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Hemodynamics of revascularization of the corpora cavernosa in an animal model

A preliminary report

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Summary. Numerous revascularization procedures are used for the treatment of vasculogenic impotence. In an animal model we created three different types of bypasses: inferior epigastric artery to dorsal penile artery, to dorsal artery and to dorsal vein (anastomotic arteriovenous fistula), and to dorsal vein alone. Epigastro-dorsal anastomoses remained fully patent without anticoagulants in 3 of 4 animals. With erection the flow in the inferior epigastric artery and the retrograde flow in the dorsal artery (towards the cavernous artery) increased significantly. In the 4 studies incorporating an anastomotic arteriovenous fistula we could not establish a clear reason to incorporate the artery; runoff was demonstrated only to the venous system. Arterial bypass to the dorsal vein with a simulated emissary vein increased outflow resistance as well as improved intracorporeal pressure during erection of the corpora in 4 animals. As resting pressure was also elevated, the penile smooth muscle might be at risk for further degeneration with this procedure.

Key words: Impotence – Penile revascularization

Up to now barely any experimental data have come up in the literature regarding the hemodynamic effects of the different revascularization techniques in impotent patients. As the indication range – predominantly of deep dorsal vein (DDV) arterialization procedures – was extended from pure arterial disease to combined arteriovenous disease and predominantly venous disease [1, 6], it appeared necessary to define the hemodynamic properties of the most commonly used procedures. The clinical success rate seems to depend more on the indication than on the type of procedure chosen for treatment and varies in a range from 30% to 80% [12]. A small number of patients with pure arterial disease (e.g., dysplastic or posttraumatic) benefit from pure arterial bypasses (dorsal artery, cavernous artery) [4]. DDV arterialization [6, 14] has found a wider field of indications up to now, and the hemodynamic mechanisms of these procedures should be clarified in order to define the indications and to improve the technique. The Hauri procedure integrates both dorsal artery and dorsal vein [10] – the function of the dorsal artery remains unclear. All this uncertainty warranted an experimental study to clarify some fundamental and specific questions regarding each procedure.

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Materials and methods

Twelve healthy male mongrel dogs, weighing 20–30 kg, were used in this study. Dogs were premedicated with acepromacine (0.1 mg/kg body weight) and ketamine (5 mg/kg body weight) subcutaneously and anesthetized with intravenous sodium pentobarbital (30 mg/kg body weight, with a bolus injection of 25–50 mg/h as needed to maintain an adequate level of anesthesia and spontaneous respiration). Fluid maintenance consisted of intravenous infusion of normal saline solution (2 ml/kg body weight per h). The dogs were placed in a supine position on the operating table. Through a median incision from the xiphoid to the pubic bone the abdomen was opened, and in the caudal part of the same incision the corpora cavernosa were exposed. The bowels were displaced cranially, and the bladder and prostate as well as the large vessels in the retroperitoneum were exposed, and an open clamp was positioned around the common iliac trunk, to be closed if necessary. The right pudendal artery was ligated just below the vesical artery to reduce blood flow to the ipsilateral corpus cavernosum.

For the induction of erection, the pelvic plexus was located, and the cavernous nerves were identified by eletrostimulation along the posterolateral aspect of the prostate. A bipolar cuff electrode (Avery Laboratories) was placed around the cavernous nerve. Stimulation was performed for 30 s at a time with a Grass stimulator using the following parameters: 0.5–5 V, 20 Hz, and a pulse width of 200 μs. In some studies erection was induced by the intracavernous injection of papaverine-HCl.

For pressure recordings on a Grass polygraph, two 21-gauge butterfly needles were inserted in the corpora cavernosa and connected to Statham transducers. The same setup was used to record pressures from the dorsal penile vessels.

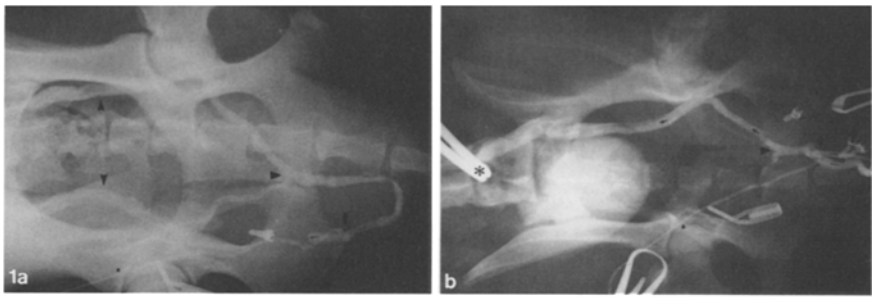

Fig. 1. a Angiogram after Hauri procedure. *Vertical arrow* points at site of anastomosis. To the left of the anastomosis a valve stops the flow. There is no opacification of the arterial system. b Angiogram after Hauri procedure. The clamp at the far left (*) closes the common iliac trunk. Even with this reduction in arterial pressure there is no opacification of penile arteries

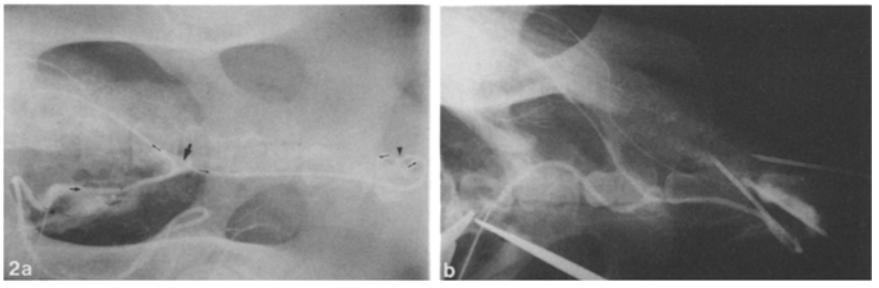

Fig. 2. a Angiogram after IEA to dorsal artery anastomosis (at rest). Good opacification of the vessels, no dye in the corpus cavernosum. b With stimulation there is a clear opacification of the proximal corpus cavernosum. Pointed clamp at right indicates needle for contrast injection into the IEA. The anastomosis can be seen in the middle, needles at right serve for pressure recording

The left corpus cavernosum served as a control in all the studies. Systemic blood pressure was monitored through a catheter placed in the femoral artery. Blood flow in the inferior epigastric artery and the dorsal artery of the penis was recorded with an ultrasonic blood flow probe (1.5 mm diameter, Transonic Systems).

The right inferior epigastric artery was harvested at the ventral surface of the rectus muscle and was used as a donor vessel in all animals. All vascular anastomoses were done with microsurgical technique, and 10-0 and 9-0 nylon was used as suture material.

The effects and hemodynamic mechanisms of three different surgical procedures were studied:

Group A

In 4 acute studies a Hauri operation [10] was carried out. Hemodynamics were evaluated by angiograms through the inferior epigastric artery (IEA) before and after induction of erection by electrostimulation. After intracorporeal injection of papaverine at the end of the study, methylene blue was injected into the IEA, and cannulae were inserted into the corpora, the distal and proximal portions of the dorsal artery, and the dorsal vein to evaluate the distribution of the dye.

Group B

In 4 acute studies a Virag V operation [14] was done. The IEA was anastomosed to the ipsilateral dorsal vein end-to-side. A 5 mm side-to-side anastomosis was created between the vein and the corpus cavernosum 2 cm proximal of the first anastomosis. Pressures were then recorded from the corpora cavernosa and the proximal and distal portion of the deep dorsal vein at rest and after induction of erection by electrostimulation.

Group C

In 4 chronic studies a branching site of the IEA was used to do two end-to-end anastomoses to the distal and the proximal part after transection of the dorsal artery (Y-anastomosis). No anticoagulation was used in the postoperative period. Follow-up as 3 months long. Then the animals were anesthetized again, and the penile vessels were surgically exposed. Electrodes were positioned for stimulation and the blood flow recorded at rest and during erection as mentioned above. Finally, angiograms were performed under the same conditions.

Results

Group A

Contrast medium injected into the IEA opacified only the venous system as illustrated for the erection state in Fig. 1a. Even clamping of the common iliac trunk and the resulting reduction of antegrade arterial flow to the penile artery did not cause contrast medium to penetrate to the arterial system from the anastomosis (Fig. 1b). The patency of the anastomosis and the dorsal artery was repeatedly checked throughout the experiment. Methylene blue injected into the IEA could not be detected in the penile arteries or the corpus cavernosum.

Group B

After finishing both vascular anastomoses, pressures were recorded from the proximal and distal DDV and from the corpora. The average resting pressure in the corpora was 16.5 cmH_2O (range 9–20 cm H_2O), similar to the values recorded by Jünemann in a larger series [11]. After opening the bypass and with the 5-mm window (side-to-side) between the DDV and corpus cavernosum and the proximal DDV left open, the resting pressure in the corpus cavernosum rose to an average of 39.2 cmH_2O (range 22–48 cmH_2O); this is 236% higher than the normal baseline values. During erection, the intracorporeal pressure rose to around 90% of the control (average 112 cmH_2O on the study side, 129 cm H_2O on the control side) and indicates that there cannot be a high escape through the open proximal DDV. Pressure curves in the DDV ran parallel to the pressures inside the corpus, but they always were 9–10 cmH_2O higher than the intracorporeal pressures. The difference is not significant, but there is a clear trend. There was practically no difference between proximal and distal DDV pressures. Figure 5a (at rest) and 5b (erection) demonstrates the results in one of the animals.

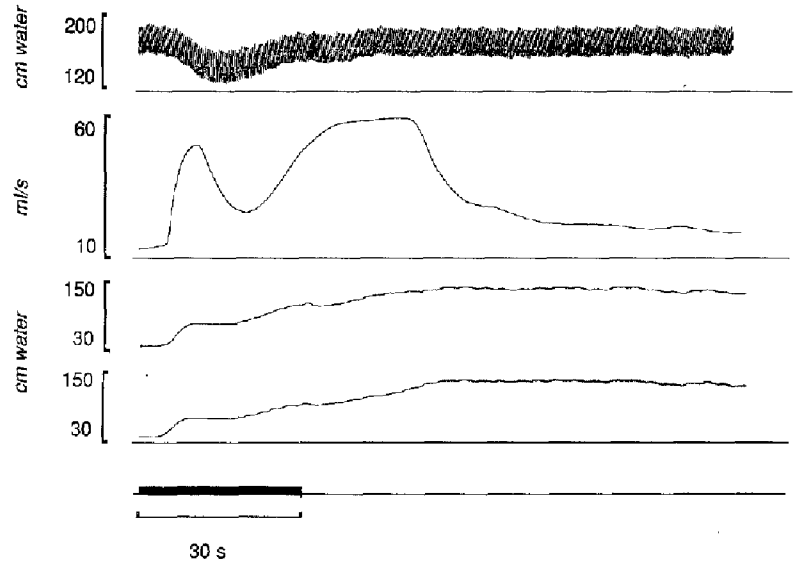

Fig. 3. Simultaneous recording of systemic blood pressure (BP), IEA flow, and intracavernous pressure (pCC rt) demonstrates the effectivity of the IEA bypass. The drop in IEA flow during stimulation is most probably due to the drop in systemic blood pressure at the same time

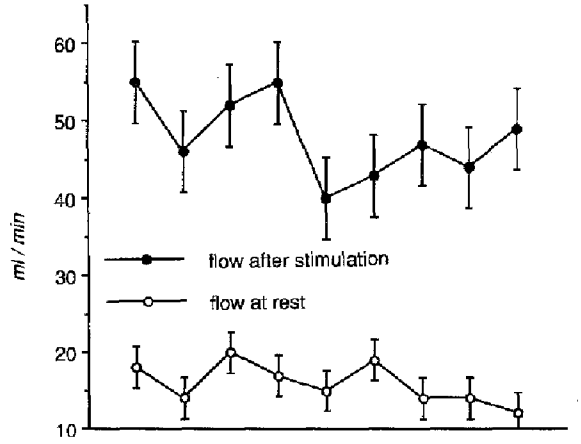

Fig. 4. Average (and SD) flow values from nine consecutive stimulation periods performed in all 4 animals demonstrate the significant increase after stimulation

Group C

All four dogs were followed for 3 months. Three out of four anastomoses were perfectly patent; the one failure was obviously due to a severe postoperative wound infection. Figure 2a demonstrates the runoff of contrast medium at rest. The distal as well as the proximal portion of the dorsal artery is very well filled. During and after stimulation there is clear evidence of dye entering predominantly the proximal portion of the corpus cavernosum (Fig. 2b). This was confirmed by the results of the pressure and flow measurements. Figure 3 shows a typical recording with a 305% increase in IEA flow (18–55 ml/min) after electrostimulation. The intracavernous pressure corresponds to the control, as the ligation of the right pudendal artery is compensated by the IEA bypass. Nine consecutive measurements were performed in each animal (Fig. 4). The average flow was 15.8 ml/min (±2.7 SD) before stimulation and 47.8 ml/min (±5.3 SD) after stimulation, resulting in an increase of 302% with stimulation. The increase in retrograde flow in the proximal part of the dorsal artery was identical to that in IEA.

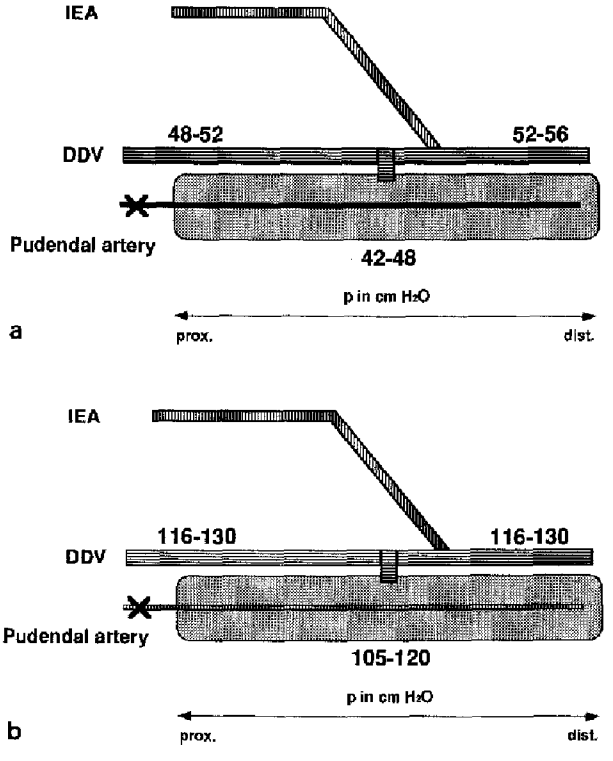

Fig. 5. a Range of consecutive pressure recordings after deep dorsal vein (DDV) arterialization. There is a slight drop in pressure between DDV and corpus cavernosum. This drop culd also be demonstrated in the other studies. b During erection the pressure comes close to systemic arterial pressure throughout the DDV. IEA, inferior epigastric artery

Discussion

Numerous different methods have been applied clinically to increase the blood flow to the corpora cavernosa. Most frequently, the IEA serves as the donor vessel. It has been used for arterial bypasses to the corpora cavernosa, as described by Michal et al. [13] or to the penile arterial

vessels [4]. Direct arterial communications between the dorsal artery and the cavernous artery have been described [7], but looking at their capacity, they do not appear to be hemodynamically important. In our experiments there was clear evidence that the grafted IEA fully substitutes the ipsilateral pudendal artery after ligation. The flow study demonstrated a similar increase in the flow of the grafted IEA after induction of erection, as described for the pudendal artery under physiologic conditions [11]. The same increase was noted in the proximal part of the dorsal artery in the retrograde direction. In conjunction with the angiographic studies (Fig. 3b) showing an initial pooling of contrast medium in the proximal part of the corpus cavernosum, we can assume that there is significant retrograde flow to the corpora via the cavernous artery. As there are regular communications between the cavernous and the dorsal arteries at the hilum of the penis in humans as well [3], the epigastrico-dorsal bypass seems to be an appropriate method for compensating a lack of arterial flow in the pudendal and/or penile arteries.

The dorsal veins were integrated in the revascularization process for different reasons. Hauri proposed an anastomotic arteriovenous fistula [9], referring to a technique that had been used in distal limb salvage to maintain the patency of the arterial graft [5], mainly by maintaining arterial runoff to the venous system. Although a clinical study showed slightly better results in comparison with conventional bypasses, an experimental study on the same technique concludes that "an adjuvant arteriovenous fistula may improve bypass graft flow, but is unlikely to benefit distal limb perfusion" [8]. From our radiologic studies we have to draw the same conclusion for the corpus cavernosum, as under no circumstances we could observe any runoff to the penile arterial system. We still have to supply numerical data regarding flow and pressure studies, but in our opinion the angiographic studies show a clear trend towards a compelete venous runoff (Fig. 1a, b).

After arterialization of the DDV we found a surprisingly high rise in baseline pressure, although we left the proximal leg open. This might suggest caution, especially in younger patients with a predominantly arterial component. Breza et. al. found a marked reduction in the number of sinusoids and smooth muscle hypertrophy only 2 months after arterializing the cavernous vein in a similar experiment [2].

The pressure drop from arterial to venous system is not immediate at the site of the anastomosis. There is a very high pressure zone throughout the DDV, particularly during erection, when DDV pressure reaches 80%–90% of the systolic pressure. There was even a slight drop towards intracorporeal pressure that seems to imply enhanced filling and a significant outflow reduction.

More work will be necessary to evaluate fully all the procedures, but from these preliminary data we can say that in cases of proximal arterial stenoses the IEA-dorsal artery bypass appears to be a very effective method to supply the cavernous artery via retrograde flow. A natural branching of the IEA could help to create a Y end-to-end anastomosis after the transection of the dorsal artery and avoid turbulences and thereby thrombosis. We found two end-to-end anastomoses to be less complicated than an end-to-side anastomosis. Regarding the Hauri procedure, the mechanism of action appears to be similar to DDV arterialization. There is no evidence of any benefit of the three-vessel anastomosis, as of now.

DDV arterialization procedures have the widest range of application. The exact flow and distribution pattern of the bypass blood are still unclear. As to our results, the proximal DDV should be left open (it can be closed, if absolutely necessary). As venous pressure is rather high (probably a hemodynamic not a mechanical phenomenon), ligating the distal part seems appropriate to avoid glans hyperemia. In young patients with pure arterial impotence, DDV arterialization obviously carries the risk of intracorporeal pressure rise and smooth muscle damage.

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