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Is CT still a method of monitoring patients after endovascular treatment of abdominal aortic aneurysms?

Czy TK jest nadal metodą monitorowania chorych po wewnątrznaczyniowym leczeniu tętniaków aorty brzusznej?

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Key words

abdominal aortic aneurysms (AAA), aortic stent grafts, computed tomography (CT), duplex Doppler US, ultrasound contrast media (UCM)

Słowa kluczowe

tętniak aorty brzusznej (TAB), stentgrafty aortalne, tomografia komputerowa (TK), ultrasonografia dopplerowska, ultrasonograficzne środki kontrastujące

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Summary

Introduction. The endovascular treatment of patient with abdominal aorta aneurysms has been a recognized alternative to classic surgery. One of the most common complications is an endoleak developing due to incomplete exclusion of the aneurysmal sac from circulation.

Aim. To assess the value of ultrasound contrast agents for the diagnosis of endoleaks in patients with AAA treated by stent graft implantation.

Material and methods. One hundred and ninety-eight patients with AAA were treated with stent graft implantation. Follow-up examinations, i.e. pre- and post-contrast ultrasound and angio-CT, were performed 6 months after treatment in all patients. In each ultrasound examination, colour, power, Bflow options were used before and after contrast injection; additionally, contrast-enhanced ultrasound (CEUS) was performed after contrast administration.

Results. During the follow-up examinations after 6 months, pre-contrast ultrasound performed in all options (colour, power, Bflow) revealed 16 endoleaks: 6 type IA, 4 type IB, type 2 IIA and 4 type IIB; in post-contrast ultrasound using CEUS 22 endoleaks were confirmed and additionally 4 endoleaks were diagnosed: 2 type IIA, and 2 type IIB. In angio-CT, 22 endoleaks were diagnosed: 1 type IA, 5 type IB, 4 type IIA, and 7 type IIB. None of the four additional endoleaks observed with CEUS was found in angio-CT.

Conclusions. The use of ultrasound contrast media significantly increases the sensitivity of ultrasound in the diagnosis of endoleaks, particularly type II ones.

CEUS examinations show the greatest sensitivity in detecting endoleaks, as they disclose the endoleaks unrecognized by other techniques, including angio-CT.

Post-contrast ultrasound can replace angio-CT in monitoring patients after stent graft implantations.

Streszczenie

Wstęp. Metoda wewnątrznaczyniowa leczenie chorych z tętniakami aorty brzusznej stała się uznaną alternatywą dla operacji klasycznej. Jednym z najczęściej spotykanych powikłań jest zaciek krwi do worka tętniaka, pojawiający się w wyniku niecałkowitego wyłączenie worka tętniaka z krążenia.

Cel pracy. Ocena przydatności ultrasonograficznych środków kontrastujących w diagnostyce zacieków u chorych z TAB leczonych na drodze śródnaczyniowej.

Materiał i metody. 198 chorych z TAB było leczonych na drodze śródnaczyniowej. U każdego chorego 6 miesięcy po implantacji stentgraftu przeprowadzono badanie kontrolne; najpierw badanie ultrasonograficzne przed podaniem i po podaniu środka kontrastującego, a następnie badanie TK. Każde badanie usg wykonywano w opcji color, power, Bflow przed podaniem, a następnie po podaniu środka kontrastującego, dodatkowo po podaniu środka kontrastującego przeprowadzono badanie w technice CEUS.

Wyniki. W badaniu kontrolnym po 6 miesiącach w usg przed podaniem kontrastu we wszystkich trzech technikach: color, power, Bflow rozpoznano 16 zacieków, w tym: 6 typu IA, 4 typu IB, 2 typu IIA, 4 typu IIB. W badaniu ultrasonograficznym po podaniu środka kontrastującego we wszystkich opcjach – color, power i Bflow – potwierdzono wcześniej rozpoznane 16 zacieków i dodatkowo zdiagnozowano 6 zacieków: 1 typu IB, 2 IIA i 3 IIB. W badaniu usg po podaniu środka kontrastującego w technice CEUS potwierdzono 22 rozpoznane zacieki i dodatkowo zdiagnozowano: 2 zacieki typu IIA i 2 IIB. W badaniu angio-TK rozpoznano 22 zacieki: 6 typu IA, 5 IB, 4 IIA i 7 IIB. Żadnego z 4 zacieków dodatkowo rozpoznanych w technice CEUS nie zdiagnozowano w angio-TK.

Wnioski. Zastosowanie środków kontrastujących znacząco podnosi czułość badania ultrasonograficznego w rozpoznawaniu zacieków, szczególnie typu II.

Badanie z użyciem techniki CEUS wykazało najwyższą czułość w rozpoznawaniu zacieków, bo ujawniło te, których nie rozpoznano w innych technikach, łącznie z angio-TK.

Technika CEUS może zastąpić badania angio-TK w monitorowaniu chorych po implantacji stentgraftów.

INTRODUCTION

An aneurysm is the local dilation of the lumen of a vessel by 50% compared to the proximal, unaffected segment. In practice, the abdominal aortic aneurysm is diagnosed when its diameter is at least 30 mm, measured from the internal to external vessel outline (1-7). The normal diameter of aorta in the subrenal segment is 1.66-2.16 cm in women and 1.99-2.39 in men (8, 9). With age, the aorta lumen gradually dilates. Aneurysms develop due to lesions in the vascular wall. The diameters of aortic aneurysms range from 30 to 150 mm. The frequency of abdominal aortic aneurysms is 4-7.6% in the population > 55-65 years, is believed to increase with age, and is 4-8 times higher in men. Screening examinations are the most objective assessments of the incidence of this pathology. The majority of aneurysms are asymptomatic until complications develop, such as rupture or secondary thromboembolic incidents. Small aneurysms do not generally cause any characteristic symptoms. Their growth may not be detectable due to a relative large area in the retroperitoneal space and susceptibility of the parietal peritoneum.

The most severe complication of abdominal aortic aneurysm is its rupture, which mainly depends on diameter. Abdominal aortic aneurysms of diameters < 5 cm were demonstrated to rupture in 0.5-5% of cases while those with diameters > 7 cm rupture in 20-40% of patients within one year after diagnosis (10, 11).

Abdominal aortic aneurysms are treated with surgical and endovascular methods. Conservative treatment is to inhibit the growth of aneurysm, predominantly by normalisation of arterial blood pressure (pharmacological treatment).

The first recognized surgery of abdominal aortic aneurysm was carried out by an excellent English surgeon, Sir Astley Cooper in London in 1817 (12, 13). Moreover, the surgical procedure performed by Charles Dubost was of importance for further development of surgery; in 1951, he excised an aortic aneurysm and implanted a cadaveric human (homograft) thoracic aorta (14). In 1952, Voorhees produced the first synthetic graft, which successfully replaced a homograft (12). In 1966, Oscar Creech suggested to cover the implanted graft with the aneurysmal sac during reconstruction. Since then, this method has been used with very good remote outcomes (15).

Endovascular treatment involves the exclusion of aneurysms from the circulation by inserting a stent graft to the lumen of aneurysm-containing aorta.

A new era in the treatment of abdominal aortic aneurysms started in 1991, when in Buenos Aires Juan Parodi performed the exclusion of abdominal aortic aneurysm from the circulation using the Palmaz stent expanded on a balloon attached to a knitted Dacron prosthesis (1, 16-18). In the same year, Volodosa published his report on endovascular treatment of abdominal and thoracic aortic aneurysms (19). In Poland, the first stent graft implantation into the affected abdominal aorta was carried out in the Department of Interventional Radiology and Neuroradiology, Medical University of Lublin in 1998.

The endovascular treatment of patients with abdominal aortic aneurysms has been a recognized alternative to classic surgery. However, the method is not free of complications.

The minor complications of endovascular treatment of abdominal aortic aneurysms include post-implantation syndrome, which occurs in less than 50% of cases and manifests with elevated body temperature, leucocytosis, and elevated heart rate above 90/min (16-18). Infections of stent grafts are extremely rare. The cases described in literature resulted from inadequate sterility of treatment rooms. The presence of gas bubbles in computed tomography angiography (angio-TK) around the stent graft is pathognomic for the infected prosthesis (19). The more serious complications, occurring despite fully effective procedures of prosthesis implantation, are ruptures, migrations, and bending of stent grafts, endoleaks, endotension, thrombosis of the main branch or femoral branches of stent grafts (19, 20). Stent graft rupture is one of the most dramatic complications (1). According to the EUROSTAR report of 2003, this complication develops in 1% of patients within the 5-year period of observation (19). Stent graft migration, thrombosis, obstruction are currently rare complications and occur in about 4% of patients within the first year of observation. A substantial reduction in the number of these complications is associated by wide availability of new generation stent grafts, which are more advanced and enable permanent suprarenal fixation of prosthesis (21). Stent graft shift by over 10 mm in relation to renal arteries is considered its migration. The migration can be caused by unstable fixation of the main prosthetic branch, lesions in the wall of the vessel adjacent to a stent graft, dilation of the aneurysm neck (22). Stent graft thrombosis is usually caused by angular bending of the prosthetic iliac branch; its risk is 2.4-11.7%. The main risk factors of thrombosis is bending of a stent graft and significant atherosclerotic changes in the iliac segment. Stenosis of the main branch or iliac branches of stent grafts is more common in cases of tortuous iliac or femoral branches of stent grafts (3, 19). One of the most common complications is an endoleak developing due to incomplete exclusion of the aneurysmal sac from circulation (23, 24). Endoleaks are classified according to their source; five types of endoleaks are known (fig. 1).

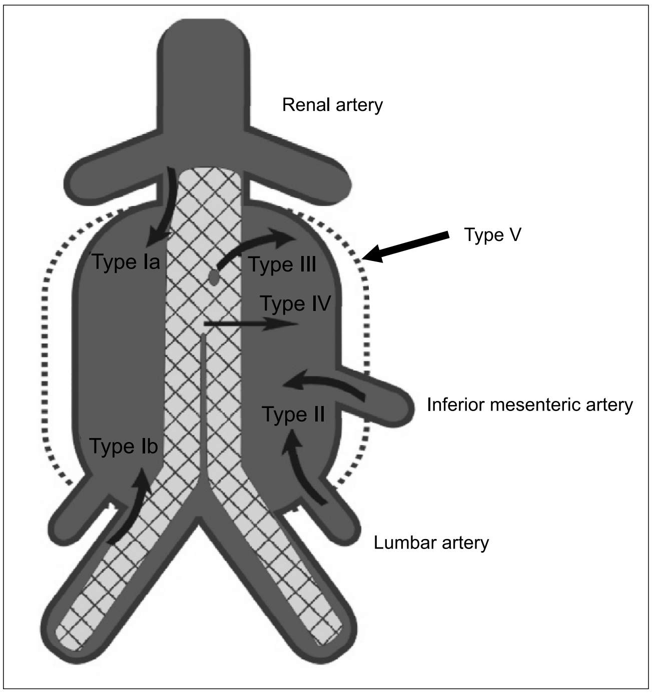

Fig. 1. Five types of endoleaks.

There are also the following subtypes of endoleaks:
- type I a: in the region of proximal stent graft fixation,
- type I b: in the region of distal stent graft fixation,
- type I c: in the region of iliac artery occluder,
- type II a: from the inferior mesenteric artery,
- type II b: from the lumbar artery,
- type III a: due to disconnection of stent graft parts,
- type III b: due to tears of the material covering the stent graft,
- type IV: due to porosity of the material covering the stent graft,
- type V: endotension, endoleaks of undetermined origin.

Patients after stent graft implantation require follow-up examinations to detect possible complications. Spiral computed tomography is considered to be the gold standard for monitoring of this group of patients 3, 6, 12 months after implantation and then once a year.

AIM

To determine the usefulness of ultrasound examinations with Doppler options, with special attention paid to ultrasound contrast media (UCM), for monitoring patients with abdominal aortic aneurysms treated with the endovascular stent grafting and for exclusion or confirmation of endoleaks.

MATERIAL AND METHODS

The study included 198 patients treated with the endovascular technique due to abdominal aortic aneurysms in the Department of Interventional Radiology and Neuroradiology in Lublin. The study population consisted of 166 men and 32 women aged 46-90 years. All patients with abdominal aortic aneurysms underwent stent graft implantation in the angiographic laboratory of the Department of Interventional Radiology and Neuroradiology in Lublin.

Each patient after endovascular treatment of abdominal aortic aneurysms had follow-up examinations 6 months after the procedure; first pre- and post-contrast ultrasound (SonoVue), followed by abdominal angio-CT performed several days later.

Ultrasound examinations were conducted in the Department of Interventional Radiology and Neuroradiology, whereas angio-CT in the Department of Radiology and Nuclear Medicine, Medical University of Lublin.

All ultrasound examinations were performed using the LOGIQ 7 device (GE), equipped with a 3.5 MHz probe enabling imaging of blood flow with Doppler (colour, power) and non-Doppler (Bflow) options. The machine is adjusted to examinations with UCM, is equipped with harmonic imaging and special software for contrast examinations, in which colour-coded Doppler blood flow is not used. After the administration of UCM, CEUS followed by typical Doppler examination was performed in each patient. Sonographic procedures were carried out in the dorsal decubitus position with knees of lower limbs slightly bent and the abdomen, sides and the region of groins (bilaterally) exposed. In the majority of patients, additionally the right and left side positioning was used. The lateral access enables to overcome effectively the limitation associated with the depth and tortuosity of vessels or presence of intestinal gases.

The first stage of examination without UCM was initiated with imaging in the B presentation; first in the transverse projection followed by longitudinal projection visualizing the aorta from the level of visceral trunk ostium (with the superior mesenteric and renal arteries included), accurate analysis of aneurysmal sac, measurement of its diameter, evaluation of the course of graft branches and iliac arteries to the level of the inguinal ligament or even common femoral arteries. Within the thrombus, in the aneurysmal sac excluded from circulation, the presence of echoless areas was meticulously analysed, which can evidence the presence of endoleaks. The next stage involved the use of Doppler options (colour-coded blood flow, including the power option) and non-Doppler (Bflow) options for exclusion or confirmation of endoleaks. All the options mentioned above were applied in each patient in search for possible pathologies. Subsequently, blood flow parameters were recorded (spectral tracings) in the detected endoleaks by evaluating the spectrum and velocity.

The second stage involved the administration of UCM (SonoVue, Bracco) in a dose of 2.4 ml. By mixing the powder with 0.9 sodium chloride solution, the suspension containing gas micro-bubbles was obtained (sulphur hexafluoride). Each bubble is smaller than the red blood cell. The bubbles reflect the ultrasound beam and ensure better signals than the body tissues. The agent is effectively present in the circulatory system for several minutes.

During the examination, the device was set at optimal performance values for UCM, i.e. 3.5 MHz at low mechanical index (MI 0.01-0.02), optimal settings of PRF and filters using harmonic imaging. Harmonic imaging at low MI prevents quick destruction of gas micro-bubbles.

After administration of SonoVue in a single dose of 2.4 ml, the examination was initiated. During the first stage, the examination was performed in the CEUS option to evaluate blood flow in the aneurysmal sac evidencing endoleaks. Subsequently, the same protocol was applied without UCM with exclusion of projection B imaging using Doppler options (colour-coded blood flow with the power option), non-Doppler options (Bflow) and spectral tracings.

Several days after ultrasound examinations, each patient underwent CT in the Department of Radiology and Nuclear Medicine, Medical University of Lublin (Head: prof. Andrzej Drop, MD, PhD).

The examinations were carried out with a 64-row CT scanner (General Electric LightSpeed Ultra). The abdominal aorta was visualized from the visceral trunk to the division of femoral arteries following the protocol of peak saturation within 30 seconds after administration of an iodine contrast medium (Ultravist 370 mg I/ml, Schering), 100-120 ml, through the automated syringe with the speed of 2.5 ml/s. The nominal slice thickness – 5 mm, table speed – 7.5 mm/s, pitch – 1.5, effective slice thickness – 2 mm.

The detailed evaluation of stent grafts was possible thanks to the use of the following options: multiplanar reconstruction (MPR), curve reconstruction, minimum and maximum intensity projection and a three-dimensional model – virtual reality (VR). Moreover, pre- and post-contrast ultrasound results were compared with angio-CT findings.

RESULTS

An endoleak was diagnosed when at optimal adjustments of individual parameters (PRF, enhancement, filters, focus) in the aneurysmal sac, the blood flow signal was found outside the stent graft. In pre-contrast ultrasound examinations, endoleaks were observed in 16 patients (8.1%) in all three options applied, i.e. colour-coded blood flow, including Doppler power and Bflow imaging (tab. 1). Type III and IV endoleaks were not detected; 10 patients had type I endoleaks and 6 – type II endoleaks. The detailed categorization of endoleak types is presented in table 2. The maximum blood flow velocity in endoleaks ranged from 15 to 97 cm/s (tab. 3). Beside velocity, the spectrum was also assessed. In two patients with type II endoleaks, to- and fro-blood flow was detected, indicating the presence of only one vessel through which the blood flows to and from the aneurysmal sac (blood flow analogous to that noted in the pseudo-aneurysm stalk). Such endoleaks were classified as type II ”simple” endoleaks, to differentiate them from “complex” endoleaks where two vessels are involved; one supplying and the other carrying out the blood from endoleaks.

Table 1. Frequency of endoleaks in pre-contrast ultrasound examinations after 6 months.

Category	Presence of endoleaks	
	No. of patients	%
No	182	91.91919
Yes	16	8.08081

Table 2. Types of endoleaks recognized in pre-contrast ultrasound examinations after 6 months.

Category	Type of endoleaks	
	No. of patients	%
IA	6	37.50000
IB	4	25.00000
IIA	2	12.50000
IIB	4	25.00000

In CEUS imaging, endoleaks were detected in 26 patients (tab. 4). None of the patients had type II and IV endoleaks; type I endoleaks were found in 11 patients and type II endoleaks in 15 patients. Detailed categorization of endoleaks types is presented in table 5.

The CEUS imaging confirmed the presence of all 16 endoleaks detected earlier on pre-contrast ultrasound with the same categorization into types; additionally, 10 endoleaks were detected, including one type I and 9 type II endoleaks, which were not visualised during pre-contrast ultrasound.

In post-contrast examinations with Doppler and non-Doppler (Bflow) options , the endoleaks considered as the presence of blood flow signal in the aneurysmal sac outside the prosthesis, were diagnosed in 22 patients (11.11%) in all three options, i.e. colour-coded

Table 3. Velocities in endoleaks in pre-contrast ultrasound examinations after 6 months.

Variable	Descriptive statistics (pre-contrast ultrasound – at 6 months)					
	Mean	Me	Min	Max	SD	V
Vmax in endoleak cm/s	48.00000	45.00000	15.00000	97.00000	23.51595	48.99157

Table 4. Frequency of endoleaks in CEUS imaging after 6 months.

Category	Endoleaks in CEUS imaging	
	No. of patients	%
No	172	86.86869
Yes	26	13.13131

Table 5. Types of endoleaks detected in CEUS imaging after 6 months.

Category	Endoleaks type in CEUS	
	No. of patients	%
IA	6	23.07692
IB	5	19.23077
IIA	6	23.07692
IIB	9	34.61538

blood flow, Doppler power and Bflow imaging (tab. 6). The presence of 16 endoleaks diagnosed earlier on pre-contrast ultrasound was confirmed, with the analogical categorization into types. Additionally, 6 endoleaks were found. None of the patient had type II and IV endoleaks; type I endoleaks were observed in 11 patients and type II endoleaks were found in 1 patients. Detailed categorization of endoleaks types is presented in table 7. The maximum blood flow velocities ranged from 18 to 147 cm/s (tab. 8). In 4 patients with type II endoleaks, the "to and fro" blood flows were detected and they were classified as type II "simple" endoleaks.

Table 6. Frequency of endoleaks in post-contrast ultrasound using Doppler and Bflow options after 6 months.

Category	Endoleaks in colour, power Doppler and Bflow	
	No. of patients	%
No	176	88.88889
Yes	22	11.11111

Table 7. Types of endoleaks detected in post-contrast ultrasound using Doppler and Bflow options after 6 months.

Category	Types of endoleaks	
	No. of patients	%
IA	6	27.27273
IB	5	22.72727
IIA	4	18.18182
IIB	7	31.81818

In the phase II of post-contrast angio-CT, 22 endoleaks were found (tab. 9). All the patients with recognised endoleaks were treated with forked prostheses. Based on images in the transverse plane and after using additional reconstructions, types of endoleaks were determined in detail (tab. 10). Eleven type I and 11 type II endoleaks were found; there were no type II and IV endoleaks.

Table 9. Frequency of endoleaks found during in phase II of angio-CT after 6 months.

Category	Angio-CT endoleaks	
	No. of patients	%
No	176	88.88889
Yes	22	11.11111

Table 10. Types of endoleaks detected in angio-CT after 6 months.

Category	Endoleak type	
	No. of patients	%
IA	6	27.27273
IB	5	22.72727
IIA	4	18.18182
IIB	7	31.81818

In pre-contrast ultrasound examinations using all three options, i.e. colour-coded blood flow, including Doppler power and Bflow imaging, endoleaks were detected in 16 patients. In post-contrast ultrasound examinations with CEUS imaging, endoleaks were observed in 26 patients.

Ultrasound examinations with Doppler (colour, power, spectral tracing) and non-Doppler (Bflow) options after contrast medium administration revealed endoleaks in 22 patients. During phase II of post-contrast angio-CT 22 endoleaks were detected. In CEUS 4 endoleaks were additionally found (all of them – type II), which were not diagnosed in angio-CT. Amongst the four endoleaks additionally diagnosed in CEUS imaging, two were through inferior mesenteric arteries and another two through lumbar arteries (fig. 2A-H).

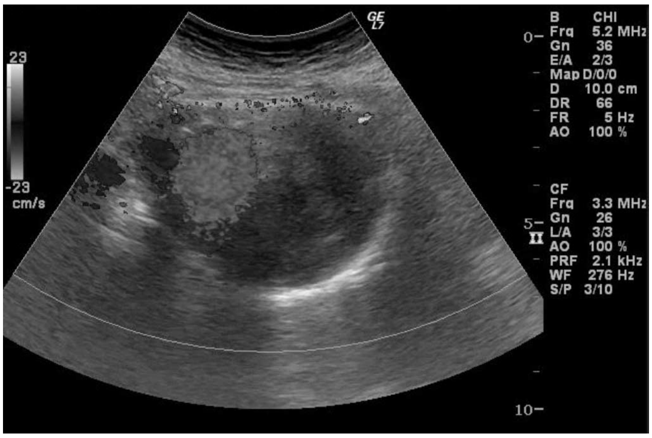

Fig. 2A. A pre-contrast ultrasound scan with the use of colour-coded blood flow option – no endoleaks found.

Table 8. Flow velocities in endoleaks in post-contrast ultrasound using Doppler options after 6 months.

Variable	Descriptive statistics (post-contrast ultrasound after 6 months III)					
	Mean	Me	Min	Max	SD	V
Vmax in endoleak	49.13636	48.00000	18.00000	147.0000	29.71980	60.48432

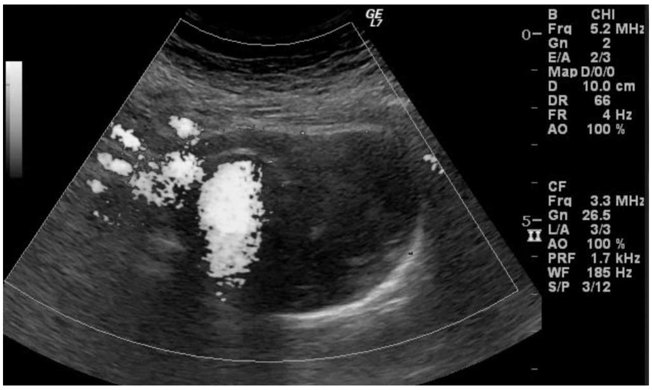

Fig. 2B. A pre-contrast ultrasound scan with the Doppler power option – no endoleaks found.

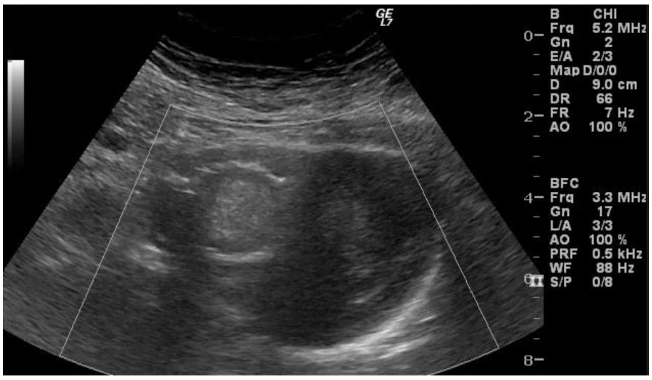

Fig. 2C. A pre-contrast ultrasound scan with the Bflow option – no endoleaks detected.

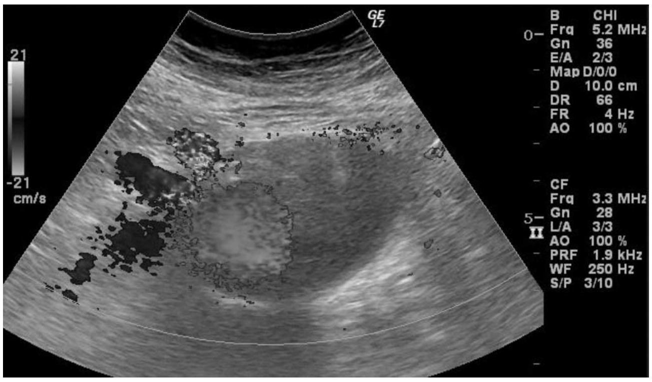

Fig. 2D. A post-contrast ultrasound scan with colour-coded blood flow option – no endoleaks observed.

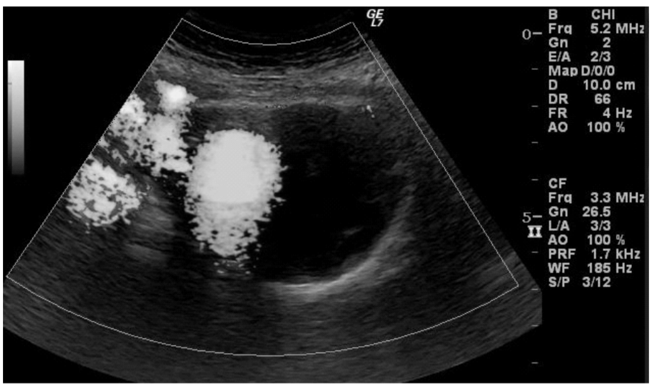

Fig. 2E. A post-contrast ultrasound scan with Doppler power option – no endoleaks found.

Fig. 2F. A post-contrast ultrasound scan with the use of Bflow option – no endoleaks detected.

Fig. 2G. CEUS (post-contrast) – a slight endoleak in the posterior-lateral part of aneurysmal sac (arrow).

Fig. 2H. An angio-CT scan – no endoleaks detected.

DISCUSSION

A new era in the treatment of abdominal aortic aneurysms started in 1991 when Parodi and co-authors published their report on the first, effective exclusion of an aortic aneurysm from circulation by endovascular stent graft implantation (25, 26). The idea of endovascular treatment differs from classic surgery. During endovascular treatment the aneurysm is not removed; the aim is to reduce the pressure within the aneurysm by excluding it from circulation and directing the stream of flowing blood only through the endovascular prosthesis, i.e. stent graft. At present, almost half of patients with aneurysms is treated by the endovascular method (27-29); in single centre, this percentage reaches even 70% (30). The method enables the treatment of patients who do not qualify for classic surgical procedures due to high surgical risks resulting from advanced cardiovascular and respiratory diseases (31). Moreover, the method is characterized by shorter duration compared to the classic method, shorter hospitalization and reduced incidence and perioperative mortality (32-34).

Although the method has more and more advocates, it is not free of complications, such as endoleaks, migration, breaking and stenosis of stent graft iliac branches, presence of perimural thrombi in the stent graft lumen, and graft occlusion.

Spiral CT considered the gold standard in monitoring of this group of patients is usually performed 3, 6 and 12 months after graft implantation, then once a year. However, this technique is associated with many disadvantages, e.g. administration of nephrotoxic contrast agents and exposure of patients to ionizing radiation. Considering the above, CT in this group of patients should be limited, whenever possible.

Despite increasingly improved stent grafts introduced to the market and vast experiences in stent graft implantation, endoleaks remain the Achilles' heel. 50% of endoleaks resolve spontaneously without any interventions. However, their occurrence can lead to an increase in aneurysmal sac and its rupture, which is in contradiction with the main goal of treatment of this pathology. Endoleaks are defined as the blood flow in the aneurysmal sac distinctly outside the prosthesis. They occur in 15-32% of patients undergoing stent graft implantations (35-37). The first endoleak was described by White over 9 years ago (38, 39). Endoleaks are categorized according to their origin; five types of endoleaks are known. Type I regards the situation in which the blood flows to the aneurysmal sac through proximal (in the aneurysm neck in the subrenal segment, type Ia) or distal (in the iliac arteries, type Ib) site of prosthesis anchoring. Type I endoleaks are observed in 4-7% of patients undergoing stent graft implantations. Detected intraoperatively or during observation, type I endoleaks can be effectively eliminated by balloon angioplasty of the anchoring place, enabling better adjustment of the prosthesis to the vascular wall or implantation of the proximal extension or self-expanding stent on the balloon to additionally fix and seal the proximal end. Type Ib endoleaks are treated by implanting iliac extension ensuring better sealing of this segment. Type II endoleaks result from retrograde inflow of blood to the aneurysmal sac through arteries branching from the aorta, e.g. one or more lumbar arteries, inferior mesenteric artery or other vessels of collateral circulation. Type II endoleaks occur relatively often. Their frequency is estimated at 27-37% (35). Some authors distinguish two subtypes of type II endoleaks: IIa, where the endoleak comes from the interior mesenteric artery and IIb when it originates from lumbar arteries. The majority of type II endoleaks can be safely observed as they frequently resolve spontaneously (40). Type III endoleaks result from structural damage to the stent graft – discontinuity of the covering material or insufficient sealing of connections between individual elements of endovascular prosthesis. This type occurs in less than 3% of patients (36). Although type II endoleaks are rare, they are an indication for endovascular or open intervention as the aneurysmal sac is exposed to the effects of systemic arterial pressure and the risk of rupture is comparable to that in type I endoleaks (or in cases of untreated aneurysms). The following subtypes of type III endoleaks are distinguished: IIIa – tears of the covering material or perforations in its surface, IIIb – the presence of post-suture perforations in the material (35).

As far as type IV endoleaks are concerned, they result from prosthesis porosity. Their frequency is estimated at about 5% (37); in most cases, they resolve spontaneously as fibrin quickly seals the stent graft material. Type IV endoleaks are rarely observed with new generation stent grafts as their covering materials are characterized by lower porosity.

The ultrasound-based diagnosis of endoleaks requires the use of the best quality devices and optimal settings of individual parameters, such as enhancement, focus, filters, PRF, particularly for colour Doppler. Improper setting of this type of imaging can lead to false positive results due to the presence of colour artifacts (flesh artifacts) or coloured pixels (bleeding) at the place where the colour is actually absent. Too high velocity values can result in overlooking of endoleaks. Additionally, a decrease in colour imaging field can be helpful. UCM increase the sensitivity of ultrasound examinations. Previously, they were used in examinations of colour-coded blood flows; at present, ultrasound devices are equipped with special software for examinations with contrast, called CEUS and are a kind of duplex examinations. Since CEUS enables the detection of slight flows without the use of colour Doppler, it can help to confirm possible endoleaks.

In our material, type II and IV endoleaks were not found in any imaging techniques used; only type I and II were detected. Amongst 5 types of endoleaks, the frequency of type II through lumbar arteries is significantly higher (1, 41, 42). Baum and co-workers describe two kinds of type II endoleaks – "simple" and "complex". The "simple" endoleaks result from re-restoration of patency of one of the arteries branching from the aortic wall. Such endoleaks resemble pseudoaneurysms as the blood inflow to the aneurysmal sac occurs during the heart systole and outflow takes place in the diastole phase. In "complex" endoleaks, the inflow through the inferior mesenteric artery and outflow through the lumbar artery are observed (20). In ultrasound examinations, the flow typical of endoleaks is even, repeatable and does not disappear in diastole (41, 43).

In pre-contrast ultrasound examinations performed at 6 months in all three options, i.e. colour-coded blood flow, Doppler power and Bflow imaging, endoleaks were diagnosed in 16 patients. In 10 of them, type I endoleaks were observed, in 6 – type II were found. In 6 cases, endoleaks from the region of upper fixation of graft were diagnosed (subtype Ia); in 4 cases – in the region of lower fixation (subtype Ib). The inferior mesenteric artery was the origin of endoleaks in 2 patients, whereas the lumbar artery in another 4 patients. Based on the spectrum noted, two type II "simple" endoleaks were diagnosed. In the post-contrast examinations with CEUS imaging, type I endoleaks were found in 11 patients while type II endoleaks in 15 individuals. CEUS confirmed the presence of all 16 endoleaks diagnosed in pre-contrast ultrasound, with the same categorization into types and additionally revealed the presence of 10 endoleaks, including 1 type I endoleak and 9 type II endoleaks, which were not visualized in pre-contrast ultrasound. In CEUS imaging, the endoleaks in the region of upper fixation of prosthesis were diagnosed in 6 patients (subtype IA) and in the region of lower fixation of prosthesis in 5 patients (subtype IB). The inferior mesenteric artery was the origin of endoleaks in 6 cases whereas lumbar arteries in 9 patients (subtype IIB). Post-contrast ultrasound examinations with Doppler options (colour, power, spectrum tracing) and non-Doppler options (Bflow) revealed endoleaks in 22 patients. The examinations confirmed the presence of all 16 endoleaks detected previously in pre-contrast ultrasound examinations, with the same categorization into types; additionally, 6 endoleaks were found. In 6 patients, the endoleaks in the region of upper prosthesis fixation were found (subtype IA) and in 5 individuals – in the region of lower prosthesis fixation (subtype IB). The mesenteric artery was the origin of endoleaks in 4 patients (subtype IIA) and lumbar arteries – in 7 patients (subtype IIB). Four patients had type II "simple" endoleaks. In the angio-CT phase after administration of contrast medium, 22 endoleaks were diagnosed. In 6 patients, the endoleaks were in the region of upper fixation of prosthesis (subtype IA), and in 5 – in the region of lower prosthesis fixation. Amongst 11 type II endoleaks found, in 7 cases their origin was the inferior mesenteric artery (subtype IIA). After using additional reconstructions, 4 "simple" type II endoleaks and 5 "complex" endoleaks were noted. In the remaining cases, the mechanism of endoleaks could not be precisely analysed. Among all the imaging techniques used, CEUS revealed the highest number of endoleaks, i.e. 26. Additionally, 4 endoleaks were found in CEUS, two through the inferior mesenteric arteries and another two through the lumbar arteries.

In the examinations performed 6 months after stent graft implantations, four methods of imaging were compared. However, the literature lacks studies discussing the issue of endoleak diagnosis in such a detailed way. The available studies compared pre- and post-contrast Doppler ultrasound examinations with the use of blood flow and angio-CT. In the most recent reports, the authors compared CEUS with pre-contrast ultrasound and angio-CT.

It was demonstrated that CEUS was characterised by higher sensitivity of endoleak detection than colour Doppler examinations (23). Imaging with contrast enables to overcome some limitations of colour Doppler, such as colour artifacts and poor ability to detect free flow. Henao and colleagues evaluated the efficacy of endoleak diagnosis in 20 patients; they found endoleaks in 9 cases, the majority of them were type II (44). The authors concluded that all endoleaks detected in follow-up CT were previously found in CEUS. Clevert and co-workers evaluated the occurrence of endoleaks in 43 patients comparing the results with pre-contrast Doppler examination and CEUS (45). CT was used by them as the gold standard. The sensitivity of pre-contrast Doppler examination was found to be 33.3% and its specificity 92.8%; in CEUS – 100% and 93%, respectively. Moreover, two results of CEUS initially considered as false positive were true positive during further observation. Our findings are comparable. In follow-up examinations after 6 months using CEUS, 4 type II endoleaks were detected, which were not confirmed in CT.

The results of examinations performed 6 months after implantations demonstrated that CEUS detected the highest number of endoleaks. 4 of the endoleaks found in CEUS were not detected in post-contrast examinations after 6 months with Doppler and Bflow options. On the one hand, the above is likely to evidence lower sensitivity of detection of low velocity values in this option, compared to CEUS; on the other hand, this can be associated with a decrease in signal enhancement with time after UCM administration. In the present study, all patients had UCM injected one time and CEUS was performed first; after several minutes Doppler and Bflow examinations were carried out. It seems justified to perform similar comparative studies after continuous administration of UCM, which would enable to lengthen the time of enhancement. In all follow-up ultrasound examinations, endoleaks were searched for in all three options, i.e. colour-coded blood flow, Doppler power option and Bflow technique. There were no differences found comparing these techniques. The literature lacks studies comparing the options mentioned above for endoleak detection. The available studies reveal that CEUS is characterized by the highest sensitivity for endoleak detection, which is confirmed by the observations of other authors (23). Our results demonstrate that ultrasound examinations with the use of UCM are comparable to those of angio-CT for monitoring patients after endovascular treatment of abdominal aortic aneurysms and can replace them in diagnosis of possible complications.

CONCLUSIONS

1. Administration of UCM statistically significantly increases the sensitivity of ultrasound examinations used for detection of endoleaks, particularly of type II endoleaks.
2. CEUS shows the highest sensitivity in endoleak detection as it visualises endoleaks undetected in other techniques, including angio-CT.
3. Ultrasound examinations with Doppler options, and the use of UCM in particular, can replace angio-CT in monitoring patients with abdominal aortic aneurysms treated with endovascular stent grafting.

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