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Role of Doppler Navigation in Minimally Invasive Procedures under Ultrasound Guidance

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Authors' contributions

This work was carried out in collaboration between both authors. Author ZAD designed the study, wrote the protocol and wrote the final draft of the manuscript. Author WJI wrote the first draft of the manuscript, managed the literature searches. Authors ZAD and WJI managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To highlight the possibilities of Doppler methods to optimize navigation and control of percutaneous echo-controlled minimally invasive interventions.
Study Design: 25,543 diagnostic and therapeutic minimally invasive interventions were carried out on organs and tissues of different localizations.
Place and Duration of Study: Department of Oncology and Radiology, M. Gorky Donetsk National Medical University, Ukraine. 25,543 diagnostic and therapeutic minimally invasive interventions (2004-2013).
Methodology: Ten years of experience in carrying out percutaneous minimally invasive interventions under ultrasound guidance using Doppler modes. Fine needle aspiration and core needle biopsy, drainage, etc of different organs and tissues, effectiveness of optimization methods of visualization and analysis of results of their use in minimally invasive treatment of liver abscesses under US control, comparative analysis of main and control groups were carried out using student t-test and chi square - $\chi 2$. Ultrasound scanners used: Dornier AI 5200, Philips HDI

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5000, Toshiba Aplio 500), probes - linear (7.5 MHz), convex (3.5-5.0 MHz). Paramount was the safety of minimally invasive procedure in visualizing instrument used.
Results: It was established that optimal was the power Doppler mode for navigation in percutaneous interventions, prevent hemorrhagic complications, select a safe acoustic window, which improved the location of fluid motion in the hollow needle and visualization of the biopsy instrument based on initiation of twinkling artifact. The use of developed methods to improve ultrasound visualization in minimally invasive treatment of liver abscesses significantly reduced pain - 12.9%, avoided haemorrhage and leakage of pus into peritoneal cavity, reduced the number of inadequate drainages - 36.6%, reduced the duration of inpatient treatment - 2.2 times.
Conclusion: It was established that use of power Doppler mode enhances the effectiveness and safety of percutaneous ultrasound-guided interventions. Thus, the studies confirmed the clinical use of optimization techniques of visualization in minimally invasive procedures under ultrasound guidance.

Keywords: Artifact; Doppler; liver abscess; percutaneous drainage; ultrasound.

1. INTRODUCTION

Minimally invasive procedures under ultrasound guidance are widely used in various branches of clinical medicine. Spectrum of possibilities in interventional ultrasound is extremely wide: diagnostic biopsy, aspiration and drainage of abscesses and cysts, local destruction of tumors, etc [1,2,3,4]. Often, however, the use of ultrasound is limited due to the risk of post biopsy complications, especially damage to the blood vessels and the course of bleeding from the trajectory puncture channel [4,5,6]. Development of complications may also be due to trauma as a result of difficulties in visualizing the distal end of the biopsy instrument - needle, trocar, drain, etc. It is necessary to develop methods and utilize them to optimize ultrasound visualization of biopsy instrument to prevent complications in minimally invasive interventions.

Development of Doppler techniques, in particular, color Doppler (CD) and power Doppler (PD) imaging, displayed in color motion in visualized structures, expands the possibility of ultrasound navigation.

1.1 Aim

This study was aimed at highlighting the possibilities of Doppler methods to optimize navigation and control of percutaneous echo-controlled minimally invasive interventions.

2. MATERIALS AND METHODS

Ten years of experience in carrying out percutaneous minimally invasive interventions under ultrasound guidance using Doppler modes is highlighted. The results and after effect of 25,543 diagnostic and therapeutic minimally invasive interventions (fine needle aspiration and core needle biopsy, aspiration, drainage, laser and ethanol destruction of lesions, local hyperthermia), on the abdominal organs (liver, biliary system, pancreas, spleen, non-organic lesions), chest (mediastinum, lungs), retroperitoneal space, thyroid and mammary glands, musculoskeletal system, ear, nose and throat organs, skin and subcutaneous tissue, lymph nodes of different localizations (Table 1).

Minimally invasive interventions were performed under continuous ultrasound guidance with ultrasound scanners (Dornier AI 5200, Philips HDI 5000, Toshiba Aplio 500) with selected probes corresponding to the depth of the intervention area (linear and convex). The instrument introduced was placed at one end of the probe so that it is in longitudinal visualized position. The free hand technique was used. Prerequisite condition considered was the visualization of distal end of the instrument throughout the procedure. When difficulties arose in visualization, we used the original methods to optimize it - Doppler methods.

To assess the effectiveness of optimization methods of visualization, we analyzed the results of their use in minimally invasive treatment of liver abscesses (LA) under US control in 86 patients of the main group (MG), (12 aspirations, 74 drainages). The comparison group (CG) included 159 patients who had similar interventions (17 aspirations, 142 drainages). The groups did not differ significantly by age and sex composition, the volume of liver abscess, and the severity of the clinical condition of patients. Severity of pain on a 10-point visual analog scale was assessed, significantly severe was considered to be from 5 points and above. Frequency of development of hemorrhagic complications, frequency and reasons of inadequate drainage were recorded, as well as comparison of duration of inpatient treatment.

The results were analyzed using conventional parametric and non-parametric statistical methods (student t-test and chi square - $\chi 2$).

3. RESULTS AND DISCUSSION

Analysis of possibilities of use of Doppler in the navigation of puncture interventions made it possible to highlight several aspects.

Important significance in color Doppler and power Doppler is choosing a safe acoustic window for visualization in color of blood flow in vessels of medium and small calibers, which may not be seen in B-mode [7]. In particular, during interventions on liver, especially in presence of biliary hypertension, relevance is the differentiation of blood vessels from bile ducts, which may be done by visualizing the blood flow. Visualization in color of blood vessels of medium and small calibers makes it possible to avoid traumatizing them in the process of minimally invasive procedures. Color Doppler and Power Doppler modes may be used in controlling and avoiding post procedural complications (Fig. 1).

It was established that in echolocation in color Doppler mode, the overall quality of the ultrasound image is reduced by redistributing the volume of post processing signal for color and gray-scale image, which makes it difficult for echographic control of the procedure. Vessel with blood in it is visualized as color structure with blurred shapes, sizes which are slightly higher than the actual dimensions (Fig. 1a). With echolocation of the same zone in the power Doppler mode (Fig. 1b), the images are clearer, blood vessels are visualized in color structure, real anatomical dimensions and boundaries are corresponding. The direction of flow is of no fundamental importance for navigation during the procedure. Therefore, power Doppler as a method to control minimally invasive procedure in our view is preferred due to more accurate and rapid visualization of blood vessels.

Power Doppler mode may also be used in difficult situations for visualization of the puncture needle or drainage in B-mode. We have proposed several techniques to optimize the ultrasound visualization of instrument.

Simple and reliable method is to visualize fluid motion in the hollow of the needle or drain in Power Doppler mode, which is reflected in color on the screen (Fig. 2). The moving fluid may be physiologic solution, anesthetic agent, content of aspirated fluid from a fluid collection or cavity.

Besides fluid motion, color Doppler may directly reflect puncture instrument. We are postulating a better method of visualization of catheter drain by manual initiation of low amplitude vibration which can be visualized in power Doppler mode (Fig. 3).

(a) (b)

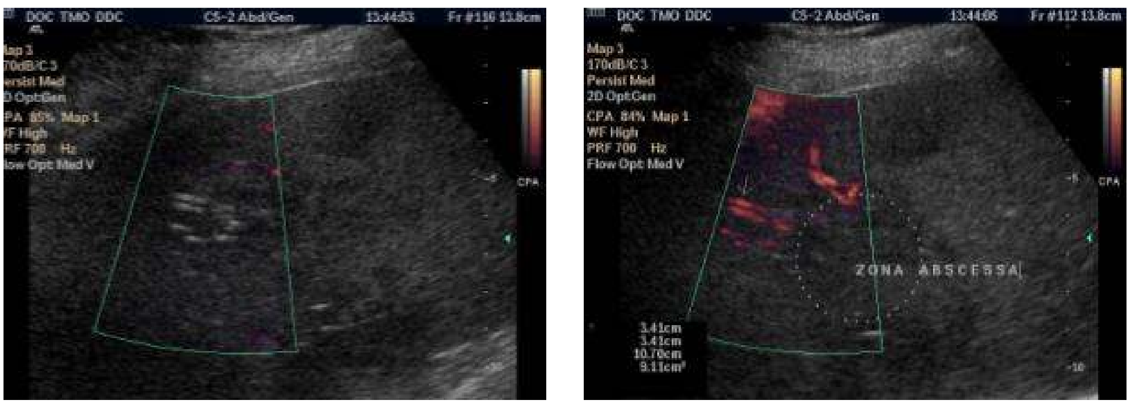
Figs. 1a, b. Doppler visualization of vessels at intended biopsy area of kidney
a- Color Doppler; b – Same Area, Power Doppler

Table 1. Summary of 25,543 diagnostic and therapeutic minimally invasive interventions (2004-2013)

Organs	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**Total**	**%**
Thyroid gland	747	806	1,193	1,365	1,072	1,191	1,136	1,207	1,136	1,207	**11,060**	43.1%
Mammary gland	1,445	1,130	1,020	1,028	962	854	554	518	554	518	**8,583**	33.4%
Liver and biliary tract	110	145	212	216	149	125	172	127	172	127	**1,555**	6,1%
lymph nodes	197	181	200	202	177	134	108	108	108	108	**1,523**	5.9%
Skin and subcut. tissue	93	97	137	137	148	117	106	90	106	90	**1,121**	4.4%
Maxillofacial area	39	49	86	88	98	61	24	47	24	47	**563**	2.2%
Abdominal organs (except liver)	62	38	44	38	52	67	57	52	57	52	**519**	2.0%
Urogenital system	26	17	34	32	20	17	17	23	17	23	**226**	0.9%
Thoracic organs	18	28	27	22	22	15	12	12	12	12	**180**	0.7%
Joints	19	10	9	19	11	13	13	21	13	21	**149**	0.6%
ENT organs	-	-	5	3	11	19	9	4	9	4	**64**	0.2%
Others	19	24	18	29	27	7	6	4	-	-	**134**	0.5%
Total	**2,756**	**2,501**	**2,967**	**3,150**	**2,722**	**2,613**	**2,208**	**2,209**	**2,208**	**2,209**	**25,543**	100%

(a) (b)

Figs. 2a, b. Visualization of fluid motion in drain placed in liver abscess cavity



(a) (b)

Figs. 3a, b. Drain placed in liver abscess cavity, power Doppler mode

a – Standard examination;

b – Examination during manually initiated vibration, drain (white arrow) visualized in form of parallel colored linear structure (red)

Twinkling artifact is a phenomenon of color structure directly behind the stationary object, which creates the appearance of movement. Features of twinkling artifact are its appearance on the boundary separating media of different densities. Appearance of twinkling artifact explains the collision of ultrasonic beams with multiple scattered reflectors constituting a heterogeneous surface; while increasing the resultant pulse duration perceived by ultrasound scanner as Doppler frequency shifts.

Twinkling artifact can manifest in different modes: spectral, power Doppler, color Doppler, B-mode [8,9,10,11,12]. In the power Doppler mode, twinkling artifact appears as a monochrome color. Its intensity can vary from single unstable color signal to highly stable colored structures with higher density and posterior acoustic shadow [13,14].

The density of the object and the condition of its surface has effects on the frequency and intensity on the formation of twinkling artifact. The size of the object does not have a significant effect. Modern studies indicate the possibility of using twinkling artifact in the diagnosis of stones, calcinations, and calcifications [15] in different locations, foreign bodies in eyes, eye damage secondary to tuberculosis, drusen melanoma, atherosclerotic vascular disease, heart, indwelling ureteral stents. Phenomenal development of twinkling artifact for visualization of foreign bodies, purposefully introduced into the body (needles, drains) presently has not yet been in use.

We have developed a method for improving the visualization of instruments based on artificial initiation of twinkling artifact. The method is to be used as a new informative parameter – appearance of artificially initiated twinkling artifact, using power Doppler to indicate the presence of an object more than that of surrounding tissue density – puncture or biopsy instrument.

The study was carried out as follows: B-mode was used to reveal structures having similar echogenic characteristics with those of biopsy instruments. Thus, the drain in B-mode was visualized as two parallel linear hyperechogenic structures. Probe was positioned so that the scanning area covers the intended zonal location of structures of interest. The power Doppler mode was turned on, positioning the structures in the energy sector scan.

The minimum power emanated increased the appearance of artifacts (noise). Ultrasonic probe was clutched to the body surface, by initiating its progressive-returnable movements; frequency and amplitude were selected empirically, causing vibration of tissue located underneath. At the interface of different densities (the instrument and its surrounding tissues) twinkling artifact appears. It was determined and visualized in power Doppler mode as bright color locus, displaceable when scanning angle changes with surface of hyperechogenic structure, remaining close to the source of ultrasound rays (Fig. 4).

In some cases it is possible to use several techniques to improve visualization of the puncture or biopsy instrument during minimally invasive interventions. Thus, Fig. 5 shows an example of visualization in power Doppler mode, fluid motion in drain placed in liver abscess cavity in longitudinal and transverse sections, showing the distal end of the "pig tail" drain. At the tortuous zone, at the initiation of vibrations twinkling artifact appears from the drain walls. Combination of twinkling artifact with posterior acoustic shadowing effect confirms distal location of a foreign body (drain).

Thus, the use of Doppler modes in conjunction with the original techniques improved visualization in all cases in the differentiation of puncture instrument, which increased the safety of minimally invasive procedures under ultrasound guidance. The developed techniques and methods are universal and can be used in echo-controlled minimally invasive procedures on any organs and tissues.

Comparative analysis of the quantity and quality of complications in the study groups showed that the improvement in visualization of instruments significantly lowered the frequency of pain ($p = .05$) requiring relief (6 or more points on a visual analogue scale): in the main group (MG) - 6 (7.0 %), in the comparison group (CG) - 30 (18.9%). This reduction, in your opinion, is associated with improved visualization of the distal end of the instrument, more careful control

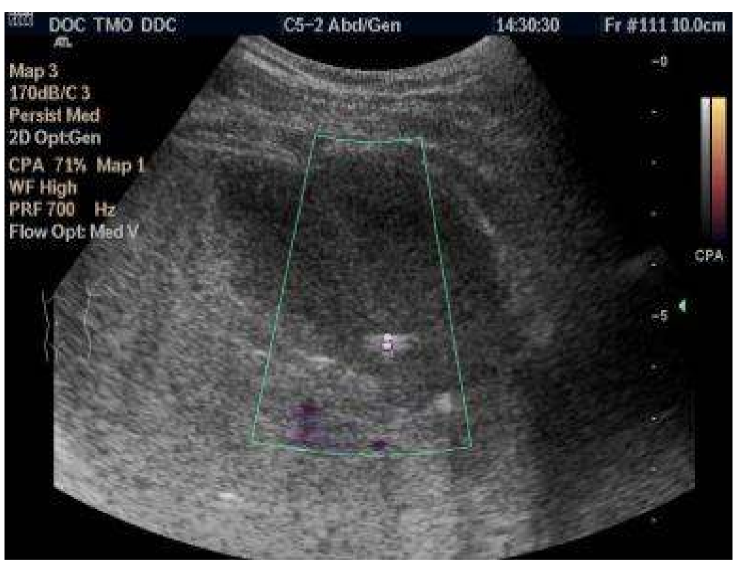


Fig. 4. Initiated twinkling artifacts from the walls of drain placed in liver abscess cavity

of its displacement and consequently, lesser trauma to intercostal nerve and the liver proper in the process of puncture. Application of the developed innovation allows one to completely avoid in the main group complications such as haemorrhage and subcapsular haematoma, as well as leakage of pus into the peritoneal cavity, as observed in the comparison group in 3 (1.9%), 1 (0.6%) and 4 (2.5%) respectively. These facts are explained in the confidence in visualization of the distal part of the instrument and safely direct it into the cavity of liver abscess.

Improving the quality of ultrasound imaging has significantly reduced the number of cases of inadequate drainage in 36.6%, from 45.8±4.2% in CG to 18.9±4.6 in the MG (P <0.001), including: fallout of drain in 20.8% (*P* = *.05*), migration of drain in 7.2% (*P* = *.05*), delayed evacuation of content due to the inflection in 6.1% (*P* = *.05*) (Table 2). The reduction was achieved, in our opinion due to careful control of the location of the drain in liver abscess cavity which was carried out by means of ultrasonic visualization using the original methods to optimize it.

Also, the analysis of the duration of hospital treatment of patients of the study groups was carried out. In the comparison group (CG), duration of hospitalization varied from 5 to 24 days, averaging 18.2±9.9 days. In the main group (MG), duration of hospitalization ranged from 5 to 10 days, on average 8.3±4.4 days, which was significantly lower (p <0.001). The results obtained indicate a statistically significant reduction in the duration of inpatient treatment in the use of the proposed measures to improve ultrasound visualization. The reduction was achieved mainly due to the reduction of cases of inadequate drainage, requiring replacement of drain and prolonging the healing process.

Thus, the studies confirmed the clinical use of optimization techniques of visualization in minimally invasive procedures under ultrasound guidance.

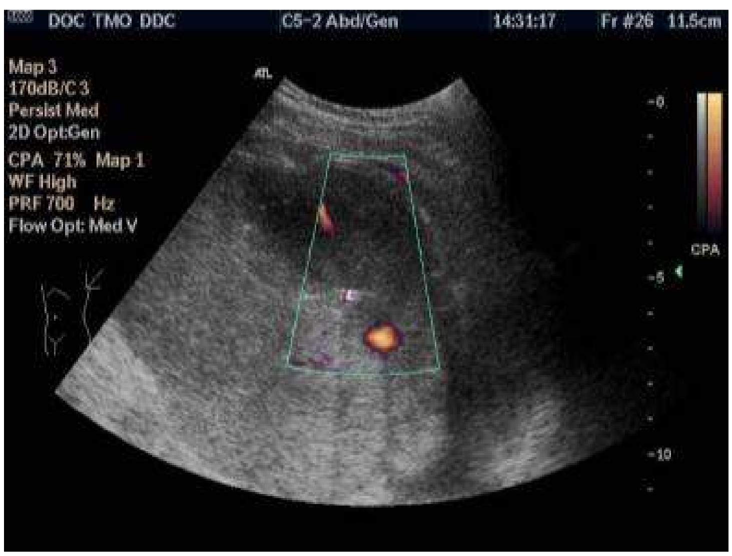


Fig. 5. Drain placed in the liver abscess cavity. Power Doppler mode. Explanation in the text

Table 2. Frequency of inadequate drainage in subgroups *CG and **MG

Reasons for inadequate drainage	*CG, n=142		**MG, n=74		Gradient	
	abs.	%	abs.	%	abs.	%
Fallout of drain	35	24.6	10	13.5	25	11.1
Migration of drain	18	11.3	3	4.1	15	7.2
Delay in evacuation of LA content	12	7.5	1	1.4	11	6.1
Total	65	45.8	14	18.9	51	26.9

*Note: *CG – Comparison group, **MG – Main group*

4. CONCLUSION

The use of power Doppler mode in navigation during percutaneous minimally invasive procedure improves visualization. The use of power Doppler mode made it possible to visualize blood vessels of small and medium caliber, select a safe acoustic window and prevents possible haemorrhagic complications in minimally invasive procedures. Power Doppler mode can be used for percutaneous minimally invasive procedures to improve visualization of puncture or biopsy instruments, including artificial initiation of twinkling artifact. The use of developed methods to improve ultrasound visualization in minimally invasive treatment of liver abscesses significantly reduces the number of painful complications by 12.9%, avoid haemorrhagic complications and leakage of pus into the abdominal cavity, reduces the number of cases of inadequate drainage by 36.6%, reduces the duration of hospital treatment by 2.2 times.

CONSENT

Each procedure was carried out after obtaining consent of the patient by signing the consent form.

ETHICAL APPROVAL

The Bioethical Committee of M. Gorky Donetsk National Medical University approved the conduct of this research with approval No. 122/16 dated November 20, 2012.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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