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SURFACE AREAS IN ULTRASOUND THERAPY

Evaluation of Seven Methods for Measuring the Treated Skin Area in Physiotherapeutic Application of Ultrasound

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ABSTRACT. Recent articles on ultrasound (US) do not contain information about precise dosage, thus risking a non-valid conclusion of possible effects. To ensure safer standards in treatment-time, the present study compared 7 methods for the calculation of areas. Measurement by eye had a median relative difference (MRD) from the true reading of 22% (lower quartile (l.q.) = −14%, upper quartile(u.q) = +46%), with large intraindividual variation, the span of MRD being −46% to +53%. Measuring with the transducer showed a systematic error: MRD was −48% (l.q. = −55%, u.q. = −35%), which is unacceptable. Areas were measured with satisfactory accuracy with 5 methods that require little training and use accessories some of which are inexpensive. Plates with ellipses of known size had a MRD of 0.1%, (l.q. = −3%, u.q. = +2%), while rulers showed MRD of −2%, (l.q. = −0.6%, u.q. = +5%) both on selected material. The most accurate and versatile instruments were a planimeter (MRD = −0.1%; l.q. = −0.6%; u.q. = +0.5%), a Mettler weighing apparatus (MRD = 3%; l.q. = 2%; u.q. = 6%), and a digitizer (MRD = -0.1%; l.q = -0.4%; u.q = +0.3%).

Key words: ultrasound, physiotherapy, dosimetry, surface area, effective radiation area, measurement, validity.

The dosage of ultrasound depends on the size of the treated surface, and the beam area. Provided the surface is plane, the total treatment time T could be calculated:

$$T = \frac{t \times A}{ERA}$$

t being time per cm^2 surface, A being the area of the treated surface, and ERA being the Effective Radiation Area. This is a common nomenclature for the area of a cross section of the US beam, in contrast to the physical contact surface of the transducer.

Abbreviations: ERA = effective radiation area, *MRD* = median relative difference between measurements and the true reading, *l.q.* = lower quartile, *u.q.* = upper quartile, *CL* = confidence limits, *US* = ultrasound.

Only a few of 15 clinical trials (1, 3–5, 7, 9, 11–15, 17–20) mentioned the size of ERA and the area of the treated surface. McDiarmid (16) reviewed 31 articles and likewise gained little information.

The conclusion of a trial may be invalidated by the uncontrolled variance. The user cannot benefit from the hypothesis tested or reproduce the setting.

When the ERA is unknown it can be estimated as 70% of the physical treatment area of the transducer. This is supported by Dyson (6). Enraf-Nonius (10) measured 4 transducers for their apparatus Sonopuls 434, and showed that ERA was smaller by an average of 28% (range 20% to 43%).

The aim of my investigation was to present methods for the measurements of surface areas and to compare them by testing accuracy. The methods were designed to measure the size of plane or cylindrical surfaces. These models describe by approximation the commonly treated regions. The tests were performed on plane surfaces. There will be a reduction in accuracy when the surface curve is ellipsoid, spherical, or of composite shape. An estimate of the maximum discrepancy was sought.

Treatment to a convex surface causes a smaller area to be irradiated in the deeply sited tissue than at the surface. Concavity reverses this effect. This problem will not be further discussed here.

METHODS

The test material comprised several sets of 16 plane drawings in the range 3–150 cm^2, representing different shapes. The drawings were constructed as polygons with 200 edges using computer aided design (CAD). The drawings were corrected

Table I. *Deviation from the true reading for all observations. Accuracy for 7 methods of measuring areas*

Lines 2b and 3b include the part of the material where area >20 cm^2 and the figure resembles an ellipse or a rectangle respectively. n is the number of measurements.

Method	n	MRD (%)	l.q. (%)	u.q. (%)	CL (%)	p
1	112	21.9	−13.6	45.9	9.9 < > 26.7	0.0001
2	112	1.4	−3.3	11.6	0.7 < > 6.3	0.0045
2b	33	0.1	−2.7	1.6	−1.6 < > +0.8	0.55
3	112	−1.9	−8.5	5.6	−3.4 < > +1.0	0.26
3b	55	−1.9	−6.0	5.1	−3.7 < > +1.5	0.36
4	48	−0.1	−0.6	0.5	−0.3 < > +0.2	0.74
5	16	2.8	1.9	5.6	2.1 < > 6.1	0.00005
6	16	−0.1	−0.4	0.3	−0.3 < > +0.4	0.75
7	32	−47.7	−54.9	−35.2	−51.4 < > −38.8	0.00001

for printer errors and errors due to Xerox-copying, thus minimizing errors to ± 0.05 mm. The calculated polygon areas were therefore considered as the true reading.

The present study investigated the following methods:

1. *Measurement by eye* was presumed to give a valuable estimate of the size of the treated surface, if it could be expressed in terms of an interval scale (cm^2). This method is normally used with an ordinal scale (small, medium, large), if any at all. Usually the estimate of the area is made without instruments.

The test persons in this case were asked to inspect the test area for about 30 seconds. They were asked to express the size of the shape presented to them in square centimeters. No visual aids such as rulers or squared paper were available.

2. *Plates with known areas*. The plates were 2 transparent films with prints of concentric ellipses with known areas, one plate with a radius ratio of 2:3, the other with a ratio of 1:2. The scale was made of 8 ellipses in the range of 5–245 cm^2. The ellipse was chosen because it is assumed that many treated regions will resemble that shape.

3. *Ruler*. Ordinary stiff plastic rulers with a millimeter scale were controlled against a micrometer. During these measurements it was assumed that the outlines of the treated regions could be approximated to rectangular and circular shapes. The linear readings were as detailed as possible (0.5 mm).

4. *Planimeter*. The planimeter was an OTT-planimeter from "Bender & Hobein", München. It is a mechanical device constructed to measure areas of any shape.

5. *Weight*. A Mettler PE 360 was used to weigh 15 sheets of A4 paper. From this the median weight/cm^2 was calculated. The test drawings were then cut out and weighed, and the areas were calculated.

6. *Digitizer*. If a sufficient number of precise coordinates can be obtained, the area can be calculated as a polygon area. A computer mouse (Genius, GM-6 Plus) was used at first to record the coordinates but proved sensitive to rotation, pressure, and speed, and thus produced unreliable results. A digitizer (GTCO Sketchmaster) was then chosen, and 200–500 coordinates were recorded by guiding the digitizer along the outline of the treated region.

7. *Transducer*. The transducer was used as a measuring tool. The treated region was outlined on the surface and the transducer was moved across the delimited surface like a stamp making adjacent prints.

Measurements

The accuracy of these methods was tested by 7 physiotherapists. Each made 16 measurements with each of the first three methods (by eye, plate, and ruler). The intraindividual variation using the planimeter, weight, and digitizer (methods 4–6) was expected to be insignificant. Three participants used the planimeter and one tried out the weight, the digitizer, and the transducer. Each of these physiotherapists again made 16 measurements.

The MRD derived from the discrepancy between the plane model and a curved object was determined. Four spheres with diameters of 1.4 cm to 14.7 cm were painted with circles at different heights above the "equator", thereby forming different caps. The areas of these could be calculated from the diameters of the sphere and the base of the cap. Diameters were measured with a slide gauge. 90 measurements were made drawing the outline of the caps onto transparent paper and measuring the area with the digitizer.

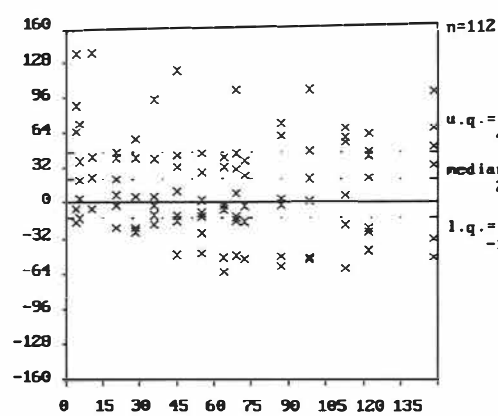

Fig. 1. Plot of relative differences between the true reading and measurement by eye (method 1). x = true reading, y = rel. difference. $n = 112$, and all participants contributed.

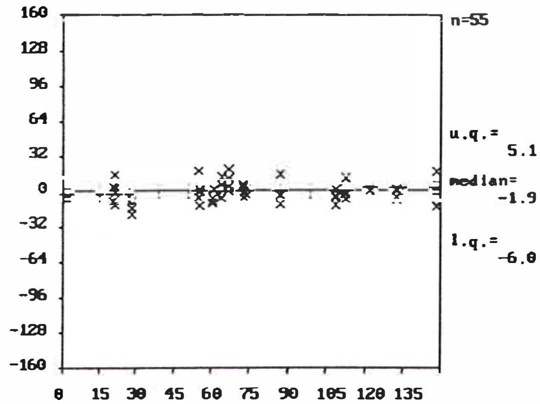

Fig. 2. Plot of relative differences between the true reading and measurement by ruler on selected material for all participants (method 3B). x = true reading, y = rel. difference. $n = 55$.

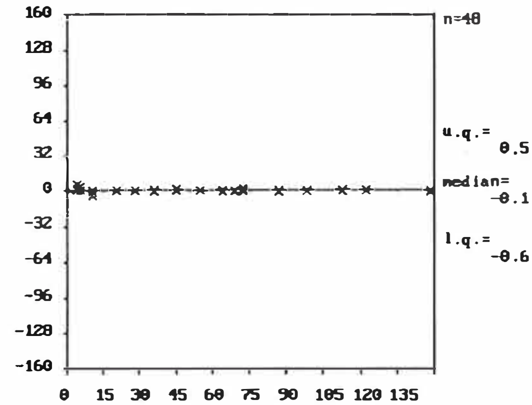

Fig. 3. Plot of relative differences between the true reading and planimeter (method 4). x = true reading, y = rel. difference. 3 persons participated. $n = 48$.

Statistical methods.

With measurements on plane surfaces, the differences between measured values and the true readings were calculated. The median relative difference and the upper and lower quartiles of the differences were found. The results were graphically displayed, x being the true reading and y being the relative difference (2).

The relative difference tends to increase as the measured value decreases. It was clinically relevant to seek an acceptable lower limit of measurement for methods 2–3, and the calculations were repeated on a selection of the material. Only regions with outlines resembling the model of ellipse or rectangle, respectively, and areas > 20 cm^2 were included in this selection.

The one sample rank sum test for paired data (Wilcoxon, Pratt) was used to test the difference between measurements and the true reading. The confidence limits (CL) were calculated accordingly (8).

The level of significance chosen was $p < 0.05$, and the level of CL 95%.

Table II. *Deviation from the true reading for each examiner. The results are the median relative differences (%).*

	Examiner						
Method	A	B	C	D	E	F	G
1	40.6	52.7	−15.0	1.8	−46.2	9.5	45.5
2	0.3	6.1	−0.9	−0.5	15.4	1.6	0.5
3	−3.0	6.8	−5.8	−2.9	−0.2	−10.7	1.5
4	0.0	−0.7	0.0	*	*	*	*
5	2.8	*	*	*	*	*	*
6	−0.1	*	*	*	*	*	*
7	−47.0	−50.0	*	*	*	*	*

RESULTS

Accuracy. Table I shows the deviation from the true reading for all methods.

Fig. 1 shows the results from method 1 (measurement by eye). The relative differences between that method and the true reading are plotted, and there is an obvious scatter of values.

The relative differences using the ruler (method 3) ($n = 112$) are seen in Fig. 2. The ruler was more versatile than the plates with ellipses (method 2). Although a selected material reduced MRD to an insignificant value for the plates, the number was reduced to 33. Looking at the individual measurements showed that the error was large when the drawing differed from the elliptical model. This applied to the rectangular model of the ruler as well. The two methods are complementary and should be used together for better results.

The slight, evident deviation from the true reading in the weight (method 5) could be minimized by carefully cutting out the figures at the centre of the outline.

Measuring with the transducer (method 7) showed a remarkable MRD of −47.7%. One source of error is the circular shape of the transducer plate, because it leaves 'islands' that are not measured. The difference between the ERA and the metal plate will reinforce the underestimation.

The planimeter and digitizer (methods 4 and 6) produced the best results. See Fig. 3 for a plot.

Interindividual variation is shown in Table II. Measurement by eye is not recommended because of

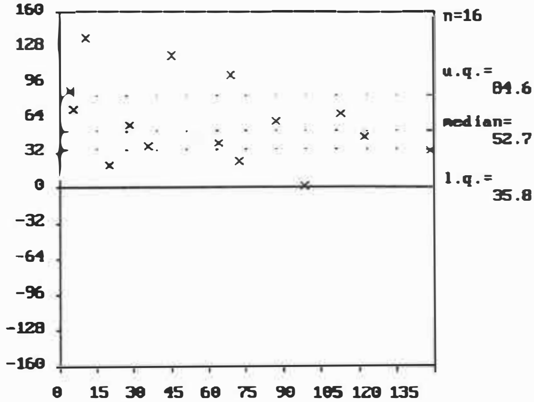

Fig. 4. Plot of relative differences between the true reading and measurement by eye (method 1). x = true reading, y = rel. difference. Test person "B". $n = 16$.

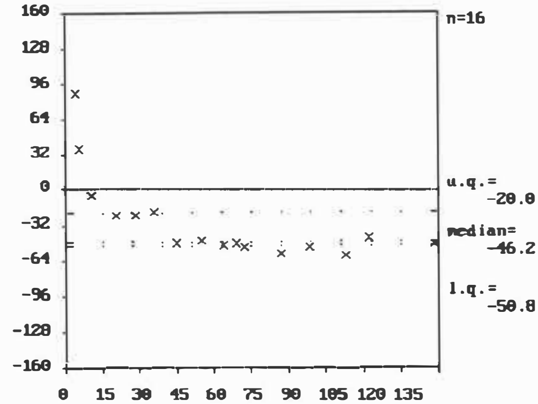

Fig. 5. Plot of relative differences between the true reading and measurements by eye (method 1). x = true reading, y = rel. difference. Test person "E". $n = 16$.

its range of 98.9%. In Figs. 4 and 5 the two most extreme examiners are pictured.

Spheres. The 90 measurements on the caps showed a MRD of 2.5% (l.q. = 2.0%, u.q. = 7.7%), when the base of the cap was 65 degrees above the equator. At the height of 35 degrees the MRD was 10.3% (l.q. = 9.8%, u.q. = 10.9%). When measuring at the equator the MRD was 24.5% (l.q. = 13.4%, u.q. = 28.0%).

DISCUSSION

The shapes and the range of the areas of the test material were chosen to cover the regions and indications used today. When measuring on a curved surface where the radius is small or the area large, the area measured must be corrected. The MRD of measurements on spheres will serve as a maximum estimate of the error. Dividing a curved surface into smaller, approximately plane facets can minimize the problem.

A very good estimate of the truth was available because the measurements were restricted to plane surfaces.

Several manufacturers of US-equipment supply the user with lists of standard dosage. However, haematomas, decubitus ulcers, and other conditions may vary in size by several hundred per cent. Considerable variation may occur between individuals in the size of structures in the musculoskeletal system. Such variations are easily determined using one of the more sensitive methods in this trial.

Measurement of surface areas by eye, as well as standard dosage, should be abandoned because of their considerable variation. Measuring with the transducer is not recommended because of a large systematic error which will vary with the design of the transducer.

This study demonstrates that it is possible to be more exact than is the case with today's standard. Inexpensive and easily-learned methods are at hand with ruler and ellipses. For more demanding purposes, such as clinical trials, the use of planimeter, weight, or digitizer is advised.

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