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Arterial Pressurization of the Cadaver Using a Specially Designed Device: "Remote Revascularization Dynamic Device (R2D2)"

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ABSTRACT

*A part of carrying out tests with cadavers (whole body) is to inject the arterial system. It can be done before the test, before and during the test, or even after the test. The characteristics of the liquid injected allow three aims to be reached: First of all, it is a liquid providing an initial physiologic arterial pressure. Secondly, the liquid is coloured using an additive solution in order to facilitate the identification of the vascular injuries during the autopsy. Thirdly, as the last property, the liquid has to **fix** the tissues.*

For this study, the choice has been made to inject the cadaver before, during, and after the test. To do this, a device has been specially designed corresponding to the following initial request,s keeping in mind that " simplicity is the best way to obtain reliability particularly when the acceleration level that can be reached is close to 30g": (1) Injected volume max equal to 4 litres (mix of ethanol with Indian ink); (2) Remote control of the beginning of the injection that becomes autonomous when the test is started; (3) Compressed air propelling system providing a linear pressure; (4) Separating membrane between the liquid compartment and the air compartment; (5) No loading due to the separating membrane deformation; (6) Auto-static device ending the injection when the tank of ethanol/Indian ink is empty; (7) Robustness of the device having to endure acceleration up to 30g.

This paper deals with the following: Principles of the technique, description of the device (R2D2, Remote Revascularization Dynamic Device), validation tests of the device, cadaver dynamic tests and results, and dissection. Revascularization was performed on six cadavers during crash tests using R2D2. The injection pressure was determined to be stable during the tests. The auto-static termination of the injection works well, no leakage occurred, and no part of the device was destroyed. The quality of injection that was checked during the autopsies appeared to be satisfactory. The most difficult part of the process was to determine the level of the air pressure that, finally, defines the initial vascular pressure before the beginning of the test.

INTRODUCTION

The aim of the revascularization consists of an arterial injection of liquid using a superficial artery (carotid artery) in order to obtain, during the test, a physiological pressure and an anatomical volume of the arteries. The use of an injecting solution allows for an evaluation of the quality of the injection, a fixation of the tissues injured, and an improvement of the identification of the arterial injuries during the autopsy.The solution that has been chosen consists of a mixture of ethylic alcohol (not formaldehyde because of the toxicity) with Indian ink.

The procedures previously used consist of an injection done before the test only, before and during the test, and during the test only. At CEESAR, the procedure consists of, first of all, a pre-injection a few minutes before the test in order to pre-fill the aorta and to check the efficiency of the injection objectified by visible black leakages occurring at the level of the incised zones. Secondly, another injection begins 30 seconds before the test in order to obtain a physiological pressure, continuing all along the test and ending about 30 seconds after the test. This procedure provides a good identification of the injuries during the autopsy.

METHODS

Specifications of the device

A maximum injected volume equal to 4 liters is specified for the device. The injection is remote controlled in order to begin 30 seconds before the test (the device becoming autonomous as soon as the test begins). A liquid propelling system using compressed air is used. Air pressure is regulated and there is a separating membrane between the liquid compartment and the air compartment preventing pressure gaps caused by air injected into the arterial system. There is no loading due to the separating membrane deformation leading to the use of a **plastic bag folded** when the liquid tank is full. A device ends the injection automatically when the tank of liquid is empty. The device has a robustness, allowing acceleration up to 30g to be endured.

Principle components of the device

The supply of air consists of a 10 liters metallic tank. The output tube of the tank is connected to the pressure regulator allowing a stable pressure of air to be provided. The manometer shows the pressure of air circulating in the circuit and thus allows an adequate pressure to be regulated. The electrical air flood gate allows the admission of air in the liquid tank to be driven and thus the injection of liquid in the carotid artery to be carried on. The separating membrane (folded in Figure 1) prevents the input air from being mixed with the liquid because of the acceleration. The output tube of the liquid tank is connected to the carotid artery.

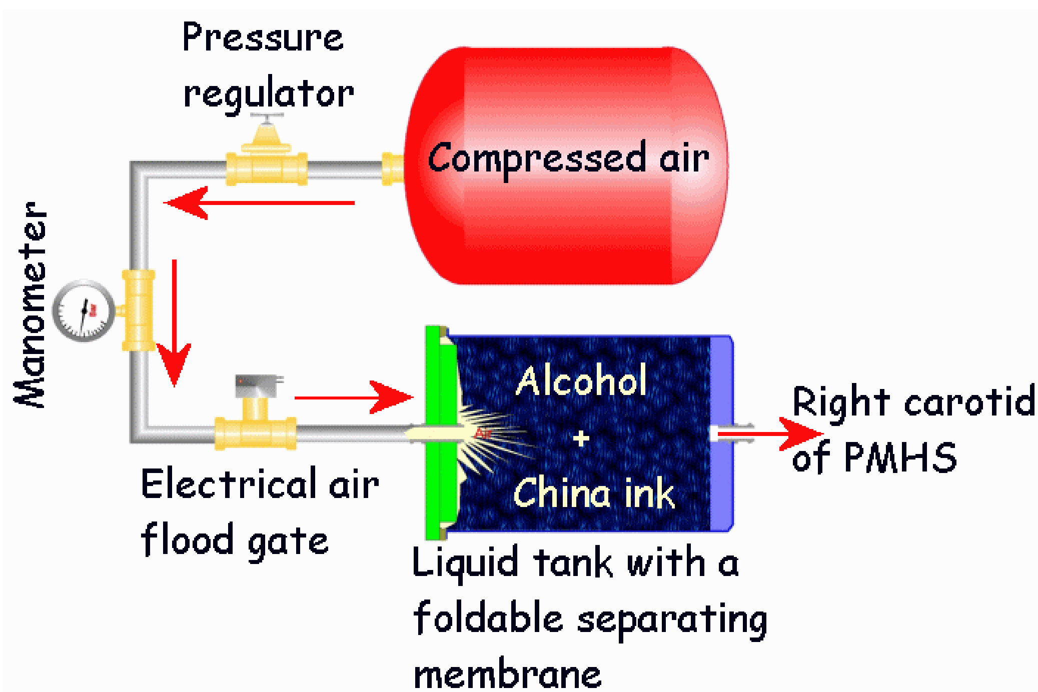

Figure 1: Drawing of the principle components of R2D2.

Description

The main parts of the device, consisting of the liquid tank, the air tank, the electrical air flood gate, the boarded driving box, the batteries, the air pressure regulator and the manometer are shown in Figures 2 through 4.

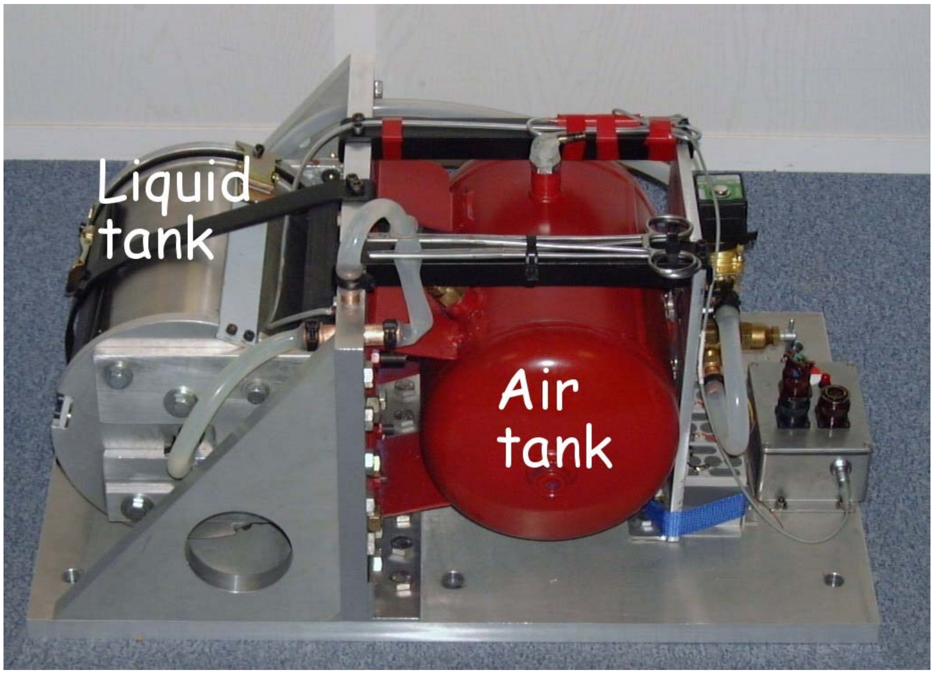

Figure 2: Side view of R2D2.

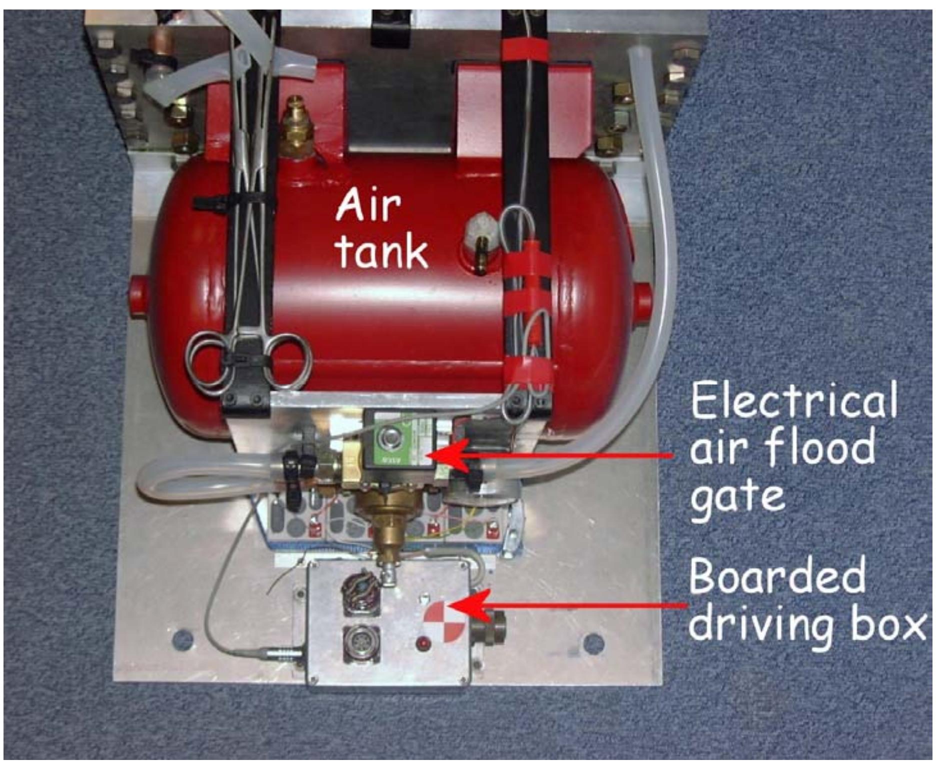

Figure 3: Upper view of R2D2.

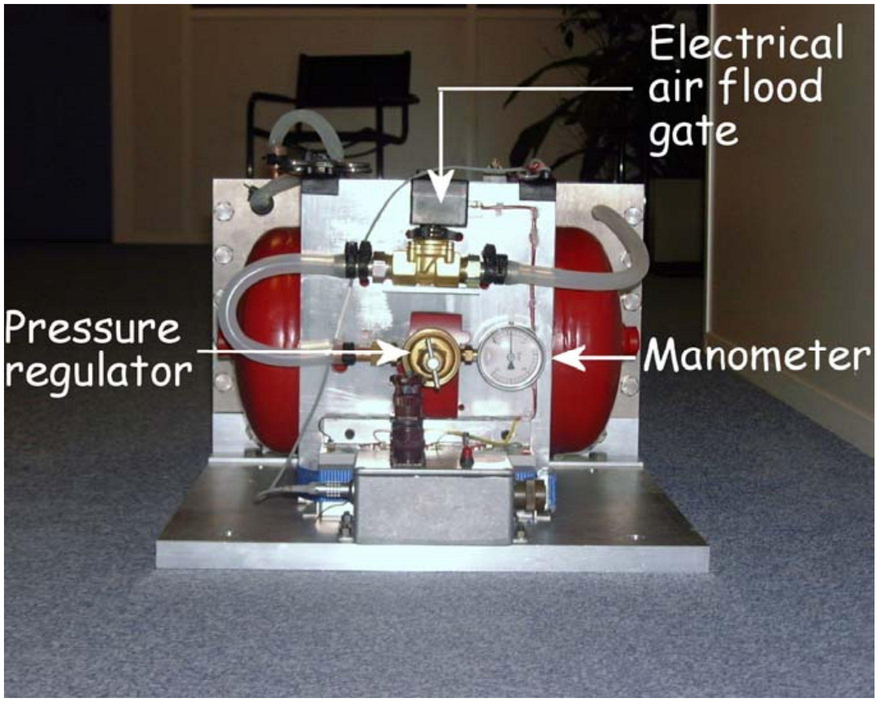

Figure 4: Control panel of R2D2.

Two complementary devices are necessary to carry out the injection during dynamic tests. The *sled boarded start box* connected to the *R2D2 boarded driving box* provides the automatic function of R2D2 as soon as the sled starts. The *manual start box* positioned in the control room allows the injection to be started before the beginning of the test.

Use of the device during a dynamic tests

Preparation of the device before the test. The tank is filled with the injecting liquid consisting of a mixture of one liter of Indian ink with three liters of alcohol and the remaining air is removed from the tank. Then the air tank is filled up to an air pressure equal to 4000 hectopascals. The air pressure regulator is adjusted in order obtain an output pressure equal to 1500 hectopascals. This value takes into account the length and the diameter of the tube between the liquid tank and the carotid artery in order to obtain a physiological pressure. After this, the electrical air flood gate is connected with the two starting boxes. The first one allows the injection to be started manually before the test. The second one, boarded on the front of the sled, allows the injection to be automatic when the test is begun. Next, the feeding tube is connected to the catheter inserted into the carotid artery (Figure 5). The injected circuit is pressurized for two seconds in order to rid the feeding tube of air. Consequently, the efficiency of the injection can be assessed because of black leakage occurring at the level of coetaneous incisions. A few minutes before the test, the arterial system of the cadaver is pre-filled during ten seconds.

(Contact author for picture)

Figure 5: Catheter inserted into the carotid artery.

Countdown, start, and end of the test. Thirty seconds before the start, the injection is begun using the *manual start box.* Then, as soon as the test is started, the device becomes autonomous because of the action of the *sled boarded start box.* After the test, the injection is ended when the liquid tank is empty- the expansion of the plastic bag full of air being controlled by the wall of the tank.

Special cares during the installation of the R2D2 on the sled. The position of the liquid tank output must be aligned on the position of the carotid artery on the z axis (in green on the Figure 6) first, in order to prevent added pressure variation due to the length of the tube on the x axis. Secondly, the tube must be fixed in order to prevent added pressure variation due to the motion of the tube during the test.Figure 7 illustrates the consequences of a free tube on the pressure during a validation test on a mini-sled. The output pressure initially equal to 400 hectopascals ranges from –58 hectopascals to 960 hectopascals during the test because of the motion of the tube.

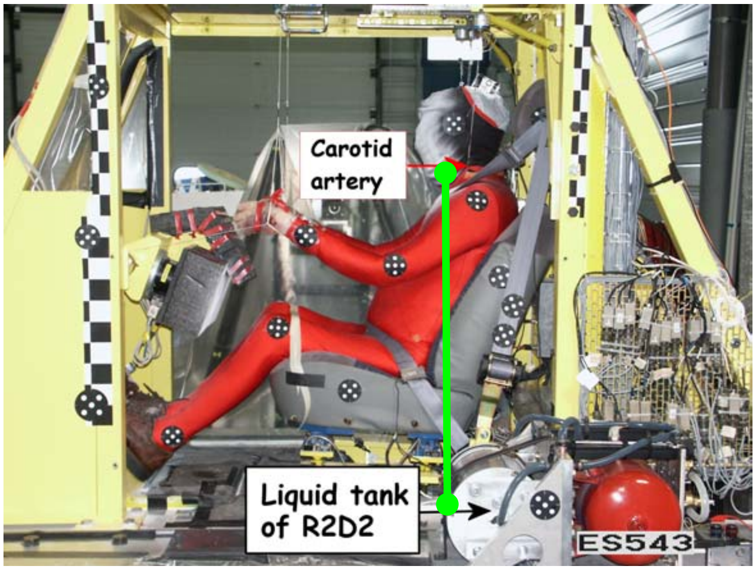

Figure 6: Position of R2D2 on the sled during a dynamic test.

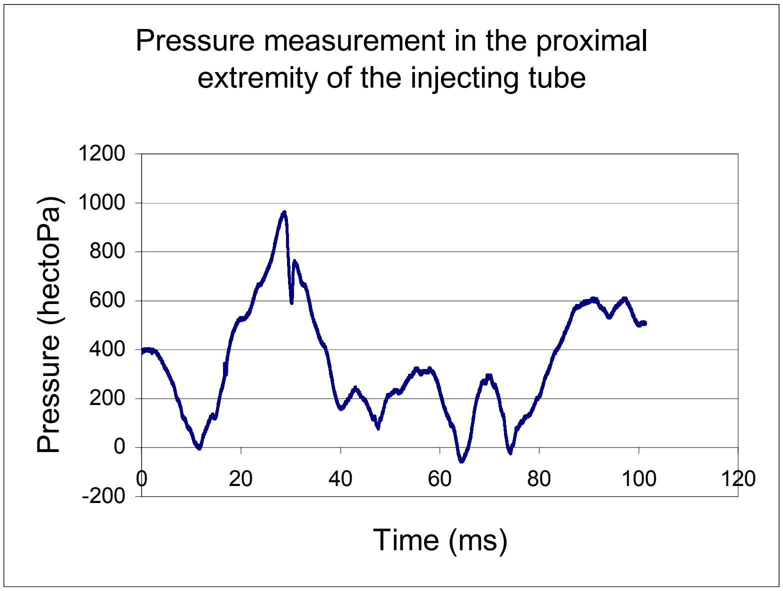

Figure 7: Pressure variation due to a free tube during a validation test.

RESULTS

Analysis of the pressure curve

The comparison of the shoulder strength and the sled acceleration with the aortic pressure leads to the following comments (Figure 8):

- The initial pressure, equal to 66 hectoPa (49.5 mmHg), is stable and close to a diastolic pressure (red curve).
- There is not any influence of the sled acceleration on the aortic pressure, the red curve showing a stable vascular pressure despite the start of the sled acceleration (blue curve).
- There is a link between the loading of the thorax illustrated by the concomitant increases of the F shoulder (green curve) and the aortic pressure (red curve).

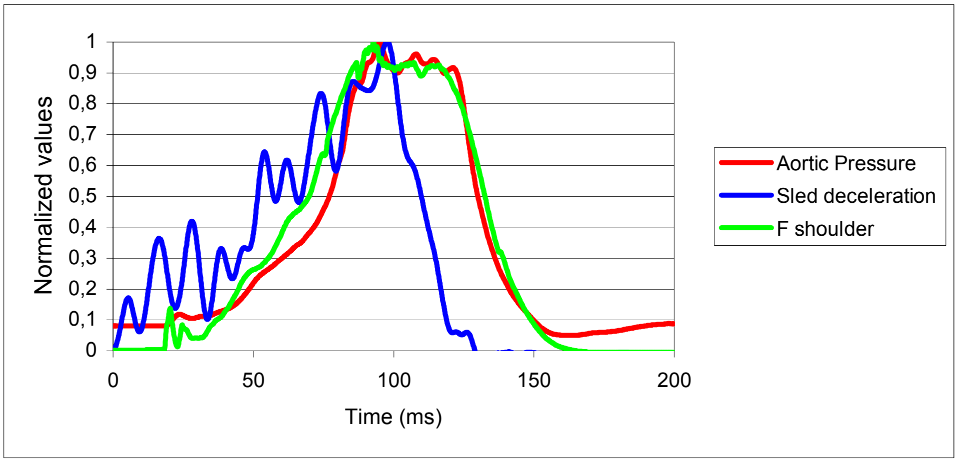

Figure 8: Comparison of the aortic pressure, the F shoulder and the sled deceleration.

Results collected during the autopsy

The autopsy allows the quality of the revascularization to be assessed. First, black tattooed areas are visible on the skin (Figure 9). Secondly, the observation of the inner organs allows a detailed assessment of the injection efficiency. Figures 10-15 illustrate the observable effects of the Indian ink injection.

(Contact author for picture)

Figure 9: Black tattoo visible on the skin.

Stomach wall:

(Contact author for picture)

Figure 10: Detailed view of the stomach wall.

Figure 10 shows the injection of very thin arteries inside the stomach wall. The many black tattoos visible on the Figure 11 mean a good injection of the liver. Nevertheless, this is not always possible to obtain such a result despite a good injection of the whole body. Figure 12 shows the injection of a rib visible after scraping out. The Figure 13 shows many injected arteries reaching the ileum through the mesentery. The dissection on the Figure 14 shows the mesenteric arteries feeding the ileum. An accurate observation of the Figure 15 allows the state of the injection to be assessed. Indeed, the extremities of some very small arteries are partially injected, the proximal extremities being colored in black and the distal extremities being colored in pink.

The liver:

(Contact author for picture)

Figure 11: Right lobe of the liver.

The ribs:

(Contact author for picture)

Figure 12: Injection of a rib visible after scraping out.

The ileum:

(Contact author for picture)

Figure 13: Injection of the ileum.

The mesentery:

(Contact author for picture)

Figure 14: Dissection of the mesentery showing the injected arteries.

The pericardia:

(Contact author for picture)

Figure 15: Detailed view of the pericardia.

Figures 16 and 17 illustrate examples of injuries detected as a result of the Indian ink injection. Figure 16 shows an incised hematoma of the insertion of the fourth duodenum. The initial observation noted a black tattoo inside the posterior wall of the peritoneal cavity close to the insertion of the fourth duodenum. An incision was carried out in order to check the infiltration of the tissues. This type of injury could not be detected without the use of Indian ink. The black tattoo of the anterior wall of the caecum (Figure 17) allows the abrasion to be easily identified as soon as the abdomen is opened. Moreover, the area and the edges of the injury can be precisely described because of the Indian ink injection.

(Contact author for picture)

Figure 16: Hematoma of the insertion of the fourth duodenum.

(Contact author for picture)

Figure 17: Anterior wall of the caecum.

CONCLUSIONS

First, the assessment of the device and the methodology demonstrates that the injection of the whole body is possible despite the common idea that the vessels are filled with coagulated blood after death. Nevertheless, it is necessary to keep in mind that the injection concerns the arterial system only, the liver being the most difficult organ to inject homogenously. Consequently, when the behaviour of the liver is a major item of the test, a porto caval circulation must be added.

Secondly, the arterial pressure obtained during the test is practically physiological, close to the diastolic pressure. So, the behaviour of the arteries and, consequently, the behaviour of the organs during a crash-test are closer to the behaviour of the arteries and organs of a living subject. It has to be noted that, in the case of removal of a part of the PMHS during the preparation (lower limb amputation), the severed arteries must be ligatured.

Thirdly, the use of Indian ink as a component of the injected liquid allows some specific injuries to be identified during the autopsy. In the absence of Indian ink injection, the detection of these types of injuries is practically impossible. In conclusion, it can be assessed that the use of Indian ink makes the injuries report more exhaustive.

Fourthly, the fixing propriety of the alcohol seems to be satisfactory for the whole body except for the brain.

Finally, the functioning corresponds to the specification of the device providing an arterial pressure close to the physiological pressure, stable and without gap during the sled acceleration.

ACKNOWLEDGEMENTS

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DISCUSSION

PAPER: ***Arterial Pressurization of the Cadaver Using a Specially Designed Device: Remote Revascularization Dynamic Device (R2D2)***

PRESENTER: ***Pascal Potier and Guy Vallancien, Experimental Pathology Laboratory and Biomechanical Experimentation Department, CEESAR, France***

QUESTION: *Richard Kent, University of Virginia*
Do you do anything before you inject the fluid to prepare the cadaver because presumably there's blood throughout that system? And so, what happens to the blood that's in there? Where does that go to get this India ink throughout the whole system like that?

ANSWER: When the cadaver stays for a long time on the back, the biological liquid moves down in the body, in this case, toward the back. The arterial blood goes to the venous system and consequently, the arterial system is practically empty. When the arterial system is filled with the injecting liquid, the remaining blood is pushed into the venous system.

Q: Okay. So, it's just natural pulling.

A: To obtain a good pressure during the test, after having connected the tube, a very short first injection is carried out to get the arterial system rid of air. A few minutes before the test, there is another injection during few seconds in order to pre-fill the arteries, the second aim being to check the efficiency of the injection. This is possible because the subject is instrumented allowing leakages to be observed at the level of the incisions. If there is not any incision, it can be useful to make a specific one to check the efficiency of the injection before the test.

Q: Okay. Thanks.

Q: *Stephan Duma, Virginia Tech*
Along the lines of what Rich was asking, so just to make sure I have this straight in my mind: You have some initial prep before you turn the ink solution on.

A: Yeah.

Q: Thirty seconds prior to test, you turn this solution on.

A: Yeah.

Q: Before that, you also add some solution to bring the pressure up. What pressure are you going for? Is that 15 mm?

A: The scheduled pressure? You want to know how we schedule the pressure of the air in the device?

Q: Just the fluid. The initial fluid. You go to 15 mm mercury and then you turn the ink on 30 seconds prior to the test.

A: No. We start the injection about 30 seconds before the test. So during all this time, we are filling the subject, all the arterial system, particularly the aorta. It's because of the size of the aorta that it's necessary to start few seconds before the test. That's why I do a small injection a few minutes before the test in order to pre-fill the aorta. You see? Generally, we use 3 liters of liquid. Not all the liquid. I said that the range of pressure is between the diastolic and the systolic pressure because it's impossible to schedule exactly the pressure that we will obtain. So, in our example, it's a little too low. It's close to diastolic pressure. It happened that we obtained a systolic pressure close to the maximum. We are not able to schedule exactly.

Q: Okay, but the total fluid is between 3 and 4 liters, what you'll use?

A: Maximum 4 liters. But generally, we have carried out tests to evaluate the volume of liquid to be used. About 1 liter is injected before the test, between 2 and 3 liters during and after the test, sometimes more, depending on the time to have access to the sled because of the safety rules. It can't be more than 4 liters because, at this time, the device is auto-static, meaning that no more liquid and no air can be injected.

Q: Okay. Thank you.

Q: *Hans Lia, University of Fleur, Belgium*
Did you look at the brain tissue or more specific to the cerebral vasculature-- the cerebral bridging veins when doing the autopsy?

A: You are meaning brain tissue?

Q: Well, the bridging vein on the surface of the brain. Did you look at them when doing the autopsy?

A: I talked about the brain with the formaldehyde, but we are not working on the brain.

Q: So you don't look at them?

A: So, we don't look at the brain because we are not working on the brain.

Q: But imagine, could you use your system for evaluating cerebral bridging vein rupture causing acute cerebral?

A: I can't say for this example. Generally, it's necessary to test, but we have used this technique before for the brain arterial system. A few years ago, we had been working on the brain, on the head and consequently on the brain, and that's why I said that formaldehyde is better to fix the brain tissues. So, I think alcohol is not correct for the brain, but it's acceptable for the body.

Q: But, could this ink demonstrate venal failure and not only arterial failure?

A: Arterial.

Q: Only arterial.

A: It's arterial. The technique described is validated for arterial system only.

Q: *Erik Takhounts, NHTSA*
I have a question, Pascal. With regard to the viscosity of the dye, how did you make sure that the viscosity of the dye actually matched the viscosity of the blood and what is the blood stage or let's say condition that you used for that to match? You know what I mean? What is the cholesterol level?

A: You are talking about viscosity?

Q: Yes, viscosity.

A: And the preparation.

Q: Right.

A: Of the mixture? There is 1 liter of Indian ink and 4 liters of alcohol. That's the preparation, and the viscosity is not the viscosity of the blood. That's sure. Initially, the choice of Indian ink was linked to the size of the carbon particles contained into the Indian ink. The size of these particles was close to the size of the blood cells. The initial choice of the Indian was because of the size particle and not because of the viscosity.

Q: Alright. The reason I'm asking is that viscosity is a very important component to match, especially in a dynamic event, if you try to simulate the blood flow within the vessel, and that's probably one of the first parameters I would look for in order to simulate that.

A: Of course, it's not perfect. You see, the first aim is to fill. I think it's better than working with empty vessels. So, the second aim is to identify the injuries. I think it's better to fill the arterial system even if it's only the arterial system, but it's not perfect.

Q: Okay. Thank you.