

3D imaging of the pelvic veins in the male

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Abstract Three dimensional imaging with modeling by caverno-CT is the only technique that provides a precise topographical information, a true 3D map of the male pelvic venous anatomy. The aim of this study is to assess the caverno-venous leaks (CVL), which are the main cause of primitive erectile dysfunction in young men. In addition to duplex color, 3D imaging is essential for their diagnosis and to guide the surgical procedure to neutralize the CVL by ligation or embolization. To do this, we perform a precise anatomical segmentation of the Dicom data using dedicated

software (3Dslicer, Meshmixer). The result is an interactive color model of the pelvic anatomy in 3D mesh form. This 3D imaging technique allows a precise anatomical study of the variations of the male pelvic veins. This article describes the caverno-CT technique, the classification of the caverno-venous leaks and lists the variations in venous morphology in a series of 371 patients.

Keywords Erectile organs, Caverno-CT, pelvis veins, 3D modeling, caverno-venous leaks

Introduction

Anatomical studies of the pelvic veins face several technical difficulties during cadaver dissection and injection of the venous system. This is due to the presence of one-way valves but also to the venous flow which prevents the opacification of the pelvic venous axes when injecting from the lower limbs.

In men, there is a unique technical possibility which consists of injecting the corpus cavernosum on an erected penis to obtain opacification of the downstream pelvic

venous system. This technique is indicated and particularly interesting for the investigation of cavernous venous leaks which are responsible for a good number of primary impotence in young men.

The aim of this paper is to focus on the caverno-CT technique and the methods used for 3D modelling of the erectile system and the pelvic venous system in patients with CVL.

History of primary impotence due to caverno-venous leaks

Cavernous venous leaks as a possible cause of impotence in young men were first described by R. Virag et al.^{1,3} on the basis of 3D reconstruction of the erectile organs by angio scanner. In addition to the Duplex colour under pharmacological stimulation, the study of pharmacologically challenged caverno-CT with 3D reconstruction was a real revolution to assess the anatomy of the erectile organs and caverno-venous leakage.

Herwig⁴ confirmed these findings, in 2018 focused on a systematic review of 30 studies dealing with new minimally invasive methods to provide a potential solution of caverno-venous leakage. His reported long-term also show a significant improvement of erectile dysfunction.

Allaire et al.⁵⁻⁷ suggested surgical treatment of the leaks.

Material & methods

The last data consists of a series of 337 young patients complaining of primary erectile dysfunction. They were investigated by duplex colour and caverno-CT to localise a caverno-venous leak.

The risk related to Xrays exposure of testis in young male: the CT volume dose index (CTDI vol) per acquisition averages 23 mGy, that is 80 for caverno-CT. It is 200 times more than a plain radiograph, but remains very moderate.

A caverno-venous leak was strongly suspected when erection hardness score < 3 and IISF-5 > 20 and when

duplex parameters under pharmacological stimulation with a mixture of papaverine hydrochloride (40mg Renaudin - Laboratory, Ixassou, France - and 20 mcg of alprostadil powder demonstrated a venous score > 1.

The reasons is that using only alprostadil even at a maximum dose of 20 mcg does not prevent from false positive cavernous leak, provided that alprostadil alone does not Block the venous return in even non ED patients. (Yet unpublished study of non-inferiority demonstrates that papaverine 40mg and alprostadil 20mcg altogether is the cheapest and best choice)

Technique for 3D imaging assessment of the penile and pelvic veins

1. CT scan acquisition

Pharmacologically challenged cavernous CT⁸ was performed with a 64 row computed tomography spiral scanner.

15 min after intra cavernous injection of the same used for Doppler evaluation. (see above)

Spiral TDM acquisition of the pelvic region including the penis using the following parameters : 120kV et 100 mA with automatic dose modulation.

After a puncture with a 30G needle at the fingertip below the balano-preputial fold, we start with a cavernous injection of 10 mcg of alprostadil (pharmacologic stimulation)

Three consecutive CT scan are then taken:

- After injecting of 10ml of contrast iodine (Iopamiron 370) diluted with 50% serum
- After filling with 80cc of a contrast medium, or less if the CB are completely filled and patient is suffering.
- Late CT scan after emptying

2. Anatomical segmentation with 3Dslicer[®] software⁹

The 3D reconstruction is obtained by volume rendering technique or better 3D mesh vectorial modelling. The threshold and segment editor functions are used for this purpose. This makes possible to separate bones and veins.

The mesh model is then exported in .obj format in Meshmixer[®] software¹⁰, in order to simplify, reduce and smooth the mesh model (Fig 1 A) Finally, a more detailed segmentation of the veins is achieved manually with coloured 3D painting of each vein. (Fig 1 B)

This coloured segmentation technique allows easier identification of each type of opacified vein. Combined with the interactive manipulation of the 3D model, it allows a detailed interpretation of cavernous venous leaks.

3. Three-dimensional reconstruction of the venous system for anatomical analysis is also possible by VRT technique. For that, we commonly use a web database thanks to a dedicated imaging system available online at www.VIZUA.com¹¹ to display the 3D images make the anatomical analysis and classify the patient.

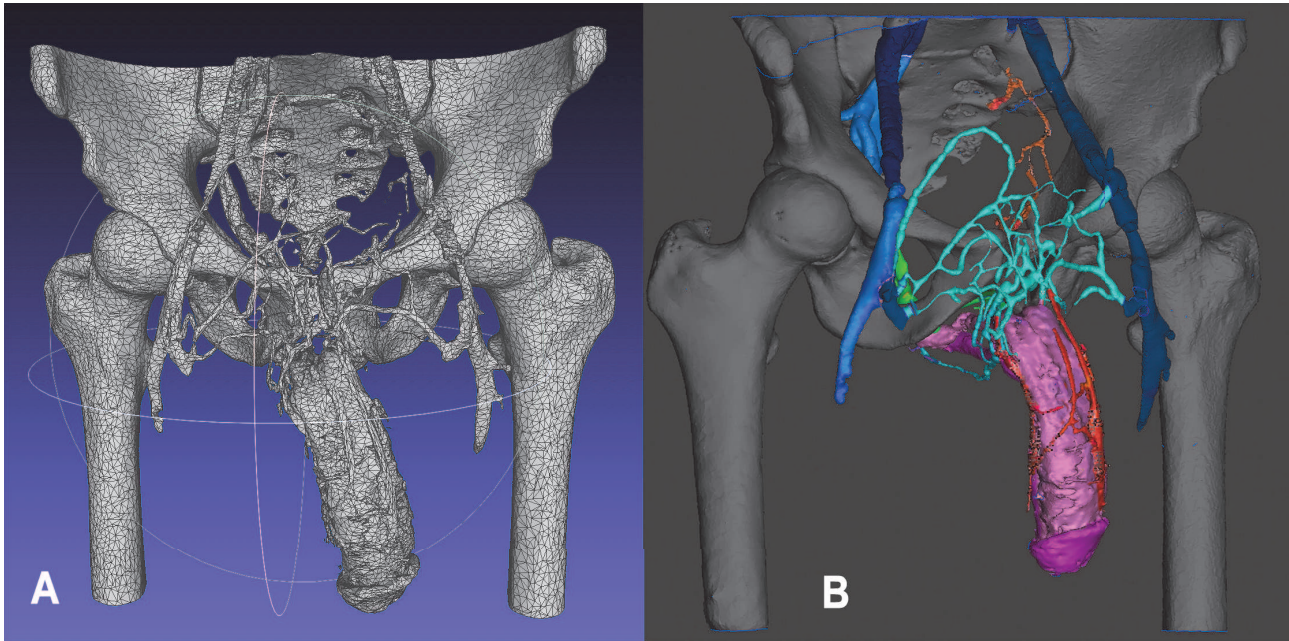


Figure 1 - 3d reconstruction by 3D vectorial modelling using 3Dslicer and meshmixer. A: 3D mesh model. B: colored segmentation

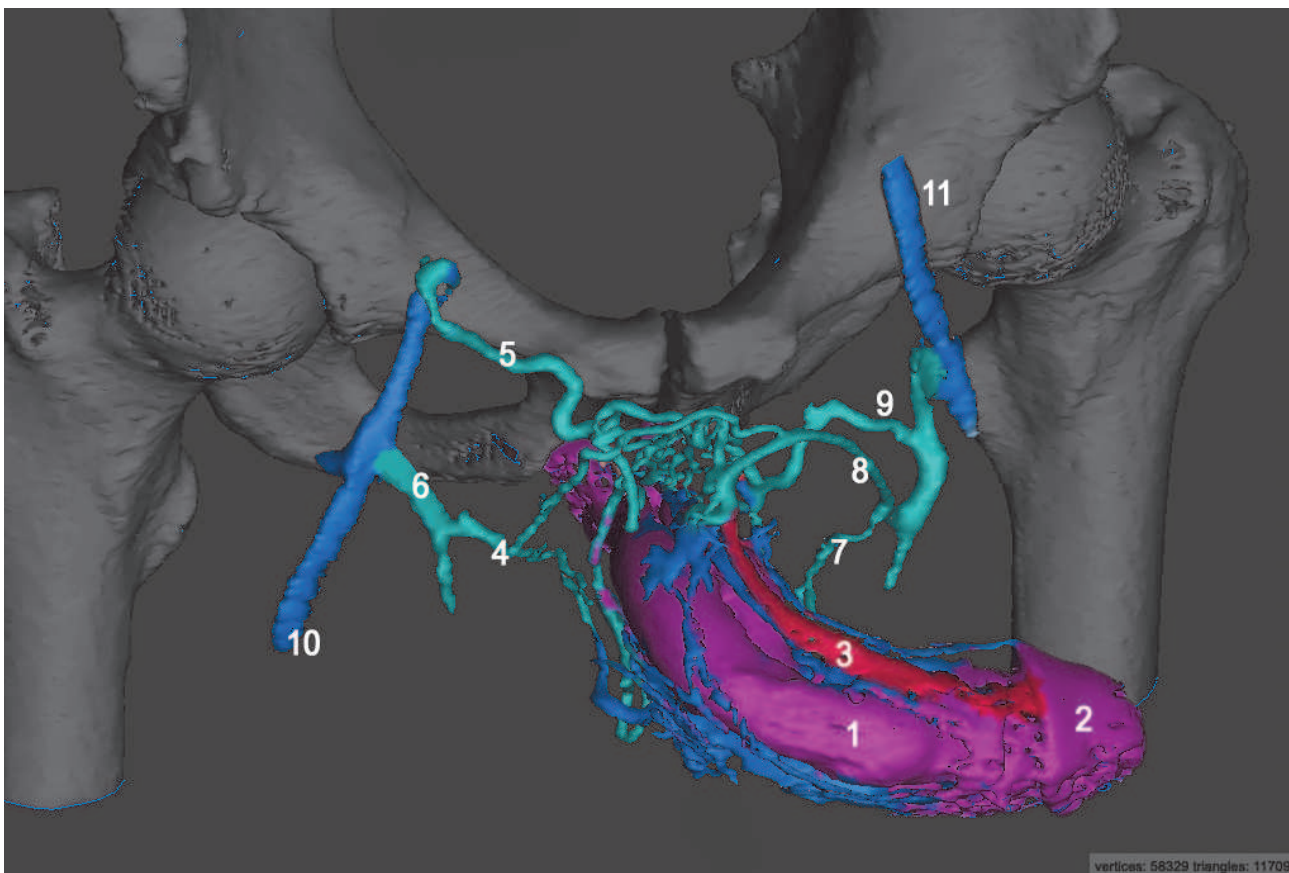


Figure 2 - superficial venous leaks (type B) 1= Corpus cavernosus 2= Gland 3= Deep dorsal vein of penis 4= Right external pudendal vein (inferior) 5 = Right external pudendal vein (superior) 6= Right great saphenous vein termination 7= Left external pudendal vein (inferior) 8 = Left external pudendal vein (middle) 9= Left external pudendal vein (superior) 10= Right femoral vein 11= Left common femoral vein

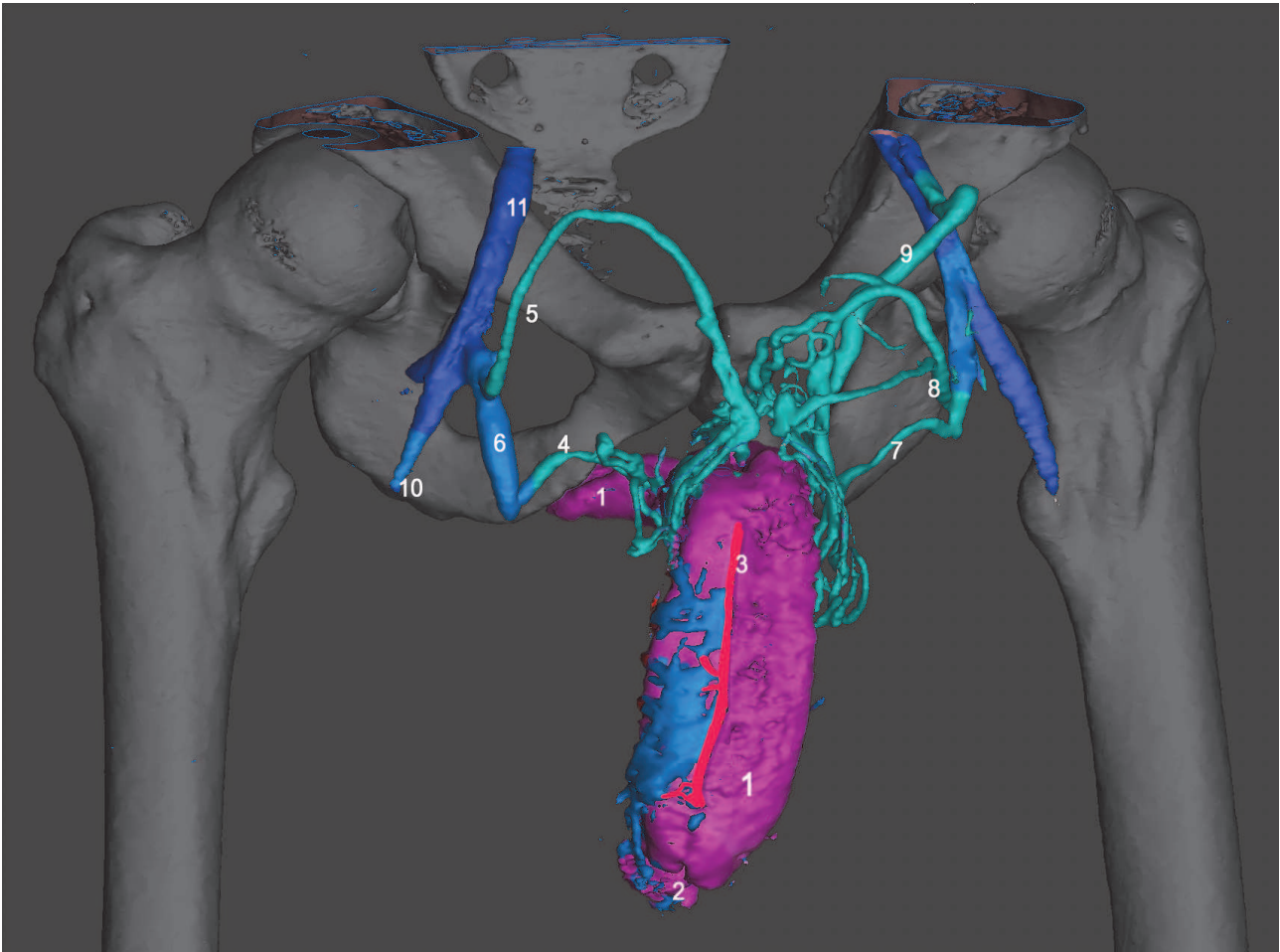


Figure 3 - superficial venous leaks (type B) 1= Corpus cavernosus 2= Corpus spongiosum (partially injected) 3= Deep dorsal vein of penis 4= Right external pudendal vein (inferior) 5= Right external pudendal vein (superior) 6= Right great saphenous vein termination 7= Left external pudendal vein (inferior) 8=external pudendal vein (middle) 9= Left external pudendal vein (superior) 10= Right femoral vein 11= Right common femoral vein

Table I: Classification of the venous leaks into 4 groups

Type	leaks	N	%
A	None	63	18.7
B	superficial	68	20.2
C	deep	51	15.1
D	superficial+deep	155	46
	Total	337	100

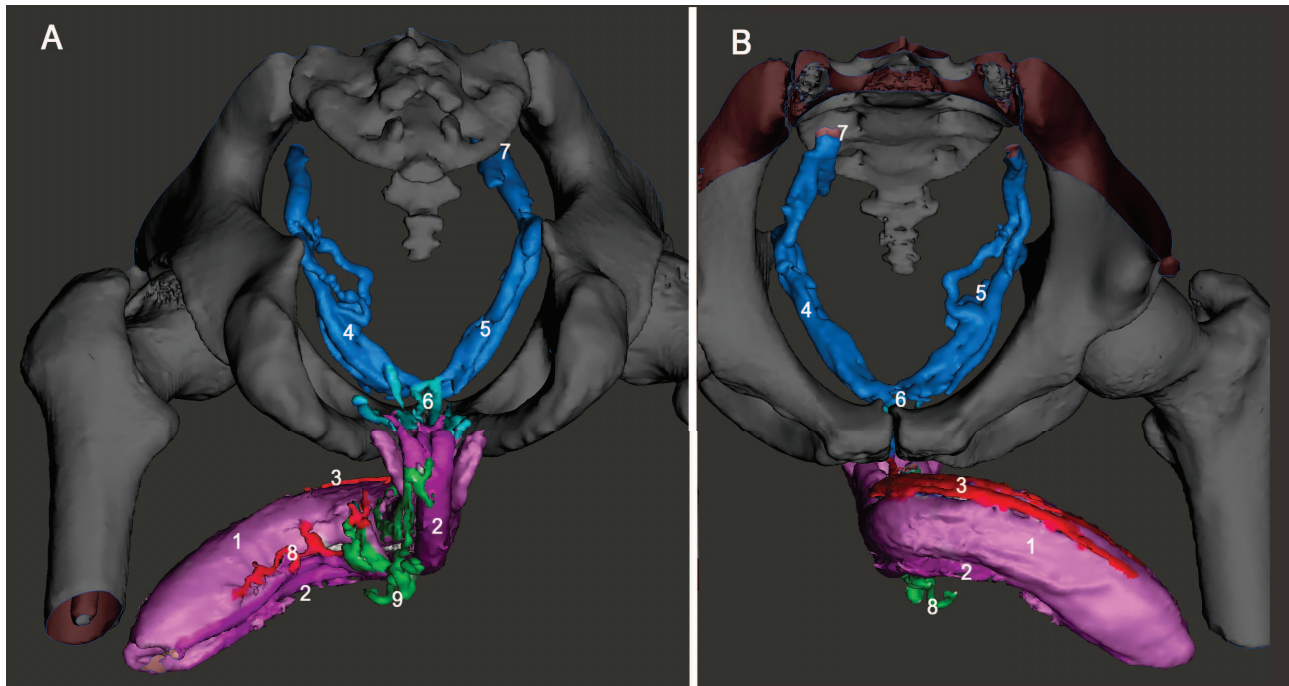


Figure 4 - Deep venous leaks (type B) by both vesical veins. A: posterior view. B: superior view 1= Corpus cavernosus 2= Corpus spongiosum 3= Deep dorsal vein of penis 4= Right vesical veins 5= Left vesical veins 6= Santorini plexus 7= Left hypogastric vein 8= superficial networks of the scrotum

Table II: anatomical distribution and mean diameter of the deep leaks

Vein name	Right	Left	Bilateral	TOTAL	Mean Diameter
VESICAL	16.7%	5.6%	36.7%	58,9%	5.5 mm
OBTURATOR	7.8%	24.4%	16.7%	48.9%	3.6 mm
Int. PUDENDAL	13.3%	15.6%	15.6%	44.4%	4.8 mm
Umbilical	0.0%	0.0%	1.0%	1.0%	4 mm

Results

The anatomical study of the 337 caverno-CT shows in table I the distribution of the leaks in 4 groups: No leaks (A), superficial leaks (B), deep leaks (C) and mixed leaks (D), combining the two previous. This Virag and Paul classification⁷ is used to characterise the leaks. (Table I)

In addition, Virag recently proposed to add 2 types of leakage: communication between the corpus cavernosus and corpus spongiosus (E type about 30%), and leaks from the posterior aspect of the corpus cavernosus (F type about 17%). Only 0,59% of the E type and 6,23% of the F type were isolated anomalies.

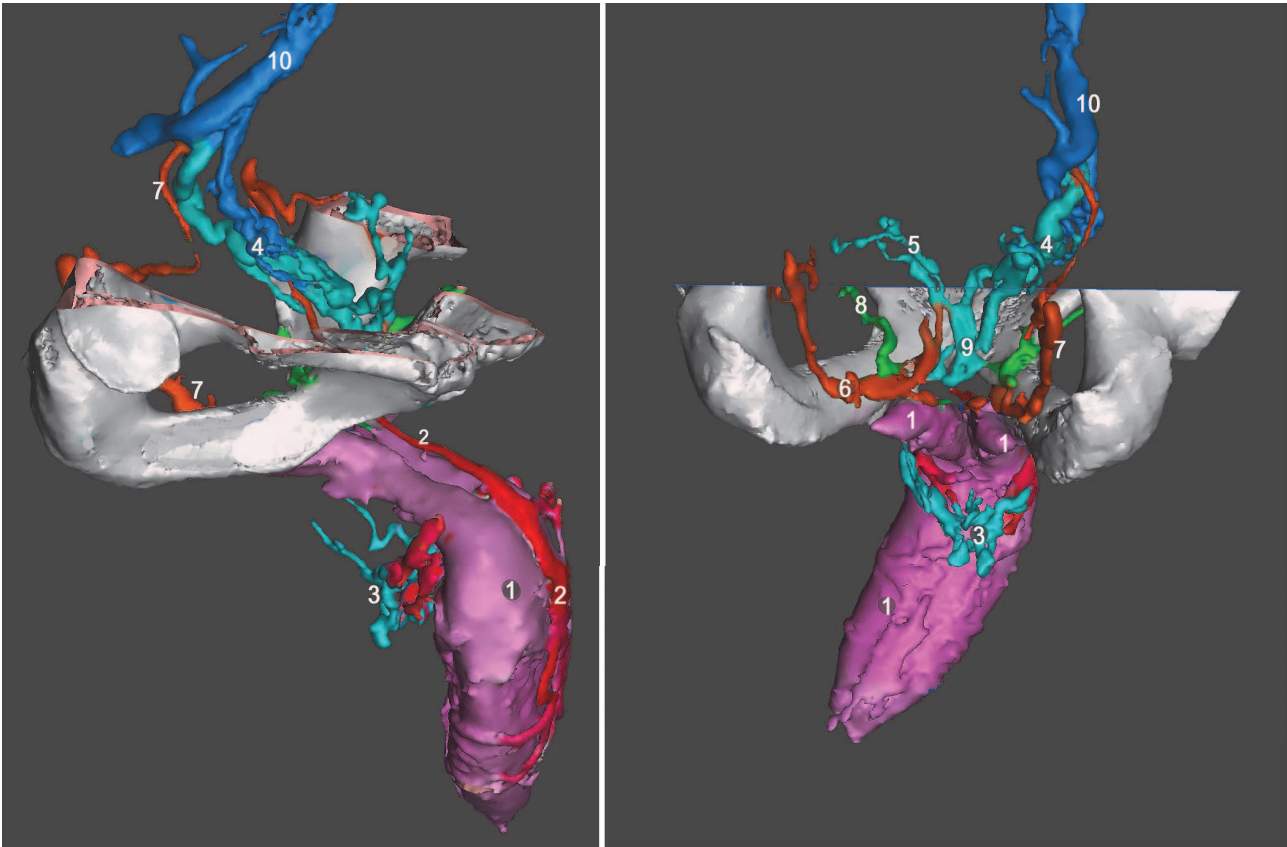


Figure 5 - Deep venous leaks (type B). A: right lateral view. B: Posterior view 1= Corpus cavernosus 2= Deep dorsal vein of penis 3= superficial networks of the scrotum 4= Right vesical veins 5= Left vesical veins 6= Left internal pudendal vein 7= Right internal pudendal vein 8= Left obturator vein 9= Santorini plexus 10= Right hypogastric vein

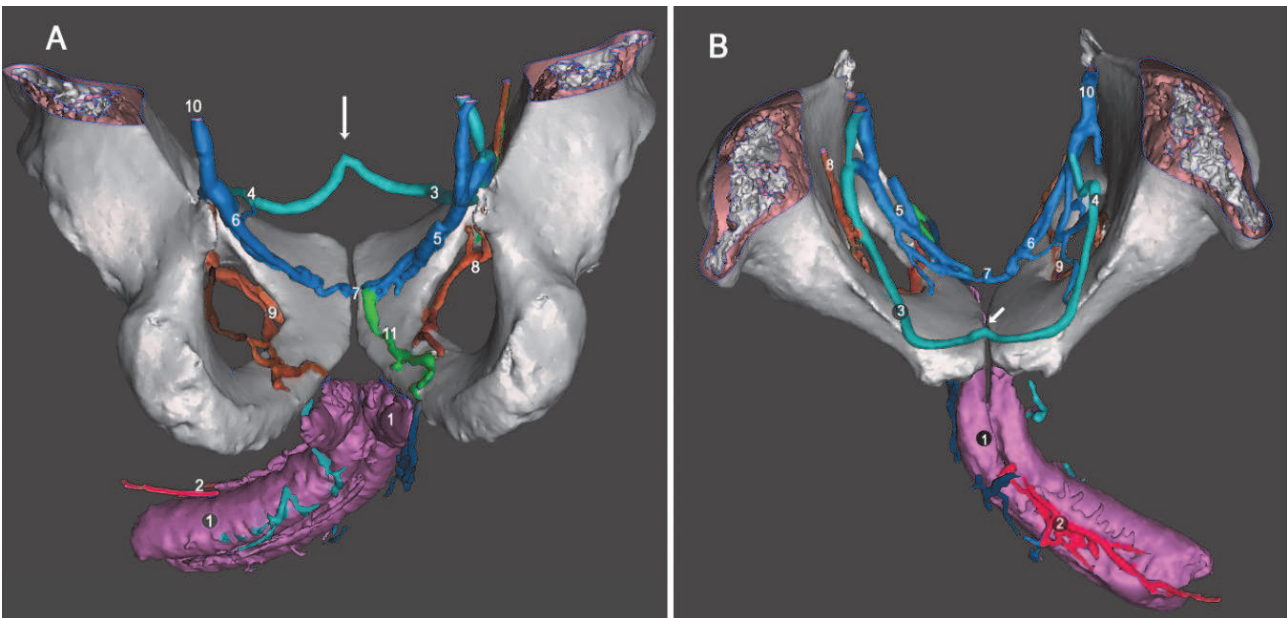


Figure 6 - Deep venous leaks (type B) by Umbilical, vesical & obturator veins A: Posterior view. B: superior view 1= Corpus cavernosus 2= Deep dorsal vein of penis 3= Right umbilical vein 4= Left umbilical vein 5= Right vesical veins 6= Left vesical veins 7= Santorini plexus 8= Right obturator vein 9= Left obturator vein 10= Left hypogastric vein. The arrow shows the connection of the 2 umbilical veins on the midline.

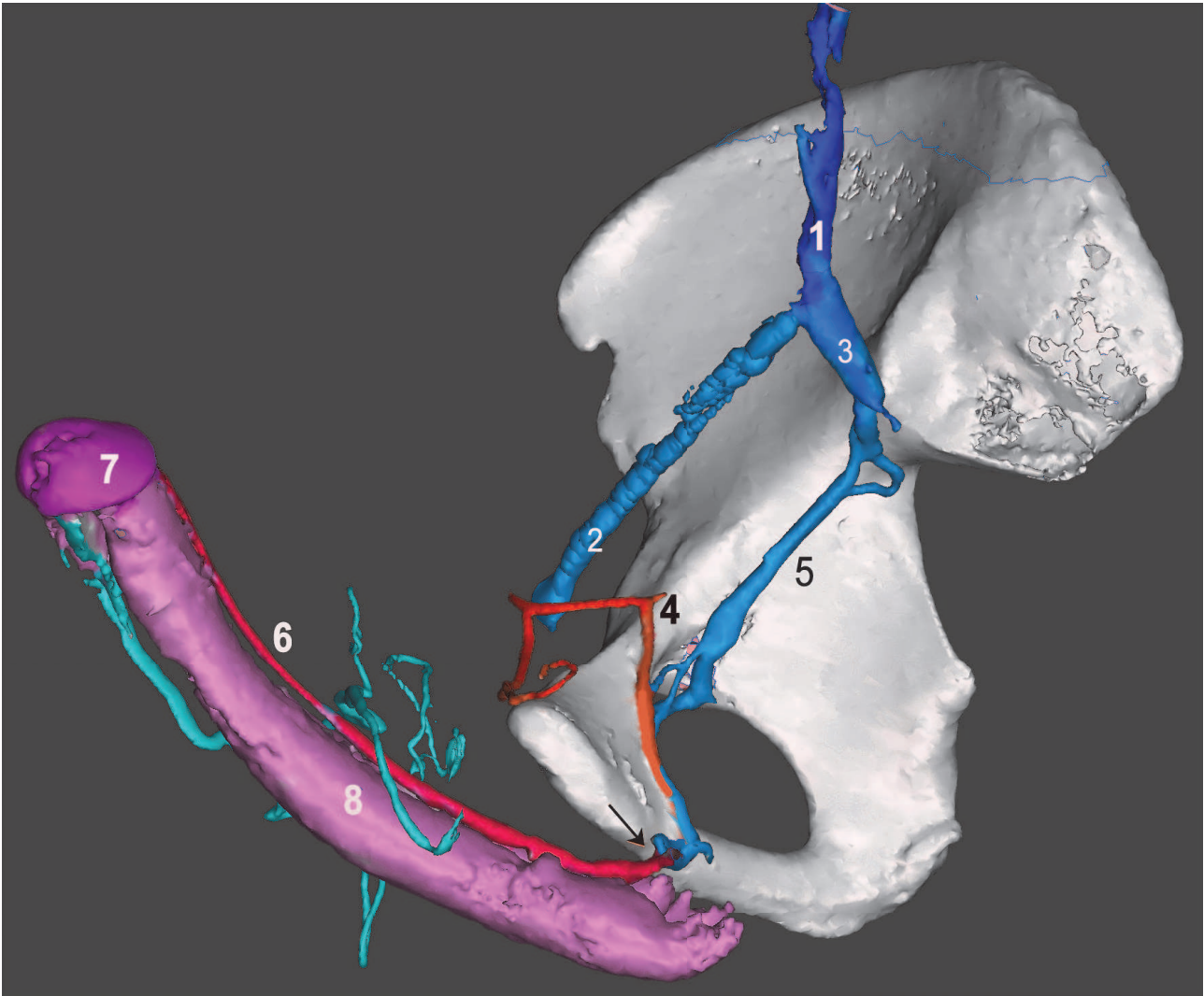


Figure 7 - Deep venous leaks (type B) by inferior (5) and superior (4) obturator veins. 1= Right common iliac vein. 2= Right external iliac vein. 3= Right hypogastric vein 6= Deep dorsal vein (DDV) of penis. 7= Gland. 8= Corpus cavernosus. The black arrow shows the leak point of the DDV with obturator vein.

1. Anatomy of the superficial leaks

Superficial leaks are mainly located in the external pudendal veins. (Figs 2,3)

These veins usually comprise 3 to 4 veins draining into the terminal part of the great saphenous vein (two of them) and into the common femoral vein (1 or 2 of them)

They often form a network with the superficial veins of the scrotum.

2. Anatomy of the deep leaks

The deep venous leaks drain directly into the Santorini plexus, which is located behind the pubic bone in the Retzius space in front of the urinary bladder. (Figs 4-6)

The Santorini plexus is a cross-road that drains commonly into 3 pelvis veins on each side:

Santorini plexus

- The 2 *vesical veins*, right and left, laterally to the bladder, ending in the anterior trunk of the homolateral hypogastric veins.
- The *internal pudendal veins* running in the Alcock canal along the internal aspect of the ischio-pubic bone together with the companion artery and nerve (pudendal nerve)
- The obturator veins include the *superior obturator veins*, tributary of the hypogastric veins coming from the obturator hole and less commonly the *inferior obturator veins*, tributary of the external iliac vein as shown in Figure 8.

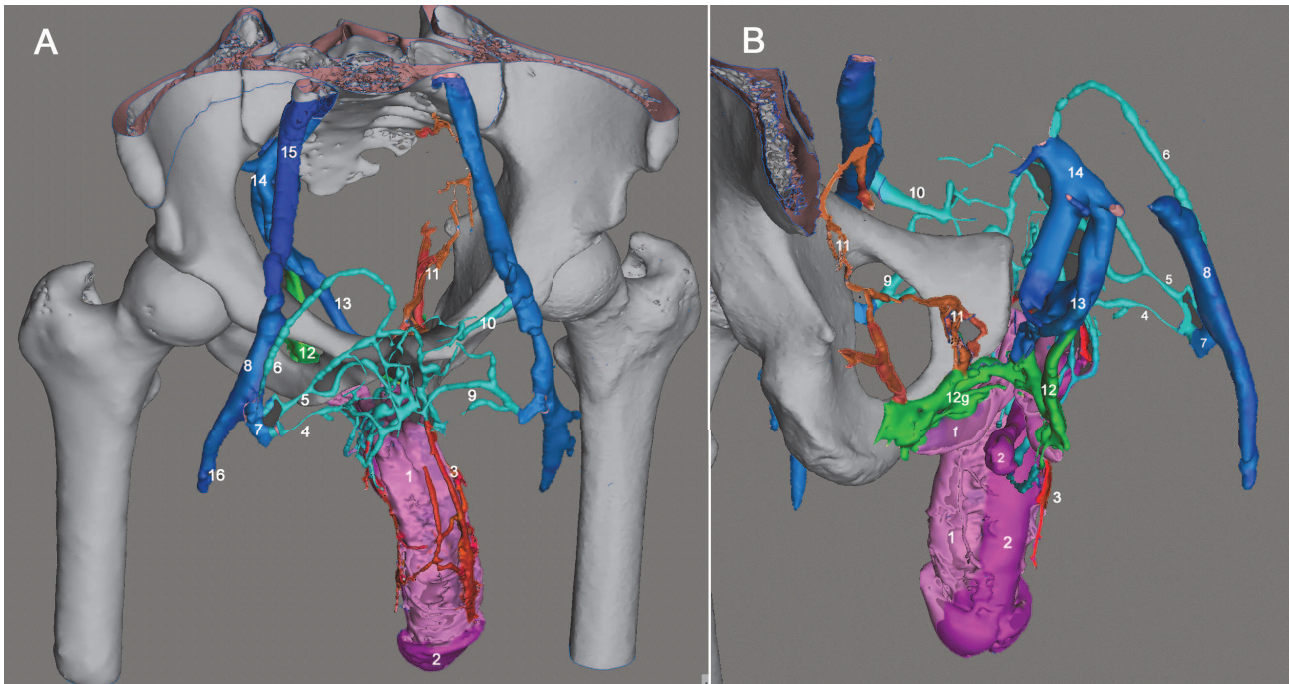


Figure 8 - Mixed venous leaks (type D). A: antero-superior view. B: Left lateral view with left iliac bone removed 1= Corpus cavernosus 2= Corpus spongiosum 3= Deep dorsal vein of penis 4= Right external pudendal vein (inferior) 5= Right external pudendal vein (superior) 6= Left external pudendal vein 7= Right great saphenous vein termination 8= Right vesical veins 9= Left vesical veins 10= Santorini plexus 11=Right internal pudendal vein 12= Right hypogastric vein 13= Right obturator vein duplicated

It is rare for the umbilical veins to be involved. (Fig 7)

In summary, Table II shows the distribution of the deep leaks: frequency of each anatomical type and mean diameter of the veins, was reported from on a series of 100 caverno-CT¹¹ (MasterI of Neveu DUACN 2021 Paris cité University).

3. **Mixed leaks** are common, associating superficial and deep venous leaks.

Interactive display of the 3D model

Various CAD software can be used to interactively study the model, including Meshmixer[®].

Moving, rotating and zooming of the model could be used for an accurate anatomical analysis.

Example are shown on caverno-CTs figures 8 and 9.

4. **Other leaks** have recently been added into the classification and form a separate group:

- Leaks of the posterior aspect of the corpus cavernosus (CC) (fig 11)
- Communications between the CC and the corpus spongiosus (CS) are seen in almost 30% of this series. Their haemodynamic significance is still unclear and need further anatomical investigation.

An example illustrating these functionalities with mixed leaks is available on the Sketchfab[®] website (<https://skfb.ly/6TvwL>)

3D printing of the anatomy is also possible through the use of Cura[®] software, for an educational perspective.

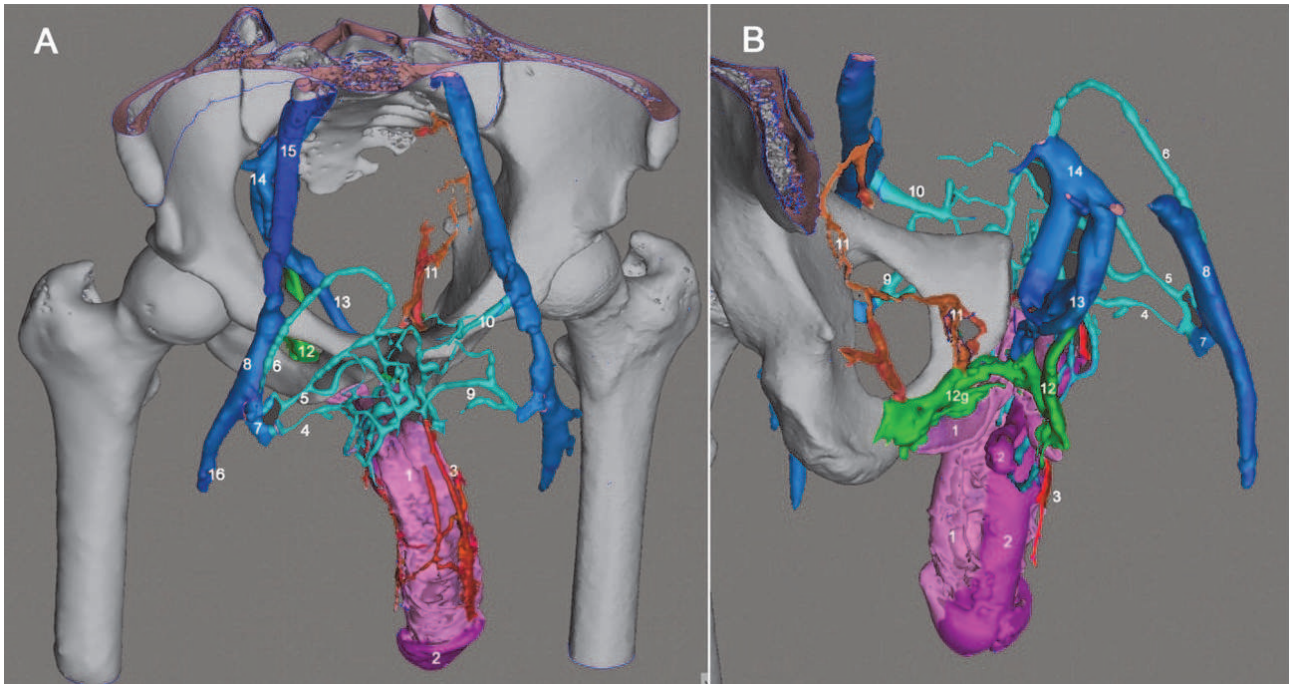


Figure 9 - mixed venous leaks (type D). A: anterior view. B: Posterior view with right iliac bone removed 1= Corpus cavernosus 2= Corpus spongiosum/gland 3= Deep dorsal vein of penis 4= Right external pudendal vein (inferior) 5,6= Right external pudendal veins (superior) 7= Right great saphenous vein termination 8= Right common femoral 9= Left external pudendal vein (inferior, duplicated) 10= Left external pudendal vein (superior) 11= Left obturator vein (connected to the internal pudendal) 12= Right internal pudendal vein 13= Right vesical vein 14= Right hypogastric vein 15= Right external iliac vein 16= Right femoral vein 17= Santorini plexus

Surgical treatment of the cavernovenous leaks (CVL)

These 3D caverno-CT models pave the way for surgical treatment of CVL.

Virag and Allaire⁵ published a series of 45 CVL treated surgically.

Many surgical techniques have been proposed to reduce CVL: ligation, venous exeresis and occlusion by embolization.

Thanks to caverno-CT, surgery can be targeted and adapted to each patient using the following criteria: Criteria for surgery included erectile dysfunction lasting more than 1 year, and evidence of a cavernous linkage based caverno-CT. Patients had to have no other somatic cause of erectile dysfunction, neurological disorder or diabetes with severe abnormalities on penile electromyography, uncorrected hormonal disorder, Peyronie's disease, significant penile curvature, psychological or psychiatric disorders, expected poor compliance with follow up.

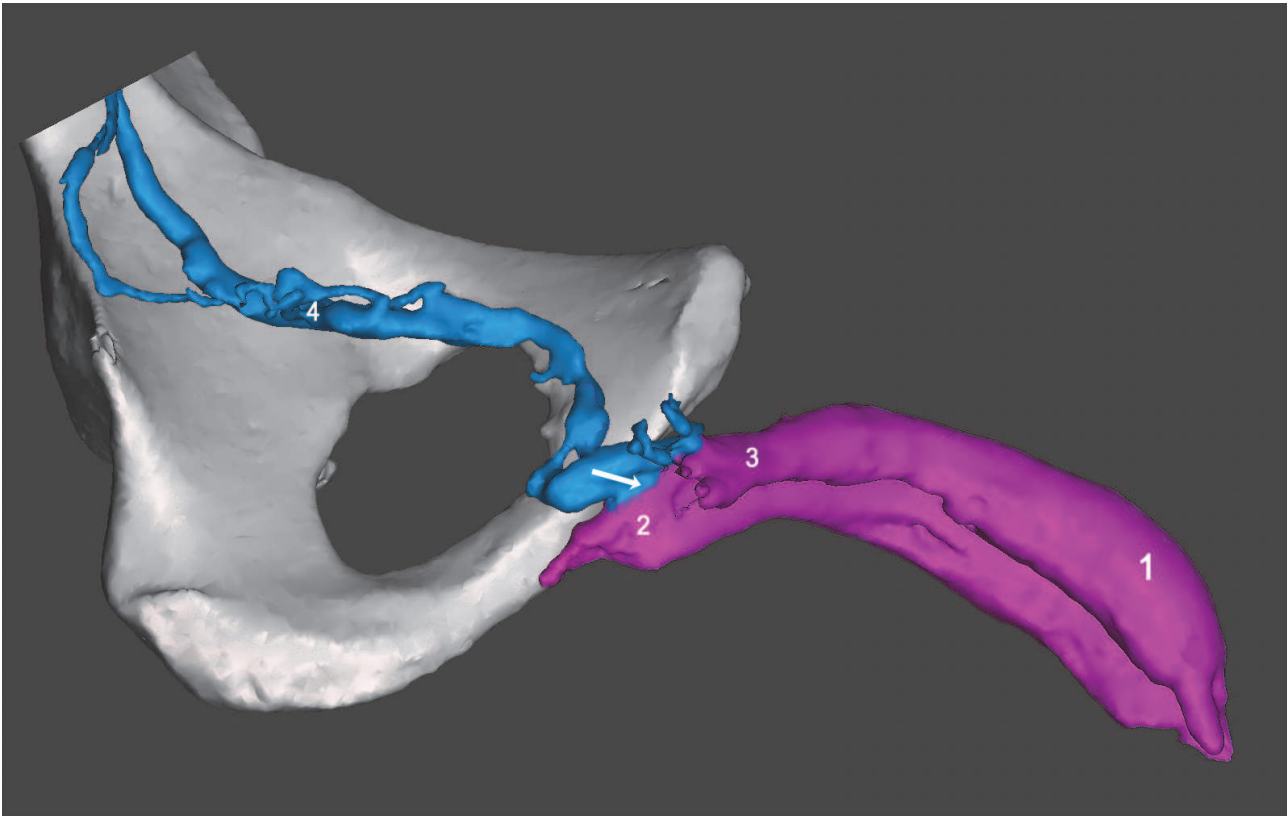


Figure 10 - Leaks of the back of the corpus cavernosus (type F) Right lateral view, right iliac bone has been removed 1= Corpus cavernosus 2= Back of the left Corpus cavernosus 3= Back of the right Corpus cavernosus 4= Left vesical veins

Conclusion

Three-dimensional imaging with interactive modelling by caverno-CT is the only technique that provides an accurate and interactive anatomical information of the erectile organs and the pelvic venous system.

In addition to the color Duplex investigation, it provides a true 3D map of caverno-venous leaks which

are a frequent cause of primary impotence in the young. This helps for their diagnosis and is essential to guide the surgical procedure to neutralize the leaks by ligation or embolization.

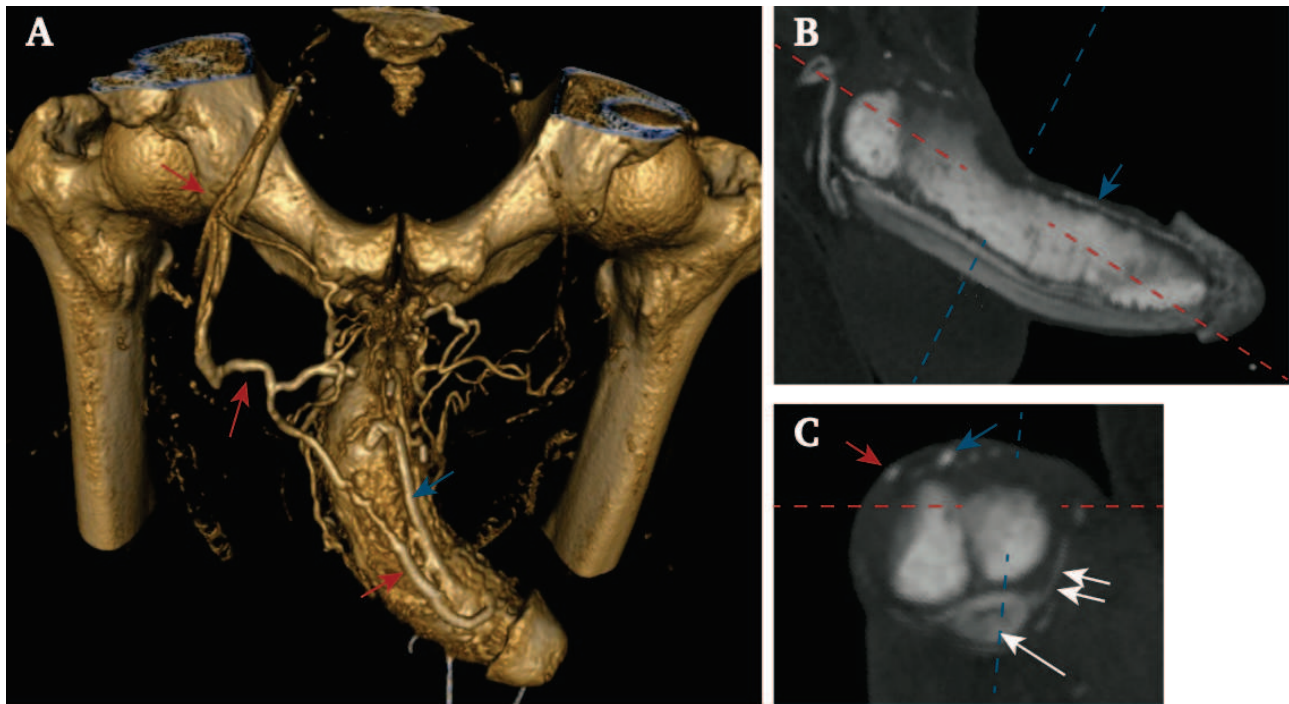


Figure 11 - Leaks between CC and CS [modified from Allaire (2021) et al. and vizua software] 3D reconstruction by VRT Pharmacologically challenged computed caverno-CT pre-operative analysis of leakage pattern in (A) volume rendering, (B) longitudinal, and (C) transversal views demonstrating superficial leakage through abnormal vein (red arrows), deep dorsal vein (blue arrows), abnormal opacification of the spongiosa corpus due to cavernospongious fistula (single white arrow; B), and circumflex vein responsible for spongiosa corpus leakage (double white arrow; C) in a patient with drug resistant erectile dysfunction caused by cavernovenous leakage.

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