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Indirect CT venography of the abdominal cavity and lower limbs in patients with the suspicion of pulmonary embolism – indications, technique, diagnostic possibilities

Spiral CT has recently become the basic method to evaluate pulmonary embolism (PE) and as a multi-slice option examination it constitutes standard management in stable patients. The symptoms of PE are present in almost 50% of patients with deep vein thrombosis (DVT). The diseases mentioned above are two aspects of the same process defined as venous thrombo-embolism (VTE). VTE is one of the major health problems of modern societies. The literature data reveal that in USA VTE is associated with 300–500 thousand hospitalization cases and results in about 50–150 thousand deaths (11, 12, 14). The survival rates in this group of patients are mainly affected by early diagnosis and proper treatment. The diagnosis of VTE consists of several aspects concerning the evaluation of the system of pulmonary artery branches during acute episodes of PE and the remaining chronic changes as well as examinations searching for the sources of embolic material in the venous system. It has been demonstrated that in the majority of cases the embolic material consists of the clots, which are formed in the lumen of peripheral veins, most frequently of the lower limb deep vessels, become detached, and are carried with the bloodstream to the right part of the heart and pulmonary arteries (16). According to many studies the clots in the veins of the lower limbs or abdominal cavity are observed in about 90% of patients with acute PE (11, 15). The VTE patients present a wide range of clinical forms – from asymptomatic to severe with sudden death. According to Wolfe and Hartsell, the most important question may not be who has a PE but who will have another embolism that may be life-threatening (21). DVT starts most commonly in the deep veins of the major calf muscles. The system of numerous branched venous vessels in the region is particularly anatomically predisposed to venous stasis when patients are immobilized due to any reason, in injuries or operative procedures of various body areas or diseases with decreased fibrinolytic activity. An independent factor increasing the risk of lesions in the peripheral venous system is age, with which the risk increases proportionally, and neoplastic diseases with lung cancer in the lead (14).

When acute proximal DVT is untreated, clinical PE occurs in one-third of patients and another one-third appears to have subclinical PE. Untreated PE in turn tends to be recurrent over days to weeks and can either abate spontaneously or result in death (14). In the acute PE cases the importance of diagnostic procedures of the venous system lies in evaluating a potential cause of embolism and in assessing the extent and character of lesions which may lead to larger embolic process or to death during the successive episode.

The aim of our paper is to describe the diagnostic possibilities of multi-slice computed tomography (MSCT) in imaging the peripheral venous vessels in patients

with VTE in comparison with other available diagnostic methods and to present the preliminary observations based on the results of indirect venography of the abdominal cavity, pelvis and lower limbs as a complement of CT angiography of the pulmonary arteries performed in our center since 2003.

METHODS ASSESSING THE LOWER LIMB VENOUS SYSTEM

At present, assessment of the venous system is based on the following methods:

1. Ascending venography – used as a basic diagnostic method of DVT till 70's. This method is considered the only technique enabling accurate evaluation of all calf and muscular thrombi and allowing to differentiate the acute and chronic lesions. It is a reliable test assessing the patency of lower limb veins. It is routinely performed in patients before thromboarterectomy and venous filter procedures. Evaluation of lesions depends greatly on the radiologist's experience (11).

2. Ultrasonography – the basic technique used to evaluate the veins of the upper and lower limbs. Its advantages include: non-invasive character, possible bed-side examinations, low costs. In the clinical practice, it is usually used as the only method of venous vessel evaluation. The meta-analysis performed demonstrated that the method showed sensitivities of 92–100% and specificities of 80–100% when compared with venography, but only with regard to symptomatic patients and proximal venous vessels. For distal vessels (calf level) the sensitivity reaches 40–87%. The examinations in asymptomatic patients show lower sensitivity rates – 38–100% for the proximal level and 38–58% for the calf level (11,12, 16). Additionally, in some patients the difficulties in imaging the individual vessels occur, particularly of the pelvis and abdominal cavity.

3. CT – the recent method used to evaluate PE and DVT. Its advantages are: short examination time, possible visualization of the system of lower limb veins, vessels of the small pelvis, inferior caval vein and lungs.

4. MR – at present not used to diagnose the venous vessels in patients with PE due to its too low resolution and visualization of big vessels only. The lack of control over patients makes its use in severe cases impossible (11).

CT IN THE PERIPHERAL VENOUS SYSTEM DIAGNOSTICS

In 1978 Steele et al. were the first to report the CT thrombus found accidentally in the inferior caval vein in two patients (11). In 1980 Zerhouni et al. reported the ilio-femoral vein thrombosis observed in CT in 5 cases (22). In 1988 Bauer and Flynn published the paper concerning the clinical use of indirect CTV in patients with indefinite results of ascending venography or when the access to the vein was impossible (2). The authors used the scanning technique during the 10-minute infusion of 150 ml of contrast into the arm vein.

In 1994 Stehling et al. presented the first case of direct spiral CT of the lower limbs (11). In 1991 Langer et al. described the results of 15 indirect venography cases (from the ankles to pelvis) including 6 cases in which thoracic CT for PE was performed (17). In 1998 Loud et al. were the first to present the combination of SCTA for the evaluation of pulmonary arteries and indirect CTV in patients suspected of having VTE (18).

The peripheral venous vessels in VTE patients may be assessed by two methods – direct and indirect. In the direct method the early phase of flow of diluted contrast injected peripherally to the veins of one or both feet is used. In the indirect method the recirculation phase is used and highly-concentrated contrast is administered to the antecubital vein. The former confines to the diagnosis of the venous system, the latter enables various examination combinations in the arterial and venous phase.

Direct CT venography. The examination involves the administration of contrast to the dorsal vein of the foot through the catheter. Thanks to the use of a tourniquet, the contrast medium visualizes the deep venous system. The use of various projections allows to differentiate acute and chronic DVT. The advantages of this method compared to classical venography include: 3D evaluation, the use of low amounts of less concentrated contrast, lower risk of post-infection phlebitis, face-up lying position on examination. According to B a l d t et al., the sensitivity of direct spiral CTV was 100%, its specificity – 96%, positive predictive value (PPV) – 91% and negative predictive value (NPV) – 100% (1, 11). The technique is less dependent on the operator when compared to US or venography, however, an inflow phenomenon may occur. It is worth noting that the amount of contrast is decreased by 80% with better opacification of the venous vessels. To visualize the deep venous system which is not always completely opacified, the contrast medium should be administered to both veins of the feet. Although the method gives the best results of imaging the peripheral veins, it was not commonly accepted in the clinical diagnostics in patients with the suspicion of acute PE due to additional vessel accesses required (in the examination of both lower limbs – even 4) and relatively long stay of the patient in the laboratory. It seems that the method may be used as an alternative in patients suspected of having DVT with clinical symptoms of acute PE whose ultrasound evaluation is difficult or in those before some planned surgical procedures.

Indirect CT venography. Indirect venography is a new and promising diagnostic technique. Its essence is the use of intravenous contrast administered earlier to assess the contrasted venous vessels within the body area examined. The examination may be performed alone or in combination with some other type of scanning, e.g., angiography of the pulmonary arteries, standard CT imaging of the thorax or abdominal cavity, abdominal or limb angiography. In our center, beside venography of the lower limbs following CTPA, in the cases with special clinical indications the procedure was also used after coronarography, aortography and limb angiography. Since 1988 when the combined technique of CT venography and CT pulmonary angiography (CTVPA) was applied for the first time, many groups of researches have dealt with these issues demonstrating high effectiveness of this method in patients suspected of having thrombo-embolic diseases (1, 3–9, 11–13, 15,18, 19). Moreover, the studies are being carried out which are concerned with optimization of the CTVPA technique, possible errors, determination of indications and likely contraindications of its use. In July 2002, the CT laboratory in our center was equipped with a modern 8-row computer tomograph, Light Speed Ultra- General Electric (Milwaukee) with three diagnostic consoles Advantage 4.2. Since the introduction of new equipment numerous vessel examinations have been performed, often replacing the invasive techniques used earlier. The most common procedures conducted include angiography of the pulmonary arteries used in patients suspected of having acute or chronic PE – about 300 such procedures were performed to date. In our opinion this method has been approved by clinicians and is gradually becoming the basic examination in patients with the suspicion of PE. The CT examinations of the venous system in this group of patients are too rarely used despite the lack of 24-h availability of Doppler procedures. We believe that one of the reasons is insufficient information about the diagnostic possibilities of this technique. Twenty-six indirect venographies of the lower limbs and abdominal cavity have been performed to date and a clearly increasing tendency in the number of referrals is observed.

THE TECHNIQUE OF PULMONARY ARTERY ANGIOGRAPHY WITH INDIRECT VENOGRAPHY

On planning combined pulmonary artery angiography and venography, one of the options can be chosen – in the first one, so-called long topograms are performed (130 cm in our center) covering the area

from the superior opening of the thorax to the calves with the extent of both examinations determined on their basis; in the second one, the topogram of the thorax is performed and the range of examination in the venous phase may be determined even after scanning of the thoracic cavity from the lower border of thoracic scanning or manually determining the location of the laser indicator. Our laboratory commonly uses this first method as the one determining most precisely the spatial dimensions of the area examined. Both phases of the examination are performed using the spiral technique with lamp rotation time 0.8s-CTPA, collimation 1.25 mm and interval 0.6 mm and IVP with collimation 2.5 or 5 mm without overlapping. While planning the examination, one of the possible techniques should be chosen – either the continuous multi-slice scanning technique with 1.2–5 mm-thick slices or sequential scanning with 5–10 mm-thick slices every 20–50 mm. The advantage of the latter is a significant reduction in the radiation dose; however it may potentially lead to underestimation of the extent of thrombosis (11, 12).

In two young patients, the technique of single 5-mm slices performed sequentially every 4 cm recommended by Ghaye et al. (11, 12) and Katz et al. (15) was used in order to limit the radiation dose. The table speed in the thorax was 13.5 mm/s, which gives the scanning time up to 15 s while in the venous phase this parameter is increased to 27 mm/s in the 8-row spiral technique, which results in the scanning time 20–45 s depending on the slice thickness. The arterial and venous phases are performed with the breath held and on limb scanning the patient breathes freely. In severe patients the table speed in both phases is increased to shorten the breath hold. The contrast medium, 370 mgI/ml (Ultravist Schering) or 400 mg I/ml (Iomeron 400) is administered to the antecubital vein using a power injector in the amount of 100–120 ml and speed of 4 ml/s.

A separate and relatively difficult problem is the determination of scanning onset time in both phases. Evaluating the pulmonary vessels for embolism, proper intensity of arteries opacification is required, not only to diagnose the central but also peripheral embolism of the 5- and 6-order branches. In peripheral venous vessels of the lower limbs where the concentrations of contrast in the recirculation phase are not very high, the optimal timing of the equilibrium phase and suitable contrast gradient between the blood, thrombus, vein wall and surrounding tissues are the prerequisites of success. For the arteriographic phase, the Smart Prep technique is most commonly used, in which the density of a chosen level in the pulmonary artery or right ventricle is successively measured and after exceeding the selected value (usually 100 HU) the caudo-cranial thoracic scanning is started. In this method the time of venographic phase onset is estimated and added earlier as a second sequence examined. It is also possible, on the basis of the real time of examination onset, to add an additional sequence and the onset is determined by the technician after the defined period of time. In four cases we used the test bolus technique which provides a curve of contrasting the pulmonary artery as well as aorta, on the basis of which the onset times of both phases can be determined. The venous scanning delay in relation to the onset of the arteriographic phase is usually 180 s, however, the factors such as circulatory failure and patient's age should be accounted for – in younger patients without cardio-vascular diseases this time may be even 120 s while in older ones or those with circulatory impairment it should be lengthened by about 60 s, or the additional Smart Prep phase used at the level of the iliac common vein.

In indirect venography the major factor differentiating DVT and normal veins is postcontrast lumen enhancement. In the recirculation phase after administration of the typical contrast amount the attenuation measurements for normal veins are within 60–140 HU and for DVT within 30–50 HU (15). The big density differences in normal veins may also be associated with the differences in maximum enhancement time or result from the examination technique. It was demonstrated that the time to achieve max. enhancement markedly differs in the individual venous levels (between IVC and popliteal veins increases from 93 ± 9.5 s to 141 ± 57 s while for calf veins decreases again to 124 ± 32 s (20).

The time-density curves for different vein levels were examined in CT by the sequential and one-or multi-row technique (11). According to Shapiro et al. (20) all densities found in veins for the time

of peak venous enhancement (93–137 HU) and the time of 420 s from the onset of contrast administration (88–103 HU) were higher than the reported attenuation of recent clots. Recent clots (less than 8 days) show relatively high densities due to high globin content in red blood cells, look homogenous and their average density, according to various authors, is 31–80 HU (11, 12). With time, globins get broken down and are removed by phagocytes and the density decreases. Therefore subacute and chronic clots (more than 8 days) are usually heterogeneous with average density of 28–55 HU (11). It seems that CT examinations may be used to differentiate acute and chronic DVT, which is relevant for therapeutic management.

The combined pulmonary artery arteriography and indirect venography provides a series of several hundred or even over a thousand of native scans. An important element is processing of the data at the workstation. For quick evaluation and initial diagnosis the technique of scan survey in cine option is commonly used. In the arteriographic part, due to high densities of contrasted vessels, beside the typical intrathoracic window (width 350, level 40 HU), the use of widened window, e.g. with 500–600, level 60–80 HU, is helpful. In the venographic part, the situation is reversed – a small gradient between contrasted blood and the clot requires the use of a narrow window, e.g. with 200–250 and level 30–60 HU. The PE arteries are evaluated with various reconstructions, the most valuable of which are MPR oblique ones (paddle view) with MIP 1.5–5 and 3D reconstructions with virtual angioscopy. The vein evaluation is mainly based on native scans and the commonly chosen methods of secondary reconstructions are the coronal and curved projections along the vessel axis.

The CT symptoms of DVT. The main CT symptoms used for the diagnosis of DVT is visualization of the intraluminal thrombus which may completely, partially or parietally fill the lumen (Fig. 1). The diagnosis of recent thrombi is difficult due to their similarity to the liquid blood.

Fig. 1. A 59-year-old patient with increasing shortness of breath and thoracic pains present for several days; (a) CT pulmonary angiographic portion of the CTVPA study shows a pulmonary arterial embolus at the division site of the left pulmonary artery (picture of subacute lesion) and (b) the extent of lumen constriction of the left lower lobe branch in the virtual angioscopy option

The other symptoms include: venous dilation compared with the normal contra-lateral side, obliteration of perivenous fat suggestive of oedema, high contrast ring-like rim of the venous wall due to contrast staining in the vasa vasorum or contrast accumulation around intraluminal clot, muscular swelling and opacification of collateral veins (12, 15, 22). The classical CT symptom of chronic DVT is a clot with

irregular borders, which may also include calcifications (Fig. 2). The clot is usually located eccentrically with the big part connected with the vascular wall. The partial recanalization of the clot in CT examination provides the image of the areas of various densities with visible contrasting of some part of the lumen. The other symptoms include: small retracted veins and ultimately a fibrous cord replacing the vein (13, 15). Some chronic clots may show vein dilation or perivascular and soft tissue edema, which sometimes makes differentiation between acute and chronic disease difficult.

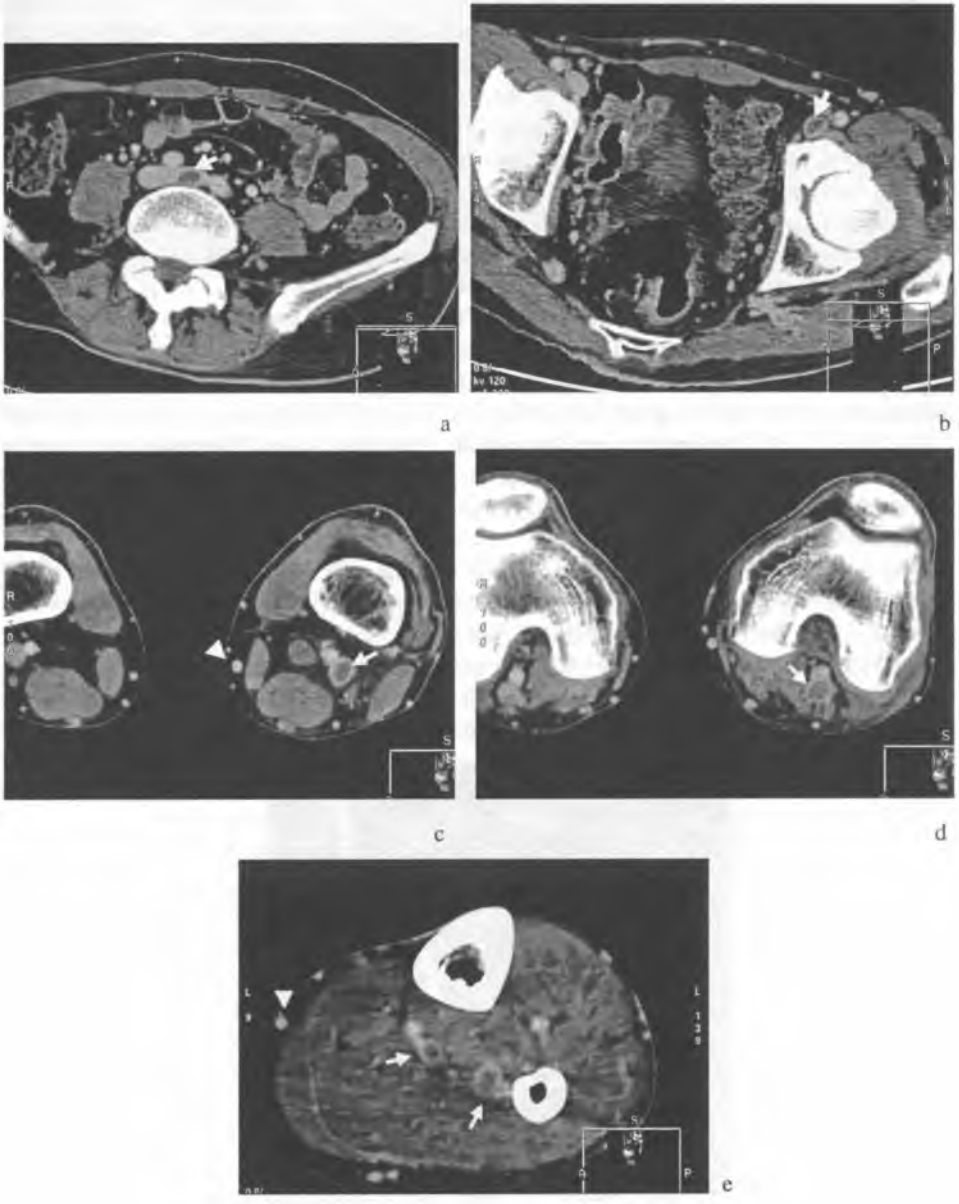


Fig. 2. CT venogram in axial views shows partial thrombosis (arrows) of the (a) inferior vena cava, (b) iliac external vein, (c) superficial femoral vein, (d) left popliteal vein, (e) posterior tibial vein and peroneal vein. Dilated saphenous vein (arrowhead)

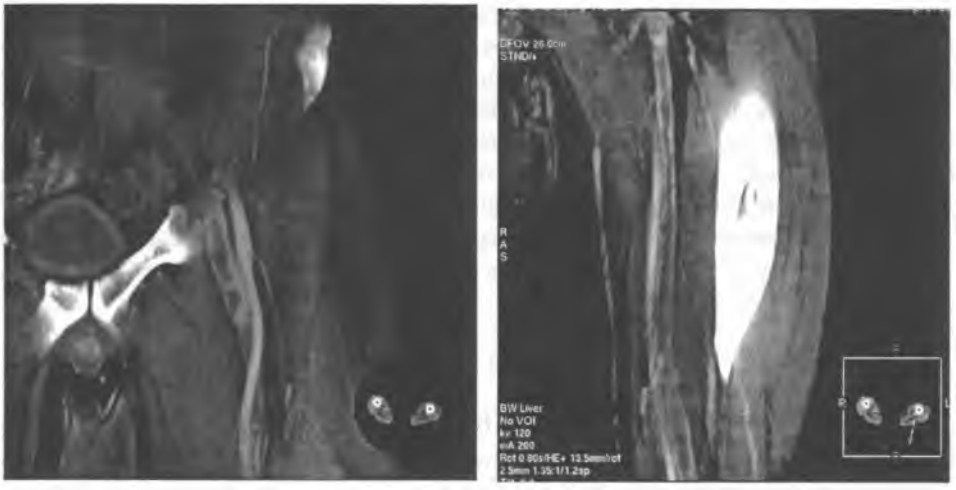
EVALUATION OF LOWER LIMB AND PELVIC VEINS AND CAUSES OF ERRORS IN INDIRECT VENOGRAPHY EVALUATION

CTV enables the diagnosis of DVT in the veins which were unavailable in US or ascending venography, i.e. veins of the small pelvis, abdominal cavity. Additionally, the combination with SCTA allows to visualize the thoracic veins. The assessment of venous diameter is crucial. The caliber of veins which have accompanying arteries (popliteat vein, superficial and common femoral veins, external and common ciliac veins and IVC), is similar. The veins above the popliteal level (deep femoral vein and internal iliac vein) have bigger caliber than their corresponding arteries. The superficial veins have no accompanying arteries. The anatomical variants are extremely important and should be taken into account in order to avoid negative CTV results. The most common causes of errors are duplications which concern: posterior tibial, anterior tibial and peroneal veins. Embryologic remnants of the sciatic vein may rarely be seen with the popliteal vein draining either in the deep femoral vein (partial form) or in internal iliac vein (complete form) (11, 12).

The difficulties of indirect venographic evaluation may depend on the technique used, normal and pathological adjacent structures or may be of an interpretative character (10, 12, 13). CTV may be performed using the sequential or spiral technique. The advantage of the former is a decrease in slice number and in total radiation dose. Too thick slices used and 45 mm- interslice gap might result in the lack of visualization of the lesions in small vessels. In doubtful cases the spiral sequences with 5 mm collimation or follow-up sonography are carried out. The non-homogenous opacities in veins may mimic DVT (11, 13). These artifacts are characteristic of improper scanning time selection or may be associated with the flow (8, 11, 13). Rescanning after 60 s eliminates such errors. CTV acquired with "low dose" or too thin slices can produce noisy images with lumen of the vessels difficult to interpret, particularly in obese patients (11).

Normal structures can imitate venous vessels with the central clot, e.g. lymph nodes, sciatic nerve, aponeurosis, ligaments, contracted and dilated ureter (Fig. 3) (11, 13, 22). Pathological structures may also suggest DVT. These include: abscess, haematoma, popliteal cyst, by-pass. The orthopaedic devices, bones, calcifications, opaque bladder or ureter may result in streak artifacts responsible for intraluminal hypodensia when overlapping the normal vessels (Fig. 4). The sharp and straight appearance of these artifacts that extend in the surrounding tissues may help correct the diagnosis (4, 13).

Fig. 3. Multiplanar curved reformation shows the transluminal cross-section of the venous vessels from the iliac common vein to the superficial femoral vein. Non-homogeneous density of the thrombus and its irregular contours, particularly in the groin region, are noticeable



a b

Fig. 4. 3D volume rendering reconstruction shows (a) the anatomic relations of the altered vein in the iliofemoral region and (b) irregular shape of the thrombus in the superficial femoral vein

BENEFITS OF SCTA AND CTV COMBINATION AND CLINICAL RESULTS

The combination of SCTA and CTV enables quick diagnosis of VTE without additional examinations, even in patients with no characteristic symptoms, and prompt proper treatment. The single contrast administration is used. The additional advantage of this combination is only slightly longer examination time without significant extra costs. Total room transit time ranges from 15 to 25 minutes. The preliminary results suggest that its cost is more effective compared to other examinations. The technique does not require the patient's cooperation and thus may be used in intubated patients incapable of breath hold (8). It may be performed irrespective of the limb position, its soreness, wounds, oedema (6, 8, 11). CTV provides better images of the veins difficult to evaluate by other techniques, e.g. iliac veins or inferior caval vein. Moreover, CTV visualizes asymptomatic DVT in the limbs, accompanying diseases (alimentary canal perforation) and other lesions which compress the venous vessels (2, 12), abdominal tumours, hematomas (6, 7, 11, 12). The examinations results affect proper management. The SCTA and CTV combination enables complete evaluation of the patient and locates the clot site. Its advantage is that it is less dependent on the operator than US or venography. C h u n g et al. stress the possibilities of diagnosing significant anatomic abnormalities of IVC or iliac veins, which may be the cause of DVT (5).

Till 2002, 14 papers were published which assessed the clinical usefulness of the sequential, spiral and combined technique. In his paper of 2002, G h a y e (11) compiled the results of these reports. The studies included 2,152 cases. The sequential technique showed the sensitivity of 97–100%, specificity 91–100%, PPV 71–100%, NPV 99–100%. These values are reliable as the examined areas were the same. The slice thickness was 5–10 mm and gaps 20, 40, 45 and 50 mm. In three cases the spiral technique was used, slice thickness was 5–10 mm, gaps 3–10 mm. The extent of examination ranged from the iliac crest to the knee. One examination evaluated the effectiveness indices. The results were as follows: sensitivity – 89%, specificity – 97%, PPV – 67%, NPV – 98%. In three cases the multi-row technique was used, in two of them the double detector spiral and in one – multi detector spiral technique. The examined areas were comparable. The slice thickness was 3.75–5.5 mm, the gap determined in one case was 5 mm. The indices of effectiveness for the double detector

spiral technique were evaluated in one case and were: sensitivity – 93%, specificity – 97%, PPV – 93%, NPV – 97%. Recently some papers concerning the use of multi-row technique compared to Doppler sonography were published. The results reveal: sensitivity – 100%, specificity – 96.6%, PPV – 93%, NPV – 100% (18). Having evaluated 70 cases, Garg et al. (8) found out that the quality of indirect venography was satisfactory or good in 97% of examinations, despite the fact that 19 patients had beam hardening from orthopedic hardware, flow artifacts or less than ideal image of contrasted veins. It should be stressed that evaluation difficulties occurred in as many as 25 US-examined patients. The interobserver agreement was moderately good (kappa 0.59). An important aspect of CT venography is also the possibility of diagnosing thrombosis in renal, portal or ovarian veins whose US evaluation is difficult (9).

CONCLUSIONS

Multislice tomography is gradually becoming the basic method of diagnosing PE and in many centers is performed routinely totally replacing scintigraphic methods. No doubt, ultrasound examinations of the lower limbs will be continued in patients suspected of thromboembolic diseases as an effective and safe procedure. The experience of our and other centers show that quick US evaluation of lower limb veins often poses great organizational difficulties and reliable assessment of thrombotic material in pelvic and deep lower leg veins in some patients is impossible. In such cases the combination of SCTA and CTV as a one-stop-shopping method gives the clinicians many benefits. The most important one is quick examination, prompt diagnosis and high accuracy, which is particularly relevant in severe patients without the history of PE or DVT. Equally important is the simplicity of the method, lesser dependence on the examiner's skills and experience and readable for clinicians picture and electronic documentation of examinations.

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SUMMARY

Multi-slice computed tomography has become the main method to diagnose and evaluate the intensity of acute pulmonary embolism (PE). The most common cause of PE is thrombosis of veins of the lower limbs and pelvis. The paper presents various aspects of the use of combined pulmonary artery arteriography and indirect venography performed using multi-slice tomography in relation to other methods imaging the venous system used so far. The authors presented the techniques of CT examination of venous vessels of the lower limbs, abdominal cavity and pelvis in patients with the suspicion of PE, typical images of lesions, results of studies concerning these issues conducted to date and their own experience based on clinical practice.

Pośrednia KT wenografia jamy brzusznej i kończyn dolnych
u pacjentów z podejrzeniem zatorowości płucnej – wskazania, technika, możliwości diagnostyczne

Tomografia wielorzędowa stała się obecnie podstawową metodą rozpoznawania i oceny nasilenia ostrej zatorowości płucnej. Najczęstszą przyczyną zatorowości płucnej jest choroba zakrzepowa żył kończyn dolnych i miednicy. W pracy przedstawiono różne aspekty zastosowania kombinacji arteriografii tętnic płucnych z wenografią pośrednią wykonywaną za pomocą tomografii wielorzędowej na tle innych dotychczas stosowanych metod obrazowania układu żylnego. Autorzy przedstawili techniki badania KT naczyń żylnych kończyn dolnych, jamy brzusznej i miednicy u chorych z podejrzeniem zatorowości płucnej, typowe obrazy stwierdzanych zmian, wyniki prowadzonych dotychczas badań naukowych dotyczących tej problematyki oraz własne doświadczenia oparte na praktyce klinicznej.