SIMULATED MICROEMBOLI DETECTION USING DOPPLER PROFILER PW2000

J. Żmigrodzki*, K. Kałużyński*, G.Bambi**, S.Ricci**, P.Tortoli**

* The Institute of Precision and Biomedical Engineering, Faculty of Mechatronics Warsaw University of Technology, Warsaw, Poland
** Dept. of Electronics and Telecommunications, University of Florence, Italy

j.zmigrodzki@mchtr.pw.edu.pl

Abstract: Microemboli are small gaseous bubbles or solid particles which can block small blood vessels. Detection and quantification methods of such elements are important for estimation of the risk of embolism. An in vitro investigation of four types of microembolic elements (gas bubbles and solid elements of different sizes) was carried out. A silicone model of artery, special blood mimicking fluid and ultrasound Doppler Profiler (PW2000) were used. An algorithm (Matlab™) was created for detection and classification of embolic signals using 2D cross-correlation. The new parameter (Embolus Strength) for describing embolic signals was developed. This parameter seems to be independent from ultrasonic beam shape and flow velocity.

Introduction

Microemboli are small gaseous bubbles or solid particles which can block small blood vessels. Detection and quantification methods [1,2,3] of such elements are important for estimation of the risk of embolism in important organs like brain, heart, lungs or limbs (blue toe syndrome) [4]. Investigation with elements mimicking the microemboli is a necessary phase in development of such methods. Below presented is a study of detection of four types of embolic elements in a carotid artery model.

Materials and Methods

The experiment was carried out in a setup enabling pulsed flow in a silicone artery model [5]. The diameter of the common branch in which the recordings were carried out was 7mm. The blood-mimicking fluid was a mixture of (percentage of weight) water (89,09%), Dextran 70000 (Fresenius-Kabi) (5,69%), glycerin (4,99%), EDTA (Carl Roth GmbH) (0,1%), Orgasol® 2001EXD Nat 1 (Atofina) (0,06%) [6]. The fluid density was 1,0375g/cm^3 and viscosity was 4,57mPa*s.

The solid emboli were simulated using chromosorb particles (Johns-Manville): AW – diameter 149-177μm, T – diameter 250-350μm.

Electrolysis was used to obtain bubbles with diameters in the range 10-100μm. Bigger bubbles were injected using a small syringe and had a diameter of hundreds of micrometers.

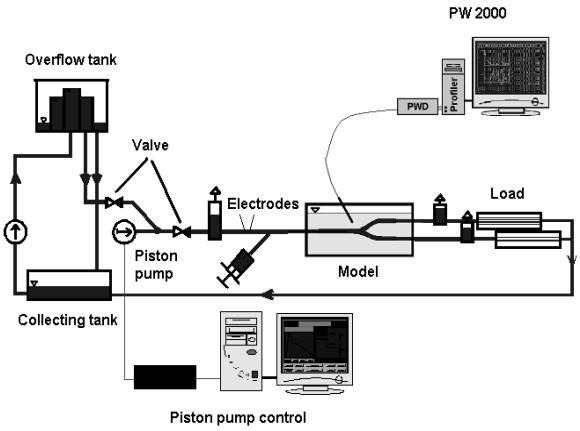

Figure 1: Experimental setup.

Acquisition was carried out using multigate Doppler profiler PW2000 connected to a PC computer with special GASP software [7]. System allowed collecting signals from 64 gates, 1mm wide each. Hardware settings and parameters during registration:

- f_0=4MHz – emitted frequency,
- PRF=7,86kHz – pulse repetition frequency,
- f_{cut}=510kHz – low pass filter (after demodulation),
- f_{burst}=5MHz – sampling frequency,
- Doppler angle=60°,
- distance between probe and model center was approximately 45mm,
- the transducer was disk shaped with diameter 5mm.

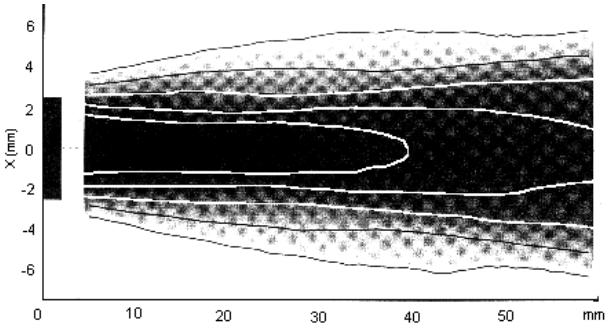

Figure 2: Section of the acoustic pressure distribution of the ultrasound probe – contour lines for -6, -10, -15, -20, -25 dB pressure levels are shown.

ISSN: 1727-1983

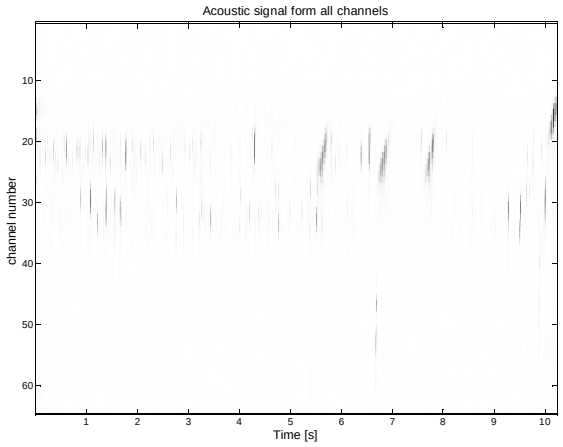

Figure 3: Example of data registered across the model section. The signals due to bigger emboli can be seen.

The signal processing is divided in three parts:

- Calculation of threshold level – A_{thr} (average amplitude of the signal registered from pure blood mimicking fluid), selection of 2D embolic signal reference (operator's choice) and data formatting.
- Searching for data blocks containing embolic signals – two-dimensional cross-correlation method.
- Calculating characteristic parameters of embolic signal and results presentation.

The searching procedure starts with area selection from registered data, having the same size as the reference. In the next step the candidate is scaled to the same maximum amplitude as the reference signal. All values below A_{thr} are treated as background and set to zero. After this procedure two-dimensional cross-correlation coefficient of reference and candidate is obtained. If the maximum of the coefficient is greater than the threshold level 0,5 (experimentally chosen), the candidate is considered as containing embolic signal. Then the candidate region is centered at the maximum of cross-correlation coefficient. Subsequently another cross-correlation coefficient is computed to determine the embolic signal core. The core is a region with values of cross-correlation coefficient exceeds threshold 0,6 (experimentally chosen). The embolic signal coordinates and core coordinates are kept (Fig.4). The procedure of computing embolic signal parameters searches the core region for maxima of embolic signal.

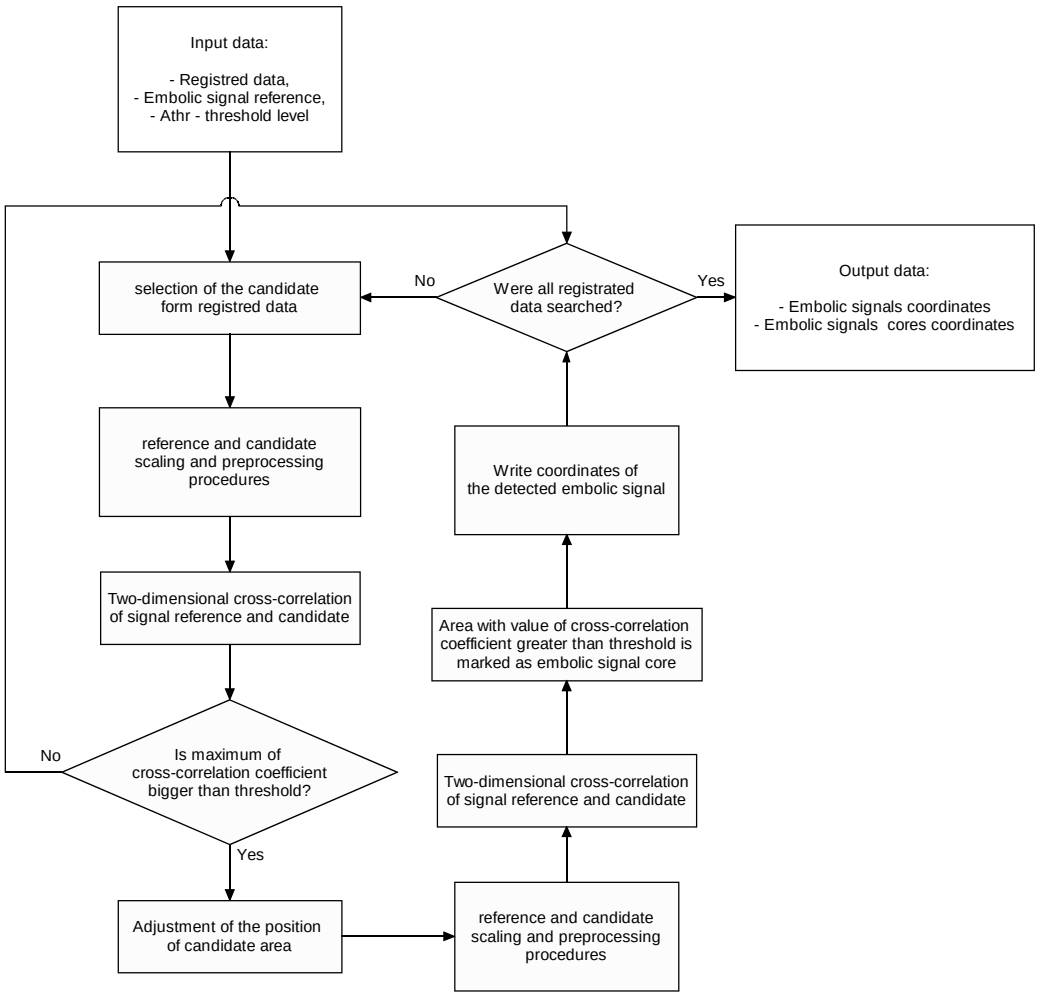

Figure 4: Algorithm for embolic signal search with 2D cross-correlation method.

ISSN: 1727-1983

In the last stage the following parameters are calculated:

- **A_{peak}** – Mean amplitude of embolus.

$$A_{peak} = \frac{\left(\sum_{i=1}^{n} |s(i)|\right)}{n} \quad (1)$$

- **EBR** – Embolus to Blood Ratio [8].

$$EBR = 10 \log\left(\frac{A_{peak}}{A_{thr}}\right) \quad (2)$$

- **ES** – Embolus strength is the area under demodulated and filtered single echo (one emission) containing the maximum peak value of analyzed signal.
- **TD** – Time duration – a time between two points for which amplitude to A_{thr} ratio is less than 3dB.

EBR and TD parameters are calculated for data picked along time axis (for consecutive emissions). ES is calculated along the depth axis and corresponds to area under demodulated single echo (one emission) from an embolic element.

Algorithm of this stage is shown in the Fig. 5.

In some cases when two or more emboli appear within small time interval or space the algorithm may result in incorrect values of parameters. For this reason the operator has a possibility to mark the result as wrongly or correctly calculated.

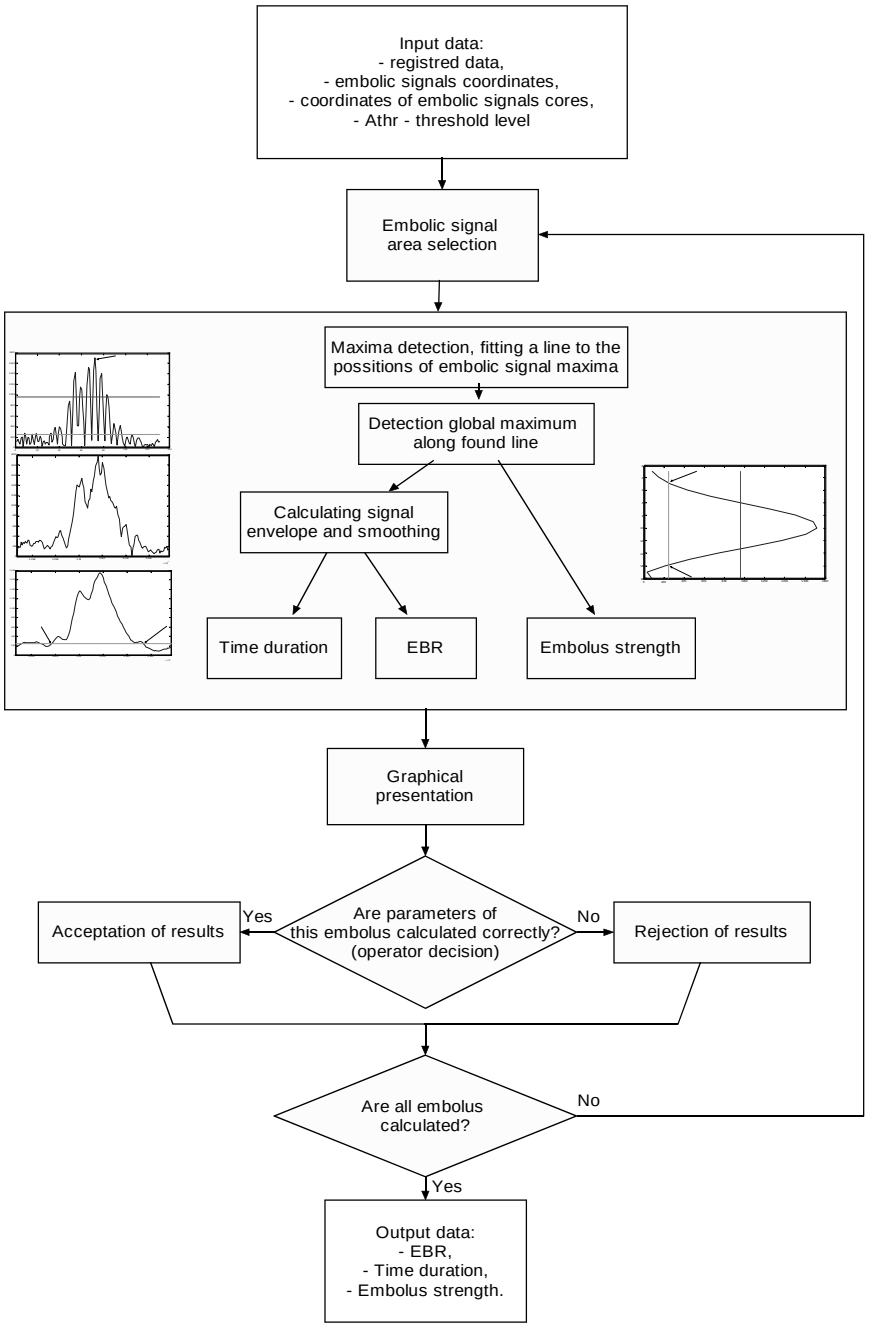

Figure 5: Algorithm of calculating embolic signal parameters.

ISSN: 1727-1983

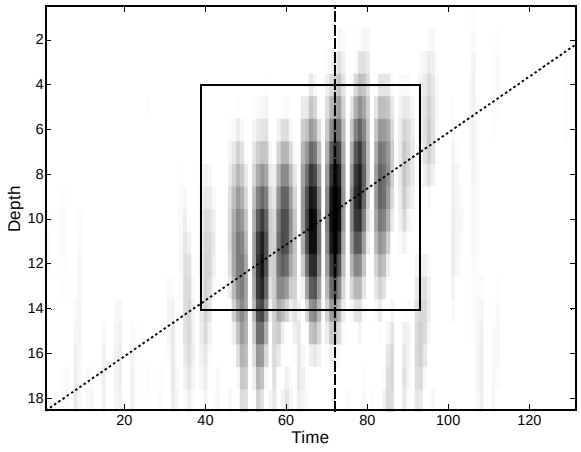

Figure 6: Typical embolic signal and illustration of some processing steps. The rectangle delimits the embolic signal core area, dotted line is fitted to signal maxima (for consecutive emissions), the dashed line along which ES parameter is calculated (for single emission).

As the experimental liquid inevitably contained aggregates of the Orgasol® particles, they must have resulted in quasi-embolic signals. Such signals were excluded from further processing on the basis of their A_{peak} value. The knowledge on distribution of these values was achieved by recording the signal from the pure experimental liquid without gaseous nor solid elements introduced.

Dedicated software for embolic signal detection and characterization was developed in the MATLAB™ environment.

Results

An example of embolic signal indicates clearly the way the element moved across the area, showing the lateral (temporal) shift and shift along the ultrasonic beam (Fig.6).

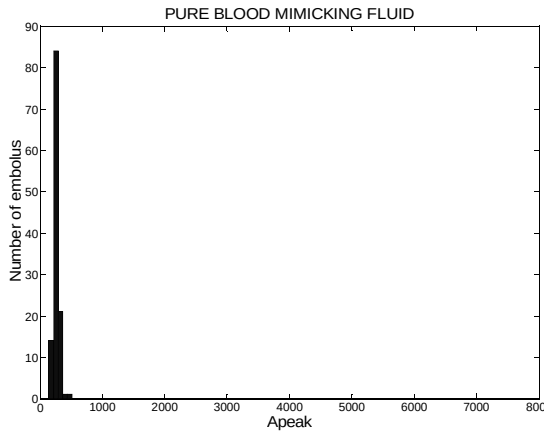

Figure 7: Histogram of A_{peak} parameter – pure blood mimicking liquid.

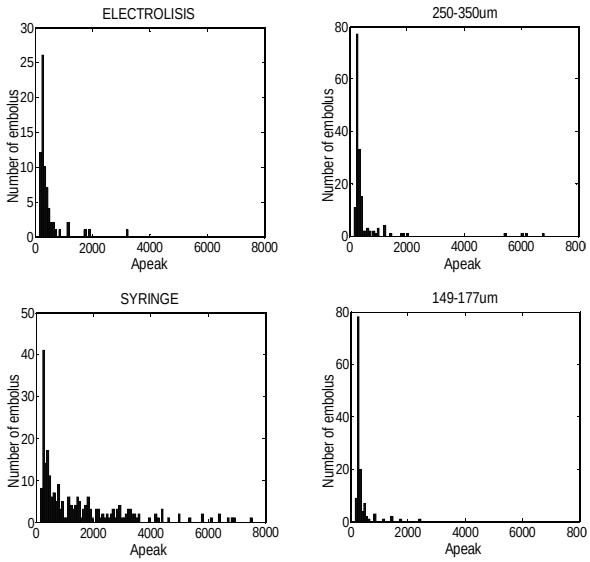

Figure 8: Histograms of A_{peak} parameter for all experiments. The part due to the signals from Orgasol® aggregates can be seen in all cases.

The histograms of the A_{peak} parameters indicate the presence of the pseudo-embolic signals resulting from Orgasol® aggregates, as well as presence of embolic signals with larger values of A_{peak} (Figs. 7 and 8).

Mean values and standard deviations of parameters (calculated from signals classified as embolic) are shown in Table 1 and Figs. 9-11.

Table 1: Mean values and standard deviations of the parameters.

	Syringe	**Electro-lysis**	**Solid particles 250-350µm**	**Solid particles 149-177µm**
EBR [dB]	16,66 ±2,45	15,02 ±1,99	14,12 ±1,61	14,82 ±1,43
ES [amp. *time]	1,4E+6 ±1,1E+6	6,9E+5 ±3,9E+5	5,1E+5 ±1,6E+5	4,2E+5 ±2,7E+5
TD [ms]	66,54 ±41,4	36,51 ±13,8	54,47 ±23,8	52,42 ±14,9

The values of the ES parameter are the highest for big air bubbles, then they decrease for small air bubbles (electrolysis) and solid embolic elements, accordingly to their size. Other two parameters show in some cases unexpected behavior, i.e. the EBR for smaller solid elements is greater than for bigger solid elements, the TD parameter is smaller for electrolytic emboli than for solid elements.

ISSN: 1727-1983

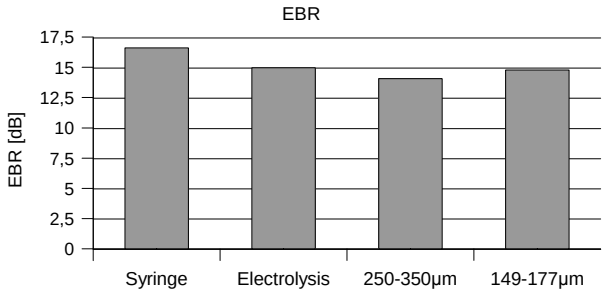

Figure 9: Mean value of EBR parameter.

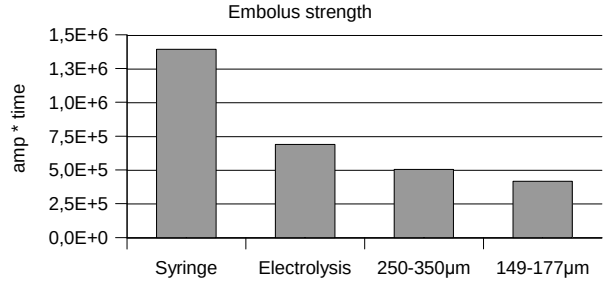

Figure 10: Mean value of ES parameter.

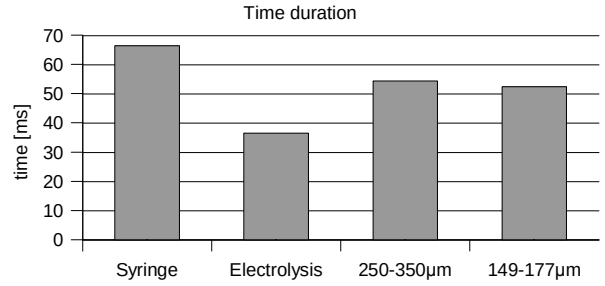

Figure 11: Mean value of TD parameter.

Discussion and Conclusions

The results show that the ES parameter is the most coherent one with the size and material of simulated emboli. This parameter is computed for the strongest individual echo selected form a sequence of echoes obtained for consecutive emissions. It may be expected that – due to the properties of pressure distribution and vessel size – these signals comes from the area where the pressure varies by less than 5dB. Therefore, the amplitude and duration of the echo are mainly the functions of the physical properties (material, size) of the element. Two other parameters EBR and TD are more strongly related to the properties of the particle – ultrasound interaction area. These parameters are computed for the signal analyzed along the time axis (for consecutive emissions) and their values depend on both acoustical properties of the embolic element and pressure distribution. The TD parameter value also depends strongly on flow velocity (important in pulsed flow).

The processing algorithm requires only a single global maximum detection to compute the ES. In the case of the EBR and TD parameters it is necessary to find all the maxima (for consecutive emissions) because the embolic element moves also in the depth direction (Fig.6). The errors of fitting a line to all the detected maxima affect the values of the TD and EBR. This is especially visible when two or more embolic signals are registered in the same time interval or at the same depth in short time. These problems are similar to uncertainty of beam position and shape, and beam to flow direction angle in standard single or dual gate system.

Summarizing, a new approach to analysis of embolic signals has been presented which makes use of possibilities provided by the multigate PW2000 device. Specifically, it enables to propose a new parameter to characterize the embolic signals, the ES, related to the acoustic properties of the element and fairly insensitive to flow velocity and ultrasonic field properties.

Two other parameters are more sensitive to field distribution (EBR and TD) or flow velocity (TD), which resulted in unexpected values of these parameters in some cases.

The continuation of this study will focus on the selection of pseudo-embolic elements with well defined acoustic properties and size, as well as on providing relation of the acoustic properties of the embolic elements and liquid as close as possible to the "in vivo" case.

References

[1] GUETBI C., KOUAMÉ D., OUAHABI A., REMANIARAS J.P. (1997): "New emboli detection methods", IEEE Ultrasonic Symposium, pp. 1119-1122

[2] EVANS D.H. (2003): "Ultrasonic detection of cerebral emboli", IEEE Ultrasonic Symposium, pp. 316-326

[3] MOEHRING M.A., KLEPPER J.R. (1994): "Pulse Doppler Ultrasound detection, characterization and size estimation of emboli in flowing blood", *IEEE Trans. on Biol. Eng.*, **Vol. 40**, No. 1, pp. 35-44

[4] MARKUS H. (2000): "Monitoring embolism in real time", *Circulation*, pp. 102-826

[5] KAŁUŻYŃSKI K., POWAŁOWSKI T., LEŚNIAK B., TRAWIŃSKI Z., PAŁKO T., LIEPSCH D. (2003): „Studies of arterial input impedance in models of carotid artery", *J. Mechanics Med. Biol.*, **Vol. 3**, No. 1, pp. 9-19

[6] RAMNARINE K.V., NASSIRI D.K., HOSKINS P.R., LUBBERS J. (1998): „Validation of a new blood-mimicking fluid for use in doppler flow test objects", *Ultrasound Med.Biol.*, **Vol. 24**, No. 3, pp. 451-459

[7] TORTOLI P., GUIDI F., GUIDI G., BERTI P., ATZENI C. (1997): „A novel instrument for high-resolution ultrasound flow-imaging", *Int.J.Imag. Systems Technol.*, **8**, pp. 438-443

[8] RINGELSTEIN E.B. et al. (1998): „Consensus on microembolus detection by TCD", *Stroke*, **29**, pp.725-729

ISSN: 1727-1983