treatment time = 1 x (no of times treatment head fits onto tissue to treat) x (pulse factor)

The **PULSE FACTOR** in the calculation can be achieved by adding the two elements of the pulse ratio e.g. pulse 1:1, adds to 2, multiply x 2. Pulse 1:4. Adds to 5. Multiply x 5

[A DOWNLOADABLE VERSION OF THIS CHART CAN BE FOUND ON THE WWW.ELECTROTHERAPY.ORG WEB PAGES]