Transmission of Therapeutic Ultrasound by Wound Dressings

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Abstract: Ultrasound has been used for the treatment of a variety of cutaneous wounds, particularly venous ulcers. Many of the published studies involved application of ultrasound to the surrounding tissue rather than directly over the wound. Insonating the wound itself may enhance the healing process, but the lack of data regarding the transmission characteristics of dressings has limited the use of this option. This study aimed to measure the ultrasound transmissivity of dressings commonly employed for wound management. Forty-eight different dressings and wound care products were tested *in vitro* using a radiation force balance. Transmissivity was found to vary significantly between dressings, from excellent to zero. These findings may be useful to clinicians in deciding whether to apply ultrasound through a particular dressing. They could also inform future studies of the efficacy of ultrasound in wound management by application directly to wounds rather than to their periphery.

Ultrasound (US) has been employed therapeutically for decades and is currently used by clinicians to treat a wide variety of soft tissue disorders.[1] In the management of cutaneous wounds, US has been found to enhance the healing process in incisional lesions, diabetic ulcers,[2] and venous ulcers.[3]

Ultrasound is sound energy of frequency > 20 kHz, which is above the normal range of human perception. It may produce a number of biophysical effects that are relevant to wound healing. These include alterations in cellular protein synthesis and release, blood flow and vascular permeability, angiogenesis, and collagen content and alignment.[4] Such effects have been suggested to provide a rationale for the use of therapeutic US at each stage of the wound-healing process.[5] However, systematic reviews have generally concluded that there is insufficient robust data to make firm judgements about the efficacy of the modality.[6–8] The favorable evidence is strongest in the case of venous ulcers.[9–11]

Many published studies of US treatment of wounds use protocols that involve insonation of the surrounding tissue, rather than the wound bed itself.[12–17] The rationale for this choice is rarely stated, but the intention is probably to avoid causing pain or trauma to the wound, or raising the risk of infection.[18] It can also retard the healing process by allowing the wound to cool—wound bed temperatures have been shown to fall by several degrees Celsius during normal dressing changes,[19] and there is a concomitant reduction in biochemical processes of healing.[20,21] Mitotic and leucocyte activity may not return to normal for several hours after application of a new dress-

ing.[20,22] The additional time of wound exposure for perhaps 5–10 minutes of US treatment might result in further cooling and slowing of regenerative processes.

These factors may account for the fact that the efficacy of US treatment of wound beds either directly or through dressings, has rarely been investigated. Such considerations are important because there is reason to suppose that insonation of the wound bed itself might be more effective than application of US to the surrounding tissue alone. Studies of physiological effects in wounds treated with US have usually investigated changes in the tissue directly exposed to the beam, rather than adjacent to it.[23–26] When US is applied only to the periwound site, it may be that insufficient US is reaching the damaged tissue to significantly enhance repair mechanisms. This may be a reason why clinical trials with US have sometimes been less encouraging than laboratory studies of its physiological effects.

There are some clinical studies in which not only the peripheries but also the wound beds have been treated. Only 2 studies[2,27] supported the use of US. In all studies the wound dressings were regularly removed for US treatment. In the 3 that did not support the use of US,[28–30] the applicator was rubbed against the wound. These factors suggest that optimum conditions for healing may have been compromised by the techniques used.

Through-dressing insonation would protect the wound from trauma, infection and heat loss, and allow the wound bed to be exposed to US energy. However if wounds are to be treated through dressings, it is necessary for the researchers and clinicians to be aware of the US transmission characteristics of the dressings. Several studies have obtained values for the transmissivity of 14 wound care products.[23,31–35] These studies show that different brands of the same type of dressing may have quite different transmissivities. In some cases studies produced significantly different values for the same dressing.[34,36] Therefore, a survey of a wider variety of dressings is needed. This is the purpose of the present study, whose aims were to measure the US transmission characteristics of a wide variety of wound dressings, and to suggest implications for the use of therapeutic US in wound management.

Materials and Methods

The ultrasound transmissivity or transmittance of a medium may be defined as the ratio of power transmitted by the medium to power incident upon it.[37] In practice beam power is first measured in a standard medium, usually water, and then again with the test medium interposed in the beam. The ratio of powers, ($P_{test\ medium}/P_{water}$), gives a relative transmissivity figure for the test medium, which may then be compared to other media.

A Radiation Force Balance (RFB) was used to measure US beam power. The device works on the principle that an ultrasonic beam incident upon a target will exert a force on the target proportional to the power of the beam.[38] The forces can be measured using a sensitive weighing balance at powers typical of therapeutic US. An EMS Precision Ultrasound Balance Model 110 (Electromedical Supplies, Greenham Ltd, Wantage, UK) was used in this study. It comprises a conical metal air-filled target mounted on a frame, which is supported by a sensitive electronic digital weighing balance. The target is immersed in a 1L container filled with water and lined with acoustically absorbent butyl rubber. The formation of bubbles that could scatter the beam is minimized by using degassed water. The absorbent rubber reduces reflection of the incident beam to minimize the occurrence of acoustic standing waves in the apparatus.

The apex of the target lies 20 mm below the surface of the US transducer head, which is held in place by a plastic collar resting on the container lining (Figure 1). The balance reads the apparent weight of the target, buoyed up by the water. Incident US energy exerts a force on the target, whose vertical component registers as an increase in the target's apparent weight. This weight may be converted to a beam power reading using a suitable conversion factor.

The balance was pre-calibrated by the suppliers and programmed with a scale factor that converts the weight reading to its equivalent temporally averaged and spatially integrated beam power. The accuracy of readings is given by the supplier as ± 10% and the resolution of the apparatus is 0.05 W. The apparatus was certified by the supplier as initially calibrated to traceable national standards. Calibration of the weighing balance was carried out by weekly checks using a known weight. The US beam was generated by a Chattanooga Intelect Advanced Combo Therapy System (Chattanooga Group, Hixton, Tenn) using a dual frequency applicator of ERA 4.0 cm^2, BNR (max) 5:1, producing a collimated beam at 1.0 MHz or 3.3 MHz (data supplied by manufacturer).

The stability of the measurement process over the course of the study was checked by taking transmitted power readings for the reference propagation medium (in this case, saline) at regular intervals. This gives an indication of the combined stability of the US generator and

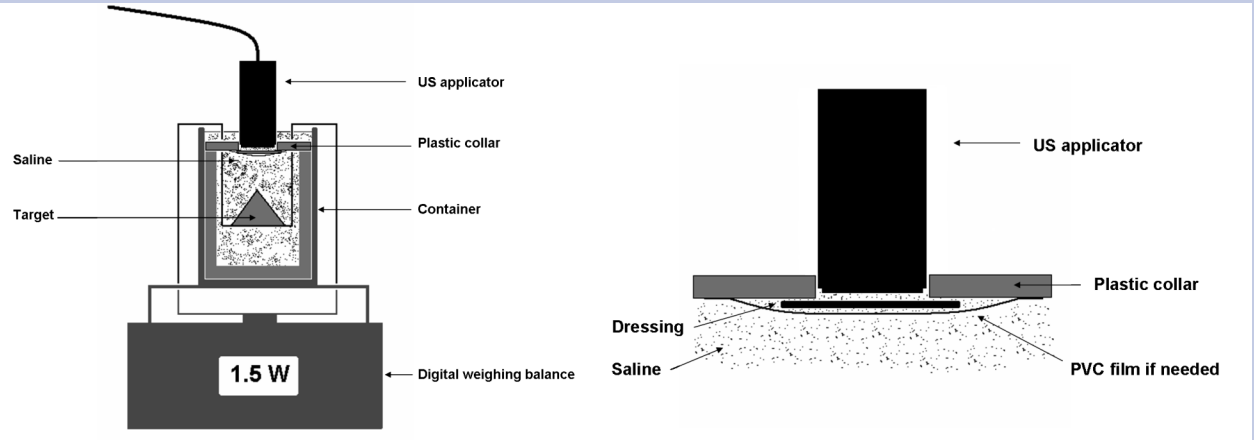

Figure 1. Apparatus used for measurement of US power transmitted by wound dressings. Detail of dressing placement is shown on the right.

the RFB. The ratio of the inter-quartile range to the median was calculated at each power value to give a median centered coefficient of variation. The average coefficient across the power range was 3.9% at 1.0 MHz and 3.2% at 3.3 MHz. Both figures indicate good measurement stability over the duration of the study.

In the clinical situation, a dressing may come in contact with and absorb wound exudate. This could change the dressing's acoustic characteristics. It was impossible to replicate wound conditions in this *in-vitro* study, but measures were taken to provide an environment bearing some resemblance to a wound bed. First, dressings for testing were immersed in 0.9 % saline made from distilled water that was degassed in a 10-minute boiling period, followed by the addition of a measured mass of common salt. Second, the temperature of the saline was maintained in the 29˚C–32˚C range while measurements were taken. This range was chosen because the temperatures of wounds under different dressings have been found to vary between 25˚C and 35˚C.[20,39]

Performance indicators provided by the supplier of the RFB assume the use of degassed water at 23ºC as its standard propagation medium. Substitution with saline at a higher temperature affects the scale factor used by the RFB to convert apparent weight to beam power. Data were collected to investigate the size of this effect. Average values for transmitted power at each nominal output power were calculated for degassed pure water at 23˚C ± 1˚C and saline at 30.5˚C ± 1˚C. Differences between average values for each medium were found to be statistically insignificant at 1.0 MHz, but at 3.3 MHz, readings for saline at the higher temperature were 3%–6% lower than those for water at the lower temperature. If the difference were due to a change in target buoyancy it would be expected to occur at both frequencies. Since it did not, the warmed saline must have attenuated the beam more at higher frequency. While this may be a noteworthy finding, it is evident that the scale factor itself is not significantly changed by the substitution of saline at the higher temperature. It was therefore deemed acceptable to use the warm saline as the standard propagation medium in the RFB.

Adherent dressings were stuck to the bottom of the plastic collar, holding a thin layer of saline between them and the US applicator. For nonadherent dressings and gels, a layer of PVC film was used to hold the sample in place. Data from a previous study by the authors[40] demonstrated that the PVC film used in this study reduces the power of the US beam by less than 1%.

For each dressing, transmitted power was measured at nominal generator output powers of 0.4, 1.2, 2.0, 4.0, 6.0, and 8.0 W (corresponding to beam intensities of 0.1, 0.3, 0.5, 1.0, 1.5, and 2.0 W/cm^2 with the applicator used) and at frequencies of 1.0 and 3.3 MHz of continuous output. This range includes the power values typically used in published studies of US for wound healing.[2,16,23,28] For some samples, readings were taken with a pulsed output on a 20% duty cycle. The US generator was cycled through a computer-generated, randomly ordered sequence made up of 30 US applications, 6 at each nominal power value. The stable balance reading at each power was directly exported to a computer spreadsheet for subsequent analysis. Each cycle began with adjustment of saline temperature within the range 29˚C–32˚C by the addition of

warm saline. Temperature was measured again at the end of each 5-minute cycle. The temperature was found to stay within the specified range. At least 5 cycles were carried out for each sample, generating a minimum of 30 readings at each data point. This enabled the stability of transmissivity values to be assessed and increased the power of subsequent statistical analysis. At least 2 samples of each dressing were tested.

Dressings were selected to represent the range commonly used in the UK for wound management. These included alginates, foams, honey-impregnated dressings, hydrocolloids, hydrogel sheets, low-adherence dressings, vapor-permeable films, and odor-absorbent dressings. Several proprietary examples of each type were obtained from suppliers. In addition, several gels used in wound management were tested. These included hydrogels, an aloe vera-based gel and a manuka honey-based gel. Investigating the full complement of dressings listed in the British National Formulary was deemed unfeasible, but the 48 samples tested were believed to provide reasonable coverage of those in current use.

In practice, multiple dressings may be applied to a wound. An alginate, for example, is held in place with a vapor permeable film. If ultrasound were to be applied through these dressings, a layer of standard couplant gel might be applied. Therefore, additional tests were carried out on combination of 2 typical dressings plus couplant gel to see if the overall transmissivity was significantly different from what would be expected by combining the data gathered separately for each component.

Results

Data were analyzed using SPSS 14.0 (SPSS Inc, Chicago, Ill) and were found to be distributed non-normally, thus, nonparametric statistics were calculated. Relative transmissivity was calculated as the ratio of power transmitted by the dressing immersed in saline to that of saline alone. For each sample and at each frequency and nominal power, a median value for the ratio of transmitted power was calculated with a nominal 95% confidence interval. These ratios were then averaged across the measured power range to give a representative transmissivity figure for each sample at each frequency.

Figures 2 and 3 plot the relative transmissivities for a range of continuous beam powers at each frequency. Figures 4 and 5 plot the data for selected dressings at a 20% duty cycle. For clarity, only a selection of the wound management products tested is shown. These were chosen to be the representative of the spread of transmissivities and confidence intervals. Dressings that were found to be completely opaque to US or unstable in their behavior are omitted. The charts are scaled similarly to aid comparison of behavior at the 2 frequencies.

Tables 1 and 2 display rank ordered values for relative transmissivity averaged across the range of nominal output powers and at each frequency. The table also provides 95% confidence interval for the transmissivities and the median-centered coefficient of variation. These values have been averaged over the range of powers used. Tables 3 and 4 present the corresponding data for samples tested at 20% duty cycle.

Salient findings demonstrated by the plots and tables are:

- There was wide variation in relative transmissivity between dressings, ranging from 100% to 0%.
- For most dressings relative transmissivity was reasonably constant across the range of beam powers. Departures from trend at 0.4 W may be an artefact, as the sensitivity of the balance becomes limiting at this power.
- Dressing transmissivity varies with beam frequency, in some cases higher at 1.0 MHz, in others higher at 3.3 MHz.
- Transmissivity figures for some dressings (eg, Hydrocoll Thin) have large coefficients of variation, indicating variation in their acoustic behavior.
- Certain dressings were unstable at higher beam intensities and their transmission dropped suddenly. In some cases this was corrected by using a lower duty cycle. Stable dressings had similar transmissivities at both duty cycles.

Of the dressings tested in this study, films, hydrogels, and alginates are overall the best transmitters, while hydrocolloids and foams are generally the worst. However, there is considerable variation in transmissivity even within the same class of dressings (eg, hydrocolloids vary between 92% and zero). Therefore, it is not possible to say that all dressings of one type will be better transmitters than all of another.

A combination of two dressings (Bioclusive and Kaltostat) and a standard US couplant, EMS gel (Electromedical Supplies Ltd, Wantage, UK) was also tested. Measurements using EMS gel in another study[40] show that its relative transmissivity is approximately 100%. The relative transmissivity of the combination was found to be 97% at 1 MHz and 86% a 3 MHz. Within the confidence intervals, these figures are the same as the sums of individual sample transmissivities at each frequency.

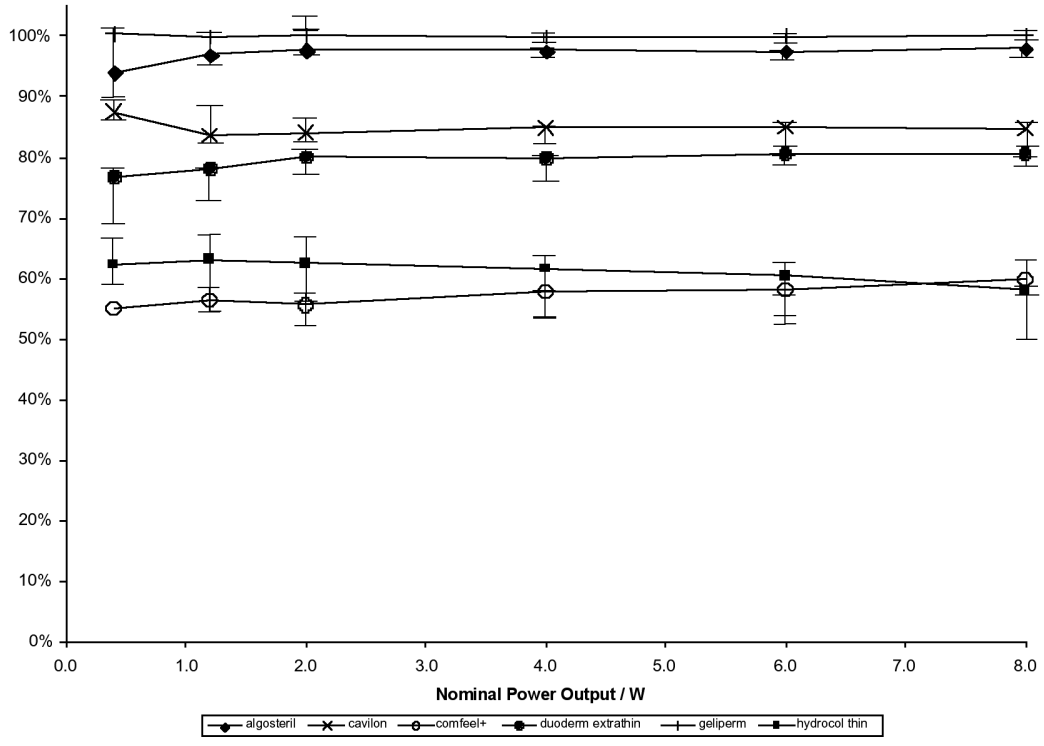

Figure 2. Transmissivity of a selection of dressings relative to saline at 1.0 MHz (continuous beam).

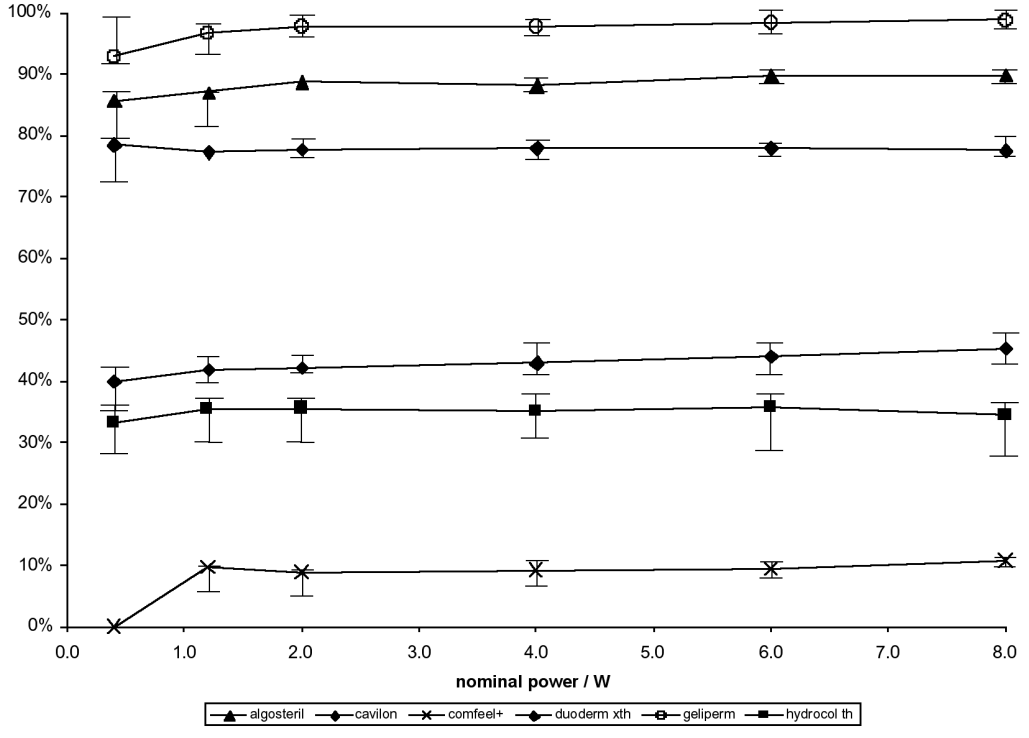

Figure 3. Transmissivity of a selection of dressings relative to saline at 3.3 MHz (continuous beam).

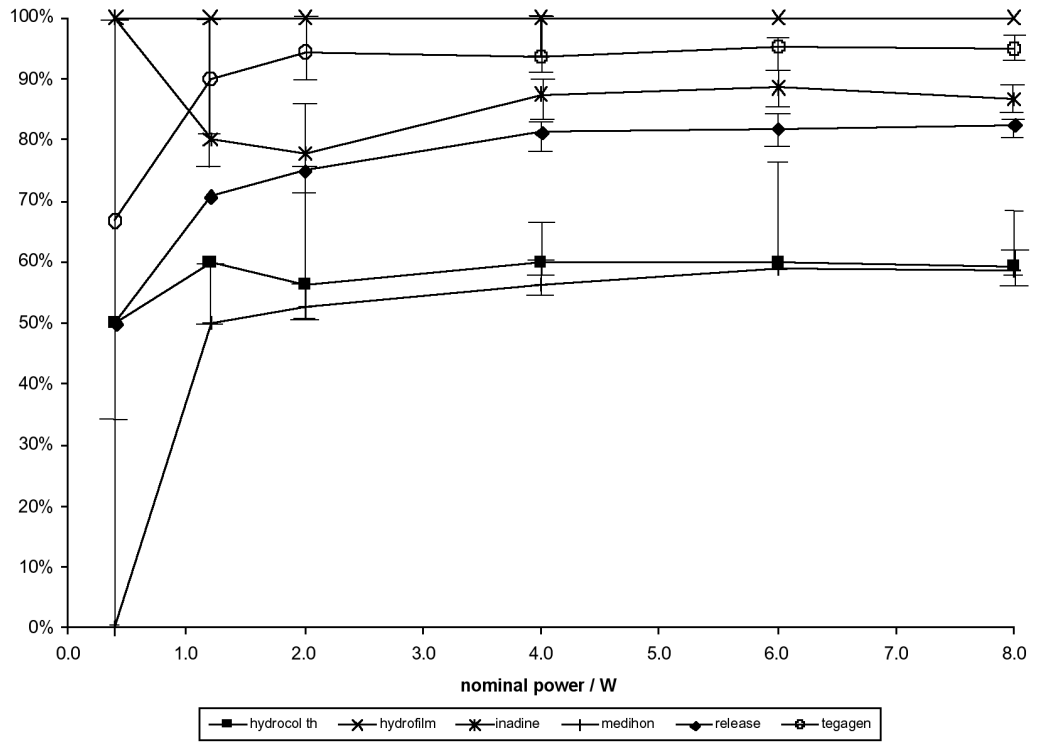

Figure 4. Transmissivity of a selection of dressings relative to saline at 1.0 MHz and 20% duty cycle.

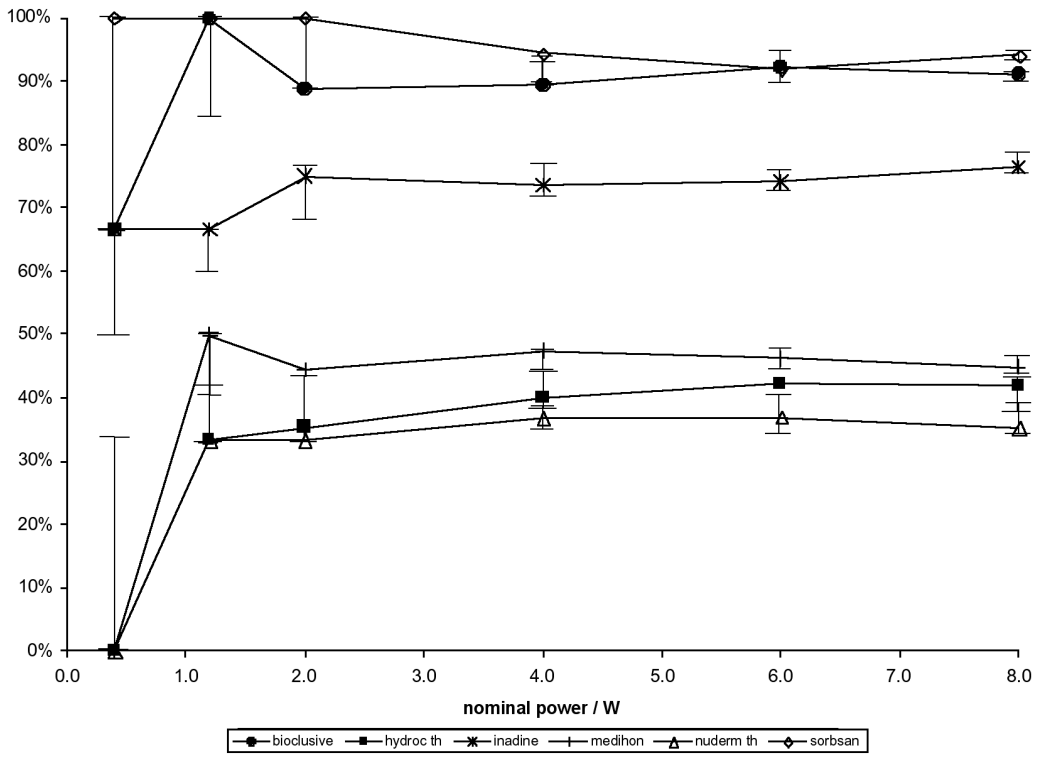

Figure 5. Transmissivity of a selection of dressings relative to saline at 3.3 MHz and 20% duty cycle.

Table 1. Transmissivity of dressings relative to saline at 1.0 MHz (continuous beam). Values for transmissivity, confidence intervals, and coefficients of variation are averaged across the power range.

Dressing	Dressing Type	Relative Tranmissivity	95%CI	Coefficient of Variation
OpSite Flexigrid	Vapor permeable film	101%	3%	3%
Geliperm	Hydrogel sheet	100%	1%	3%
Tegaderm	Vapor permeable film	100%	1%	3%
Sorbsan Flat	Alginate	100%	3%	3%
Cutifilm	Vapor permeable film	100%	2%	3%
Sorbalgon	Alginate	100%	3%	5%
Kaltostat	Alginate	98%	3%	3%
Bioclusive	Vapor permeable film	98%	3%	4%
NA	Low-adherent	97%	4%	4%
Aloe Vera	Aqueous gel	97%	4%	5%
Novogel	Hydrogel sheet	96%	4%	7%
Tegagen	Alginate	96%	4%	5%
Algosteril	Alginate	96%	4%	4%
Hydrosorb	Hydrogel sheet	96%	4%	5%
Melgisorb	Alginate	94%	3%	4%
Aquacel	Hydrocolloid fibers	94%	4%	5%
Actisorb Silver 220	Ag/Charcoal	94%	4%	6%
Tegasorb Thin	Hydrocolloid	92%	2%	3%
Seasorb	Alginate	90%	3%	5%
Purilon	Hydrogel	88%	1%	4%
Release	Low-adherent	88%	1%	4%
Cavilon	Barrier cream	85%	3%	4%
Duoderm Extra Thin	Hydrocolloid	80%	3%	5%
Nu-gel	Hydrogel	80%	12%	19%
IntraSite Conformable	Hydrogel dressing	79%	4%	7%
Tegasorb	Hydrocolloid	66%	4%	8%
Jelonet	Low-adherent	64%	9%	13%
Hydrocoll Thin	Hydrocolloid	62%	12%	24%
Comfeel +	Hydrocolloid	57%	3%	7%
Allevyn, Allevyn Lite, Allevyn Thin, Biatain Adhesive, Mepilex, Tielle, Tielle Light, Tielle Plus (foams); Combiderm, Granuflex, Nuderm (hydrocolloids); Mepore (low-adherent)		0%		
Carboflex (Ag/Charcoal), Hydrofilm (vapor permeable film), Inadine (low-adherent), Medihoney (honey gel), Nuderm Thin (hydrocolloid), Activon tulle (honey dressing)		unstable		

Discussion

The fact that many of the dressings tested are good transmitters of US suggests that there may be scope, previously unexplored, for the application of therapeutic US to wounds through a variety of dressings. The data also demonstrates that it is not appropriate to make generalizations about dressing transmissivity. Each dressing has its own transmission characteristics, which may change with both US power and frequency. For some dressings (eg, Jelonet and IntraSite Conformable), the transmitted power for a given nominal output power showed considerable variation. This suggests that the acoustic behavior of these dressings is less predictable than the others. Reasons may include, variations in physical structure of the dressings (Jelonet has an inhomogeneous distribution of soft paraffin on its gauze), or the way they are used (IntraSite Conformable is packed into a wound).

The fact that some dressings were unstable using a continuous beam, but stable when the duty cycle was reduced to 20%, suggests that there could be a thermal mechanism at work. US energy absorbed by the dressing increased its temperature and may have caused its

Table 2. Transmissivity of dressings relative to saline at 3.3 MHz (continuous beam). Values for transmissivity, confidence intervals, and coefficients of variation are averaged across the power range.

Dressing	Dressing Type	Relative Tranmissivity	95%CI	Coefficient of Variation
Geliperm	Hydrogel sheet	97%	3%	3%
Sorbalgon	Alginate	95%	3%	4%
Aquacel	Hydrocolloid fibers	94%	2%	2%
Hydrofilm	Vapor permeable film	94%	1%	2%
Tegaderm	Vapor permeable film	94%	2%	3%
Hydrosorb	Hydrogel sheet	94%	2%	4%
Melgisorb	Alginate	94%	1%	2%
Aloe Vera	Aqueous gel	94%	3%	3%
Nu-gel	Hydrogel	93%	3%	4%
Sorbsan Flat	Alginate	93%	8%	6%
Bioclusive	Vapor permeable film	93%	3%	3%
OpSite Flexigrid	Vapor permeable film	92%	3%	3%
Tegagen	Alginate	91%	2%	2%
Kaltostat	Alginate	90%	2%	2%
Algosteril	Alginate	88%	3%	2%
Purilon	Hydrogel	88%	3%	4%
IntraSite Conformable	Hydrogel dressing	88%	34%	27%
Cutifilm	Vapor permeable film	87%	4%	4%
Seasorb	Alginate	84%	2%	3%
NA	Low-adherent	82%	3%	4%
Novogel	Hydrogel sheet	80%	4%	8%
Cavilon	Barrier cream	78%	2%	3%
Release	Low-adherent	74%	2%	4%
Actisorb Silver 220	Ag/Charcoal	69%	7%	7%
Jelonet	Low-adherent	67%	4%	7%
Tegasorb Thin	Hydrocolloid	53%	3%	4%
Duoderm Extra Thin	Hydrocolloid	43%	4%	8%
Hydrocoll Thin	Hydrocolloid	35%	6%	23%
Carboflex	Ag/Charcoal	31%	1%	5%
Tegasorb	Hydrocolloid	19%	3%	18%
Comfeel +	Hydrocolloid	8%	1%	17%
Allevyn, Allevyn Lite, Allevyn Thin, Biatain Adhesive, Mepilex, Tielle, Tielle Light, Tielle Plus (foams); Combiderm, Granuflex, Hydrocoll, Nuderm (Hydrocolloids); Mepore (low-adherent)		0%		
Inadine (low-adherent), Medihoney (honey gel), Nuderm Thin (hydrocolloid), Activon tulle (honey dressing)		unstable		

acoustic characteristics to change. Indeed with some hydrocolloid dressings (eg, Hydrocoll Thin and Tegasorb Thin) there was a visible change after insonation, the material taking on a mottled appearance where the beam had passed through. This effect was only observed when dressings were exposed to continuous US at the higher powers. When the beam is pulsed at 20% the dressing has an opportunity to dissipate any heat generated before it can cause an appreciable temperature rise.

The coefficients of variation calculated for each dressing at the 20% duty cycle were large, indicating significant dispersion in the distribution of readings. This may be because the sensitivity limits of the radiation force balance were being approached at this setting. Hence the dispersion may be due to apparatus limitations rather than a feature of the dressings. Within the confidence intervals calculated, however, the transmissivities of stable dressings were the same at both duty cycles.

The behavior of the combined layers of Kaltostat, Bioclusive and EMS couplant gel is what would be

Table 3. Transmissivity of dressings relative to saline at 1.0 MHz, 20% duty cycle. Values for transmissivity, confidence intervals, and coefficients of variation are averaged across the power range.

Dressing	Dressing Type	Relative Tranmissivity	95%CI	Coefficient of Variation
Bioclusive	Vapor permeable film	100%	16%	18%
Hydrofilm	Vapor permeable film	100%	2%	17%
Kaltostat	Alginate	99%	6%	17%
Tegaderm	Vapor permeable film	98%	19%	18%
Melgisorb	Alginate	96%	16%	18%
Sorbsan Flat	Alginate	90%	17%	25%
Tegagen	Alginate	89%	20%	26%
Inadine	Low-adherent	87%	8%	19%
Release	Low-adherent	74%	15%	29%
Hydrocoll Thin	Hydrocolloid	58%	25%	39%
Nuderm Thin	Hydrocolloid	58%	22%	31%
Medihoney	Honey gel	46%	6%	20%
Activon Tulle	Honey dressing	unstable		
Carboflex	Ag/Charcoal	unstable		

Table 4. Transmissivity of dressings relative to saline at 3.3 MHz, 20% duty cycle. Values for transmissivity, confidence intervals, and coefficients of variation are averaged across the power range.

Dressing	Dressing Type	Relative Tranmissivity	95%CI	Coefficient of Variation
Sorbsan Flat	Alginate	97%	9%	13%
Bioclusive	Vapor permeable film	88%	12%	16%
Melgisorb	Alginate	87%	10%	18%
Inadine	Low-adherent	72%	8%	19%
Medihoney	Honey gel	39%	3%	27%
Hydrocoll Thin	Hydrocolloid	32%	12%	35%
Nuderm Thin	Hydrocolloid	29%	11%	25%
Activon Tulle	Honey dressing	unstable		

Table 5. Values for transmissivity of dressings obtained in other published studies.

Study	Parameters	Results
Brueton and Campbell[31]	1 MHz 0.5 W/cm^2	Geliperm (95%)
Byl et al[23]	continuous	Tegaderm (40%)
Klucinec et al[33]	Not stated	Bioclusive (53.2% ± 2.4%)
Nussbaum[36]	3.3 MHz	Nu-Gel (77.2% ± 4.6%)
Pringle[34]	0.2–2.0 W/cm^2 continuous	OpSite Flexigrid (31.5% ± 4.0%)
Young and Dyson[26]	Not stated	Tegaderm (47.1% ± 2.3%)
	1 MHz & 3 MHz	OpSite (< 10%)
	0.75 MHz 0.1 W/cm^2 20% duty cycle	Granuflex (80% at 1 MHz; 73% at 3 MHz)
		OpSite (98% at 1 MHz; 98% at 3 MHz)
		Geliperm (100 MHz; 100% at 3 MHz)
		Geliperm (94%)

expected from the transmissivity figures for the two dressings used separately. There does not appear to be an interactive effect, although this finding may not necessarily be true for other dressing combinations.

Only a limited number of the dressings tested in this study are featured in other published work. Table 5 sets out the findings from these studies for comparison purposes, although they are not strictly comparable since the parameters of frequency, dose, and measurement methods are different from each other and from this study. The figures for Geliperm obtained by Young and Dyson,[26] Brueton and Campbell,[31] and Pringle[34] are similar to those

obtained in this study. Pringle's[34] figures for OpSite are also in agreement with the data presented here, but are completely different for Granuflex, which transmitted no energy at either frequency in the present study. Pringle does not state what beam power was used. Byl et al[23] and Nussbaum[36] do not describe their measurement process so the reliability of their figures is difficult to assess.

Klucinec et al[33] produced transmissivity figures different from our own, being substantially lower in every comparable case. This may be a result of the dissimilar measurement method. In their study, the US beam passed through the test dressing, a layer of pig tissue, and 3 layers of couplant gel. Beam power was calculated by using an oscilloscope to measure the voltages across transmitting and receiving US transducers. Transmissivity values were calculated relative to pig tissue and 2 layers of gel. It may be that the interposition of pig tissue was responsible for the discrepancies between their values and those of the present study. We would argue that measurement of power transmitted by dressing alone, as in the present study, is preferable to the arrangement used by Klucinec et al,[33] where there are more layers and interfaces available to cause beam attenuation.

Kenney et al[32] investigated the transmissivity of various wound dressings when using diagnostic US. The results are not included in this table because they used a scoring system for "sonolucency," which cannot be directly compared to our transmissivity figures. However, their study indicated that the most lucent dressings included Geliperm, Jelonet, Kaltostat, OpSite Flexigrid, and Inadine. The least lucent dressing was Granuflex. These findings are in broad agreement with the findings of the present study apart from Jelonet, which the present study found to be inconsistent in its transmissivity. Possibly the paraffin gel is more transparent at the beam parameters used for diagnostic US.

The findings of the present study have a number of implications for clinicians using US in the treatment of wounds and for further research regarding the effectiveness of US in wound management.

The dressings tested vary significantly in their capacity to transmit US. Even dressings of the same type may have significantly different transmissivities. This is of particular importance in the case of hydrogel dressings, since these are recommended as a class of dressings through which wounds may be insonated.[41] Yet, as the tables show, their transmissivities may vary between 80% and 100%. This means that for a given nominal power output by a US generator, there might be considerable disparity in the power reaching the wound according to the hydrogel dressing used. Differences within some other classes of dressing are much greater, with transmissivity varying from excellent to zero. Clinicians need to keep these variations in mind when considering the application of US to a wound through a dressing.

The data show that there is a substantial number of dressings that are good or very good transmitters of therapeutic ultrasound US. This means that it may be possible to insonate wounds covered by a variety of dressings, with all the potential advantages that were identified earlier. Future investigations into the therapeutic effectiveness of US may benefit by using dressings, which allow for insonation of the wound itself, and not just its margins, while avoiding the potential disadvantages of dressing removal for treatment. Ultrasound is used diagnostically for wound assessment,[32] and scanning through the dressing may again lessen the chances of trauma and infection. Although diagnostic US is used at other frequencies and powers, the results of this study suggest that through-dressing scanning may be feasible with a wide variety of dressings.

A number of qualifications are required when interpreting this data. The first concerns the fact that this is an *in-vitro* study. The environment in which the dressings were tested in the study differs significantly from that in a real wound. Warmed saline was used as a substitute for wound exudate, but is a limited analogue for it. The composition of exudate is complex, and may vary considerably between wounds and within a wound as it evolves.[42] As a wound evolves, the make-up and viscosity of its exudate may change,[21,43] which may in turn impact on its US transmission characteristics. As a dressing absorbs exudate, its own nature may change, and this too may affect its transmissivity. Conversely, dressings may change the nature of exudate,[43] possibly leading to changes in US transmission. All these factors mean that the transmissivity of a dressing on a particular wound may differ from that measured in this study.

In clinical practice, a layer of air might be trapped between the dressing and wound surface, reducing or even preventing transmission of US.[23,44] This possibility has been addressed in some cases by filling the space with saline.[26,41] This might be practical with some of the dressings assessed in this study. If it involved temporary removal of the dressing some of the benefits of through-dressing insonation might be reduced, though the potential advantages of over-wound insonation would still obtain. It may be that this form of treatment will only be suitable for

wounds with significant amounts of exudate where there is minimal or no air present under the dressing.

There is also the question of whether absorption of some of the US energy by a dressing might change the nature of the dressing itself. As noted, this was certainly true for some of the hydrocolloids, whose appearance was changed by insonation. Changes to other dressings may also have occurred but were invisible. This raises the possibility that dressing properties, which are important to their wound management function might be changed, perhaps compromised by insonation. Conversely, such properties might be enhanced if there is a heating effect since warm dressings have been shown to benefit wound healing in some cases.[45] Sample measurements of dressing surface temperature taken after a cycle of insonation in the present study showed that in the cases of Nuderm Thin and Tegagen, the dressing temperature did indeed rise up to 30°C on some occasions. For other dressings temperature changes of this magnitude were not observed, but such readings were not taken systematically in this study.

A great number of dressings and other wound care products are available—many more than those included in this study. As shown, different brands of the same dressing type may have very different transmissivities. Therefore no conclusions can be drawn about those products not tested in this investigation.

Notwithstanding these various considerations, it is the authors' contention that the findings of this study provide data that may be of practical benefit in wound management. First, they broaden the evidence base for clinicians who are already insonating wounds through dressings. Second, they provide a basis for the choice of dressings that might be used in future studies of the effectiveness of US treatment of wounds through dressings. Third, they suggest that for many dressings diagnostic US scanning of wounds may be possible without removal of the dressing. The authors have argued that there may be considerable potential for US wound therapy by this technique, and hope that the data provided in this study may facilitate further research in an area where more effective treatments are still urgently required.

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