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BALL TARGET DIAMETER IMPACTS THE MEASURED SONOGRAPH POINT SPREAD FUNCTION

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A b s t r a c t

One measuring method applicable to sonograph imaging quality estimation utilises Point Spread Function analysis. However, the results depend, among other factors, on sphere reflector diameter.

We focused on matter using an original method which measures lateral resolution at any specified point of the sonogram with the use of Point Spread Function analysis. In our preliminary study, both characteristics, echo amplitude distribution and lateral resolution distribution from a specified sonograph and transducer set using three reflectors of different diameter were analysed. The analysis was based on a comparison of echo amplitude and lateral resolution characteristics shape as well as lateral resolution and amplitude characteristics deviation.

The results confirmed the expected influence of the reflector diameter on the parameters cited above. A spherical target diameter in the range $1\lambda < D < 4\lambda$ is recommended for PSF analysis.

K e y w o r d s

Ultrasonography, Point Spread Function, Sphere reflector, Diameter, Lateral resolution

A b b r e v i a t i o n s u s e d

A_{MAX}, peak amplitude measured in PSF; A_{MIN}, minimum level signal amplitude in PSF (background noise level); A_{+LR} (l+), echo amplitude level at a distance of l in lateral positive direction from ultrasound beam axis; A_{-LR} (l-), echo amplitude level at a distance of l in lateral negative direction from ultrasound beam axis; l, distance measured from transmitted ultrasound beam axis in lateral direction; LR, lateral resolution; PSF, Point Spread Function; ROI, region of interest; λ, wavelength

INTRODUCTION

One objective measuring method for ultrasonograph imaging quality assessment uses Point Spread Function (PSF) analysis of the received signal from which a numerical value is derived. This expresses a parameter of the Lateral Resolution (LR), judged to be of paramount importance for image quality description. The key part of the measuring system is a point reflector, which is realised using a metallic spherical target. The target diameter influence on measurement results is predicted and cited in the literature (*1*) and (*2*). We made a short study to verify these predictions and to find the optimum relation between target diameter and ultrasound wavelength.

MATERIALS AND METHODS

The basic principle of the measuring process is as follows: the measured sonograph scans a small metallic ball target that moves stepwise in a water bath on a specified trajectory. The steps are programmable in 0.01 mm in lateral and transverse directions, and in 0.1 mm in axial direction. The bath is filled with degassed water mixed with ethyl alcohol to decrease ultrasound propagation velocity dependence on temperature (*3*). The water bath walls are fitted with absorbent material. The positioning system has a ball target holder, designed according to instructions given in the ČSN IEC 854 standard (*2*). The ball target consists of a small steel sphere, a laser welded to a tiny wire which is appropriately fixed in the holder. The shape of the wire ensures that the sphere is oriented in front of the transducer in the scanned plane with the welding point in distal position. The wire is hard enough to eliminate any movement of the ball target during replacement in the water bath due to hydrodynamic forces. 3D positioning is arranged by three stepper motors connected to precise support screws. The motors are driven by a computer-controlled power unit. The video signals from the test US scanner are driven to Frame Grabber NI PCI-1411 (National Instruments), where they are converted to digital form and the Region of Interest (ROI) is stored after online evaluation. The system selects the video frame containing the peak amplitude for each measurement point in the scanning plane to derive the PSF function in a lateral direction centred in the pixel with the maximum amplitude. The PSF in the axial direction is obtained by the same procedure.

To calculate the lateral resolution parameter we analyse the PSF in lateral direction. As LR we take the width of the amplitude peak in one half of the amplitude and recalibrate for the actual amplitude level.

Values A_{+LR} (l+) and A_{-LR} (l-) are found for the following conditions:
l+ > 0 and l- < 0

$$A_{\pm LR} = \frac{A_{MAX} + A_{MIN}}{2} \qquad [1/256]$$

We can then express the LR corrected for difference between the measured maximal amplitude A_{MAX} and the maximal possible amplitude of 255 digitising units

$$LR = (l_{+} - l_{-}) * \frac{255}{A_{MAX}} \qquad [mm]$$

A_{MAX} is peak amplitude in PSF
A_{MIN} is minimal signal amplitude level in PSF (background noise level).

To date we have been able to plot the LR characteristic over the scanning plane in a 3D graph. This can differentiate separate scanning lines and even multiple focal areas for dynamic focusing systems in the plotted plane.

We used this method to assess sphere target diameter influence on the results. A sonograph Aloka SSD248 with a mechanical sector transducer ASU32-5 and a nominal frequency of 5 MHz was used to measure the LR characteristic in the same part of the scanning area (*Fig. 7*) using three sphere targets of different diameters D_1 = 0.29 mm, D_2 = 0.44 mm, and D_3 = 1.45 mm. The wavelength λ of the 5MHz ultrasound in 17% mixture of ethyl alcohol in degassed water and at a temperature of 23 °C was 0.321 mm (c = 1604 m/s). The D/λ ratio is listed in *Table 1*.

The three echo-amplitude characteristics (*Figs. 1* to *3*) and LR characteristics (*Figs. 4* to *6*) were compared to identify differences which could correlate with the target diameter. For better estimation, the original colour-scaled 3D graphs were displayed in a 2D view to better illustrate the parameter

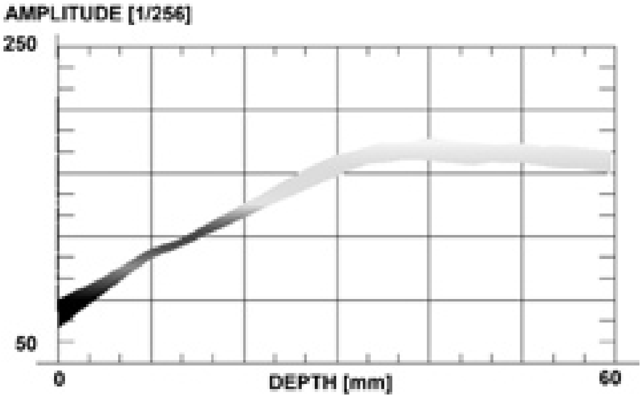

Fig. 1
Received echo amplitude characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 0.29 mm. The amplitude is measured in steps of 8-bit digitising range (256 levels). The depth axis represents axial direction.

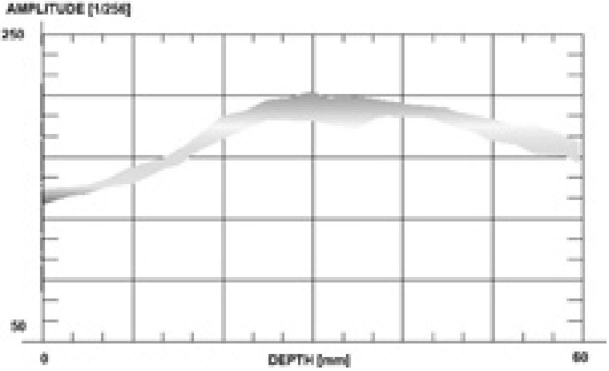

Fig. 2
Received echo amplitude characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 0.44 mm. The amplitude is measured in steps of 8-bit digitising range (256 levels). The depth axis represents axial direction.

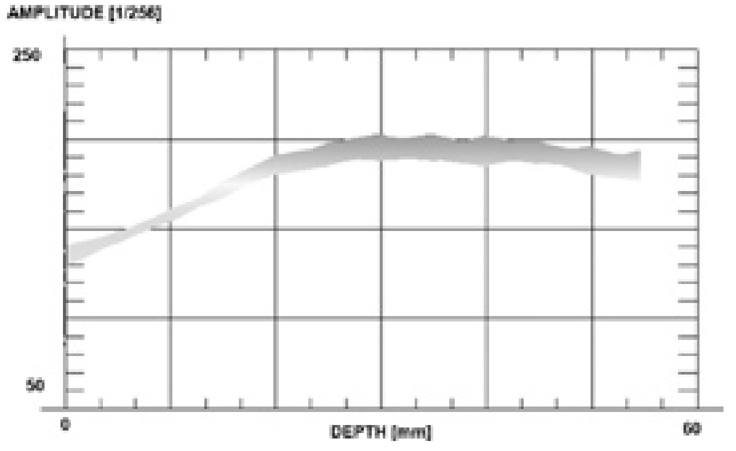

Fig. 3
Received echo amplitude characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 1.45 mm. The amplitude is measured in steps of 8-bit digitising range (256 levels). The depth axis represents axial direction.

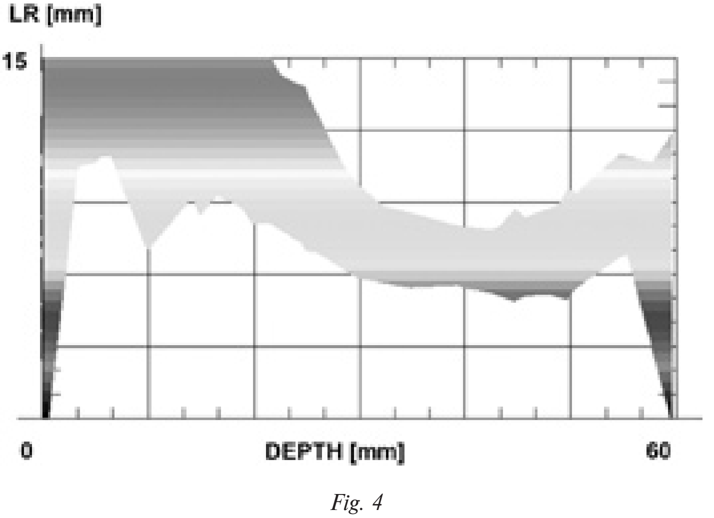

Fig. 4
LR characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 0.29 mm.

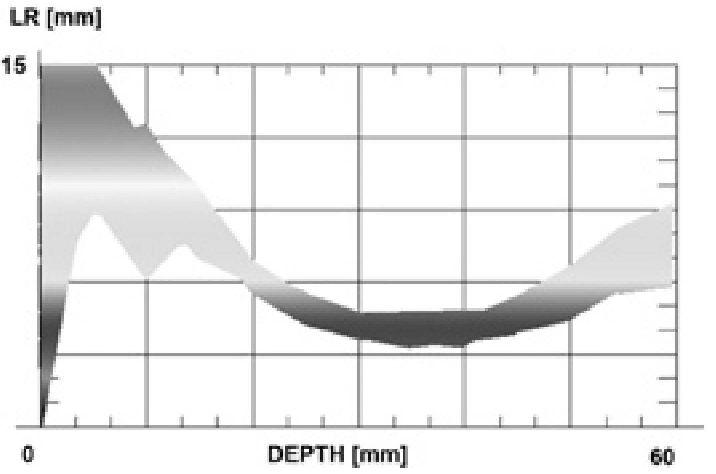

Fig. 5
LR characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 0.44 mm.

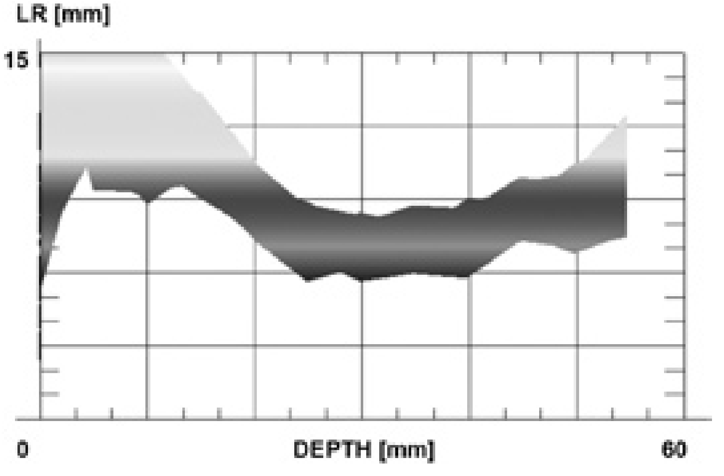

Fig. 6
LR characteristic of sonograph Aloka SSD 248 with 5 MHz mechanical sector transducer ASU32-5 measured using spherical target of a diameter of 1.45 mm.

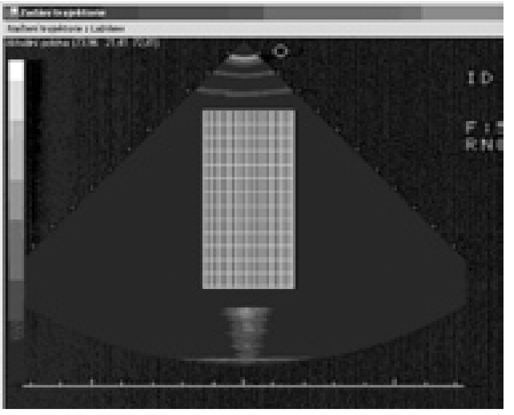

Fig. 7
Specification of the reflector trajectory in the sonogram used. Lateral width of measured area was 30 mm, axial length (depth) was 65 mm. The target positioning step was in lateral direction 0.5 mm, in axial direction 5 mm

Table 1
Summary of the target diameter, resulting graphs, and agreement with conditions given by the ČSN IEC 854 – A4 standard (Methods of measuring the performance of ultrasonic pulse echo diagnostic equipment) and by *Hasegawa* work (*2*)

Case No.	Diameter [mm]	D/λ ratio	Graphs	Agreement with conditions	
				ČSN IEC	Hasegawa
1	0.29	0.94	Fig. 1, Fig. 4	NO	YES
2	0.44	1.43	Fig. 2, Fig. 5	YES	YES
3	1.45	4.71	Fig. 3, Fig. 6	YES	NO

distribution and variability for a particular depth. The variability is expressed as width in the graphic curve, which was obtained by 3D graph conversion to 2D display. The parameter DEPTH of the x-axis represents axial direction in the sonogram. (For this article the colour scale is converted to a scale of grey due to the editor's journal regulations.)

RESULTS

We made the following assumptions from the analysis of the graphs. Comparing the maximum amplitude levels in *Figs. 1* to *3,* it is possible to say that in the case of D < λ (D/λ ratio < 1; *Fig. 1*) the maximum amplitude of the reflected signal measured is 175 digitising steps compared to the 210 digitising steps for D > λ (*Figs. 2 and 3*). From *Figs. 4, 5* and *6* evaluation we can state that if D/λ ratio > 4 or D/λ ratio <1, the LR value and variability is considerably larger even in the focal area. A spherical target diameter in the range $1\lambda < D < 4\lambda$ is recommended for PSF analysis.

DISCUSSION

The results correspond with expectancies according to the references. The ČSN IEC 854 – A4 standard recommends the following condition for spherical target diameter:

$$D > \frac{5\ \text{MHz}}{f} \qquad [mm]$$

As we used an ultrasound frequency of 5 MHz, case 1 (*Fig. 1* and *Fig. 4*) does not fulfil the conditions of the standard. Comparing the results with cases 2 and 3 we see a remarkably lower reflection effectivity and a higher LR deviation in case 1. The lower reflection effectivity is caused by the target diameter ($D < \lambda$) and the higher LR deviation by higher scattering for the same reason.

The second limiting condition for target diameter was given by *Hasegawa* in (*2*). From this work we can derive a recommendation:

$D < 4\lambda$

Observing *Fig. 3* and *Fig. 6* we see the same reflection effectivity as in case 2 but the LR deviation is much larger. The reasons for this could be ultrasound wave multiple reflections into the metallic target sphere, and also spheres of a larger diameter cannot be assumed to be ideal point reflectors.

The study is preliminary; we intend to confirm the results with measurements at different ultrasound frequencies using a larger number of targets of different diameters.

Acknowledgement

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PRŮMĚR KULOVÉHO ODRÁŽEČE OVLIVŇUJE VÝSLEDEK MĚŘENÍ SONOGRAFU METODOU FUNKCE ROZPTYLU BODU (PSF)

Souhrn

Jedna z metod, používaných pro hodnocení kvality zobrazení sonografu, využívá analýzu funkce rozptylu bodu. Výsledek tohoto měření může být mimo jiné ovlivněn také průměrem použitého kulového odrážeče.

Zaměřili jsme se na tento problém naší originální metodou, umožňující měření laterální rozlišovací schopnosti v libovolném bodě sonogramu s využitím analýzy funkce rozptylu bodu.

V naší studii jsme analyzovali charakteristiky rozložení amplitudy echa a laterální rozlišovací schopnosti získané měřením jednoho sonografu se stejnou sondou, ale s použitím tří kulových odrážečů o různém průměru. Analýza spočívala ve srovnání tvaru obou charakteristik pro různé odrážeče a v hodnocení rozptylu těchto hodnot.

Byly potvrzeny předpokládané závislosti zmíněných parametrů na průměru odrážeče. Pro analýzu PSF je doporučeno používat kulové odrážeče, jejichž průměr je větší než 1λ a menší než 4λ.

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