The Perfusing Cadaver Model and Head-Up CPR

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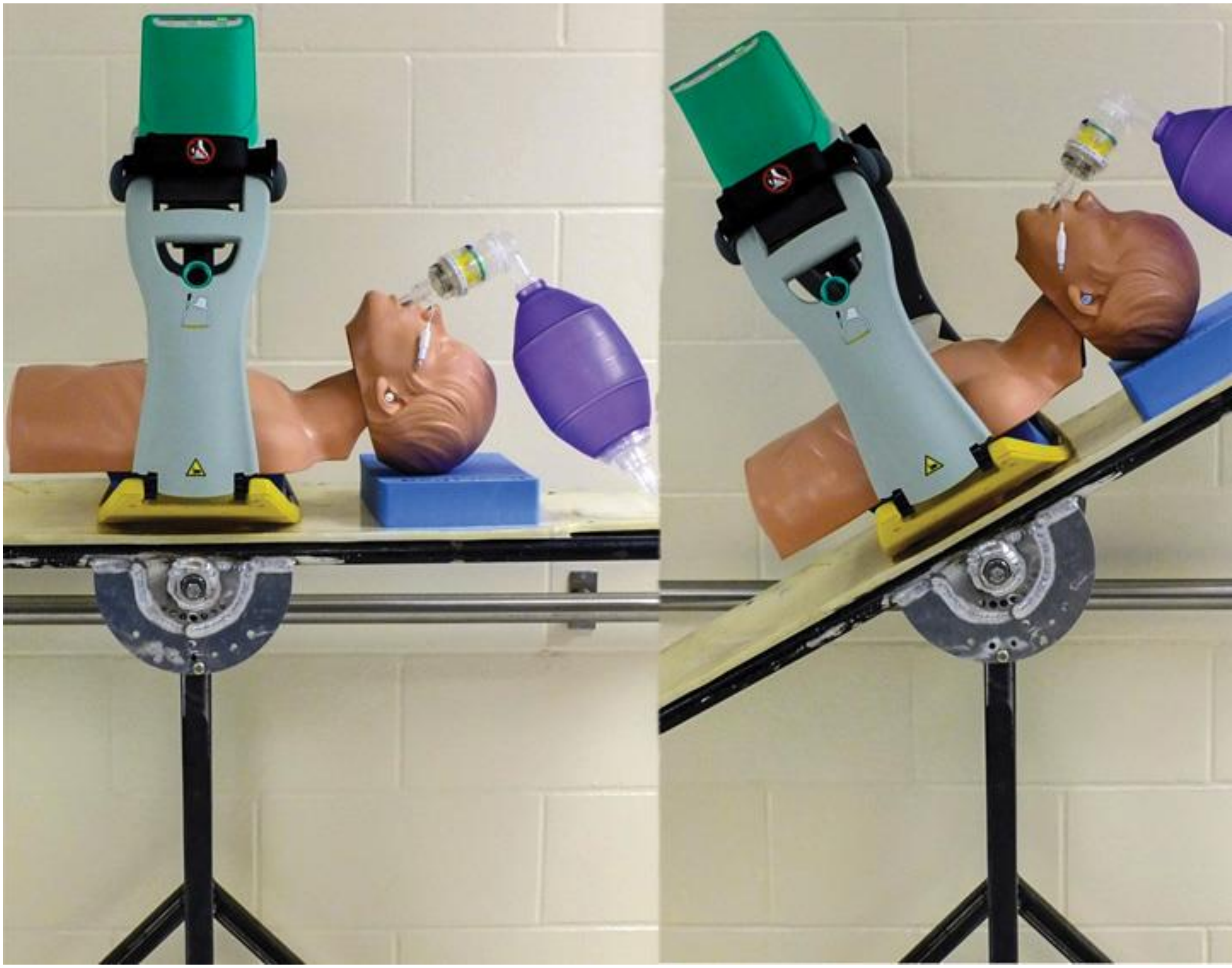

What do the high-rises in Seoul, South Korea, have to do with the hemodynamics of CPR? You'll be amazed. Seoul has a very dense population and many of their apartment buildings are 40 stories or more, with very small elevators that have always presented challenges to EMS crews. In fact, the elevators are so small that when a cardiac arrest occurs, the patient can't be loaded and transported in a flat position. Instead, the patient must be put in the elevator diagonally with the head up or down.

On a visit to the Twin Cities, Sang Do Shin, a physician from Seoul, told Keith Lurie, MD—a highly respected cardiac arrest researcher and inventor of the active compression-decompression CPR (ACD-CPR) device ResQPUMP and the impedance threshold device (ITD) ResQPOD—that he thought the best position for the patient's head while taking the elevator to ground floor should be down. Lurie immediately replied that the patient's head should be up and that he would prove it.

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Figure 1: Tilt table angles and devices tested in porcine CPR positioning experiment

Although Lurie is a lifelong, dedicated researcher who has been working on the hemodynamics of CPR nearly his entire career, he'd never worked on this specific question. In the lab, he put pigs into v fib and then treated them on a tilt table with a mechanical chest compression device performing CPR and with an ITD. Coronary and cerebral perfusion pressures were measured along with blood flow in the heart and brain.

The measurements were recorded with the pigs positioned at 30 degrees head down, supine and 30 degrees head up. (See Figure 1, above.) The results were remarkably consistent. (See Figure 2 and Figure 3, below.) All four parameters were significantly improved with the pigs' heads up at 30 degrees. More striking, the pigs started to gasp spontaneously when in the head-up position.

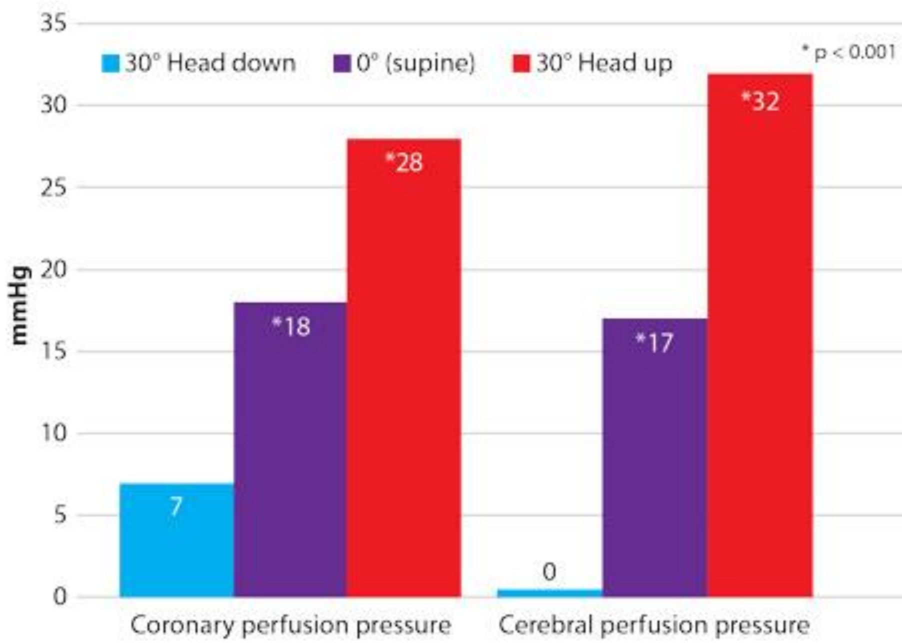

Figure 2: Study results of perfusion pressures[1]

Although it was clear that the pigs did better with their head up, it wasn't clear what the ideal elevation should be. Therefore, the same parameters were measured at 0, 20, 30, 40 and 50 degrees. All parameters improved linearly as the elevation increased. (See Figure 4, below.) Thirty degrees appeared to have the best balance between decreased intracranial pressure (ICP), increased cerebral flow and aortic pressure.[1]

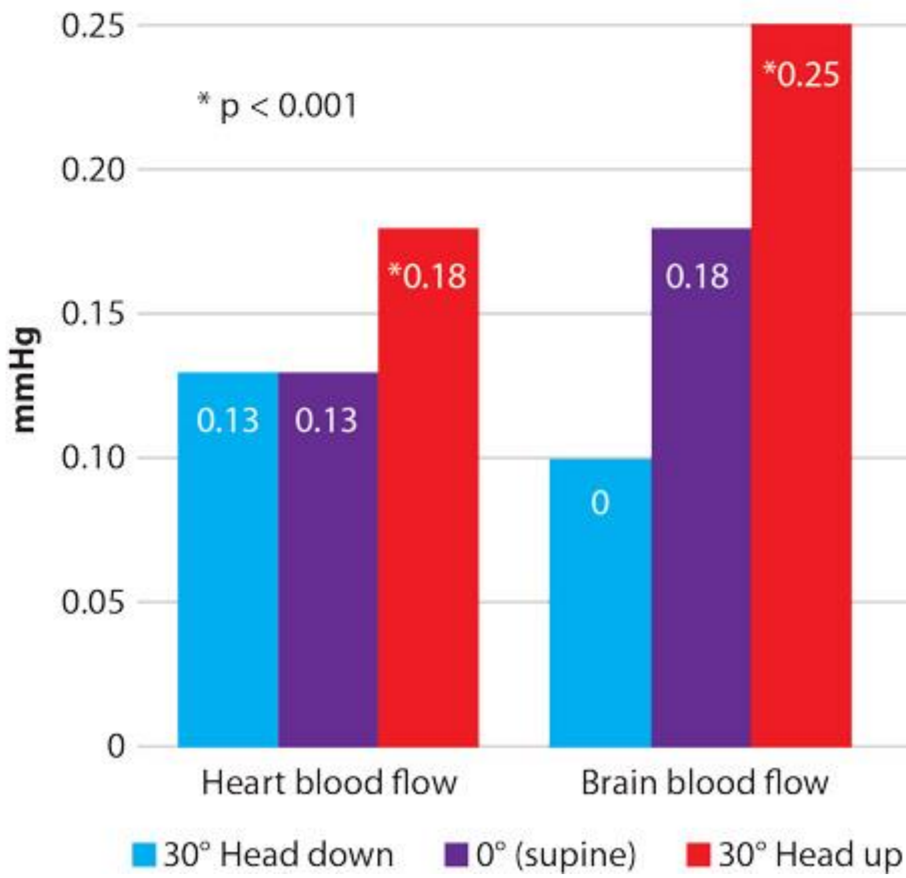

Figure 3: Study results of vital organ blood flow[1]

Now Lurie faced the challenge of proving this in humans.

Hemodynamic trials are extremely cumbersome and difficult to study in cardiac arrest—especially prehospital trials.

One of the only times this was attempted was in a study examining standard CPR with and without the use of the ITD.[2,3] In that study, over 210 patients were treated with CPR over the course of a year, but researchers were only able to look at 23 patients with invasive hemodynamic monitoring.

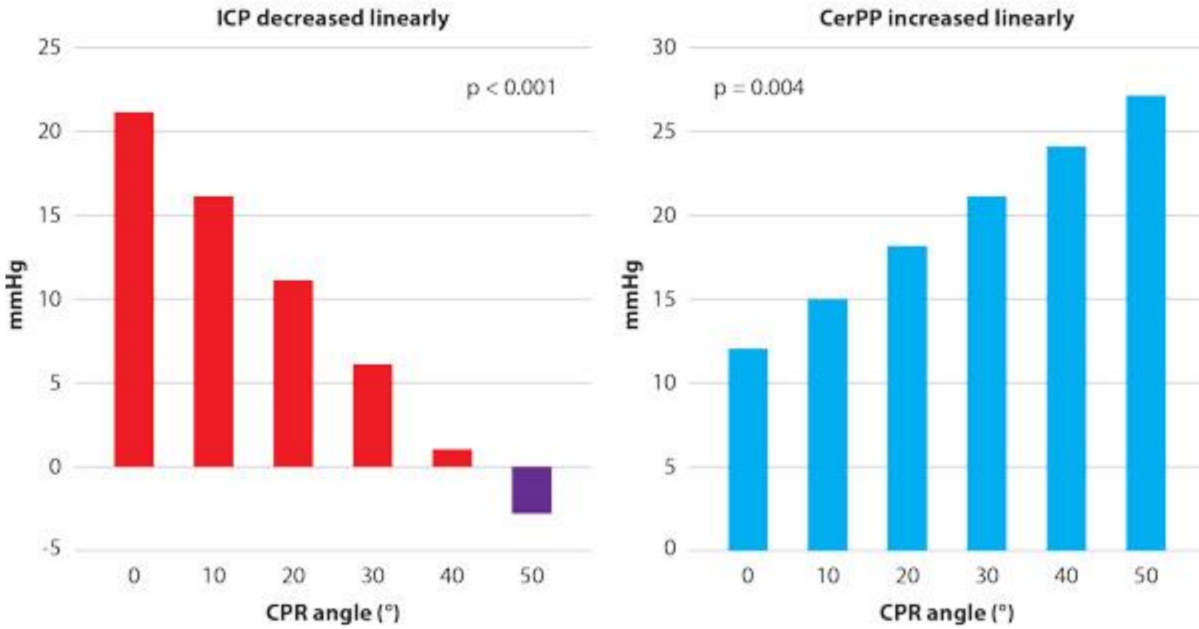

Figure 4: Study results showing the difference of intracranial pressure (ICP) and cerebral perfusion pressure (CerPP) at different angles of head-up CPR[1]

The data collection was almost heroic because it was logistically difficult and expensive to have a doctor chase an ambulance, insert a central catheter, and set up a pressure transducer during all the chaos of an out-of-hospital cardiac arrest. These efforts were worth it as the ITD was shown to double systolic blood pressure.

The Human Challenge

Recently, my group faced similar challenges when we attempted to monitor intraosseous pressure during prehospital cardiac arrest. At the same time Lurie was trying to figure out how he could prove that head-up CPR was advantageous in humans, we were trying to figure out a way we could study the effect of a msupraglottic airway (SGA) on cerebral flow in humans. We had previously shown—in pigs in cardiac arrest—that when the cuff of an SGA is inflated, the carotid artery is compressed.[4] It's reasonable to think this compression results in decreased cerebral perfusion even though that wasn't directly shown in the pig study; the problem is that pigs have a very different airway than humans.

We tried ultrasound, but that didn't work well in CPR; there was too much artifact and it was difficult to place a probe during cardiac arrest. Central lines were cumbersome and the number of monitoring sites we needed was difficult, if not impossible, to place with ongoing CPR.

We thought it might be possible to use a perfused whole cadaver, but that had never been done before. Only individual organs of a cadaver have been perfused in the past. Neurosurgeons have perfused brains to test vascular repair techniques, such as coiling. And, cardiovascular surgeons have used perfusing hearts to test valve replacement techniques and various types of equipment, and renal transplant surgeons have used perfusing kidneys to practice transplant techniques.

Perfused whole cadavers had been used before in education—notably by the Medical Education Research Institute (MERI) in Memphis, Tenn. MERI uses the arterial side or the venous side of a perfused cadaver to teach and study various techniques. They use a Biomedicus pump to move saline through a cadaver with the placement of input and output catheters.

I observed this innovative process three years ago when I traveled to the MERI lab to learn about a new hemostasis device: the iTClamp. We used a cadaver that was perfused on the arterial side to practice placing the clamp on a bleeding wound. I used the opportunity to investigate whether we could use the technique to look at the SGA question.

The MERI team felt that only the arterial or the venous side could be used in a perfusing cadaver model because of the lack of a functioning capillary beds. We were left at a loss because we couldn't figure out how to put in an output catheter distal to the carotid artery, because the vessels are very small and tortuous in that area.

When Lurie contacted us to see if we had made any progress, we discovered we were working on the same thing. Lurie was collaborating with Joe Holley, MD, FACEP, the medical director of the Memphis Fire Department and the assistant medical director of the Hospital Wing Helicopter service in Arkansas.

Holley had attempted perfusing cadavers, but he had limited success due to the fact that he was using frozen cadavers. Freezing can damage the vascular structure, especially the capillary bed. We felt that if we could successfully perfuse a cadaver, we would be able to employ very sophisticated pressure monitoring at multiple sites in the model.

Besides creating a new research model, maybe we could answer both questions: Does head-up CPR work as well in humans as it does in animals, and what's the effect of SGA cuff inflation on cerebral flow?

None of this had ever been done before in a cardiac arrest trial. We decided we would use only fresh cadavers. Besides Lurie, Holley and myself, there were many others who actively participated in the research. They include Johanna Moore, MD and Laura Klein, MD, at Hennepin County Medical Center in Minneapolis; Charles Lick, MD, of Allina Health EMS in St. Paul, Minn.; Paul Pepe, MD, MPH, of the University of Southwestern Texas in Dallas; Jim Logan, BS, EMT-P, of the Memphis Fire Department.; and Nicholas Segal, MD, PhD, of the University of Minnesota.

How We Accomplished It

Physicians don't talk to morticians often—I think for obvious reasons. But nobody knows more about cadavers than morticians. It turns out that for decades, morticians have been routinely infusing embalming fluid on the arterial side (carotid artery) and taking it off the venous side (jugular vein). Before they begin the embalming process, they use products to dissolve clots and transfuse the embalming fluid under pressure. They deal mostly with fresh cadavers, which isn't always the case in an anatomy lab.

The University of Minnesota has the third largest bequeathment program in the nation. Every year, over 600 people donate their bodies to the university. Every part of the bodies is used for education and research by physicians from all over the world.

The bodies will typically be in the lab for a year or more, and the five morticians who staff the program are dedicated to the proposition that every cell of every body be preserved over that entire period. We couldn't have accomplished this work without the generosity of the donors and the full cooperation of the Department of Mortuary Science.

Our methodology involved fresh cadavers, typically 24–72 hours old. The cadavers were infused with a product from Dodge Chemical Company called Metaflow. According to the product's documentation, Metaflow "lubricates blood cells, while dissolving clots ... It inhibits agglutination and precipitation of blood clots in aged arteries."

The cadavers were then perfused with 15 Lof saline, with 5 L left in the intravascular space. Milar pressure catheters were placed in the right atrium, the aorta and the left coronary artery. Milar catheters are solid-state catheters that have the advantage of being self-zeroing, so that any elevation of the catheter won't affect the reading. This is important because the catheters were going to be elevated along with the torso during this experiment.

An airway pressure catheter was also placed, as well as an intracranial pressure bolt. The cadaver was then intubated and ventilated. Other than in an isolated case report, one can immediately appreciate that this type of extensive physiologic monitoring could never be done in human cardiac arrest trials.

CPR was performed using: 1) standard CPR with the torso elevated to 30 degrees at the waist (head up); 2) LUCAS mechanical chest compression device/ITD with and without head up; 3) Autopulse automated chest compression system/ITD with and without head up; and 4) ACD-CPR/ITD with and without head up.

Cerebral perfusion pressure was calculated by subtracting the ICP from mean aortic pressure, and the coronary perfusion pressure was calculated by subtracting the right atrial pressure from the aortic pressure.

While the testing of head-up CPR and the effect of SGA cuff inflation on cerebral flow were the main focus of the research, other experiments were also done on the cadavers, such as using fluoroscopy to evaluate the effect of cuff inflation on carotid flow, the effect of a 10-cm ITD vs. a 16-cm ITD on intrathoracic chest pressure, and assessing the amount of artifact generated by CPR on bispectral index monitoring (BIS). While all of these are interesting topics, they're beyond the scope of this article.

The Results

So far, we've worked on 11 cadavers. In all cases, a lower ICP and a higher cerebral perfusion pressure were noted with the head, regardless of the type of CPR being performed, except for standard CPR.5 (See Figure 5, below.) It was also noted that both the ICP lowered and the cerebral perfusion pressure increased with ACD-CPR with an ITD vs. standard CPR.

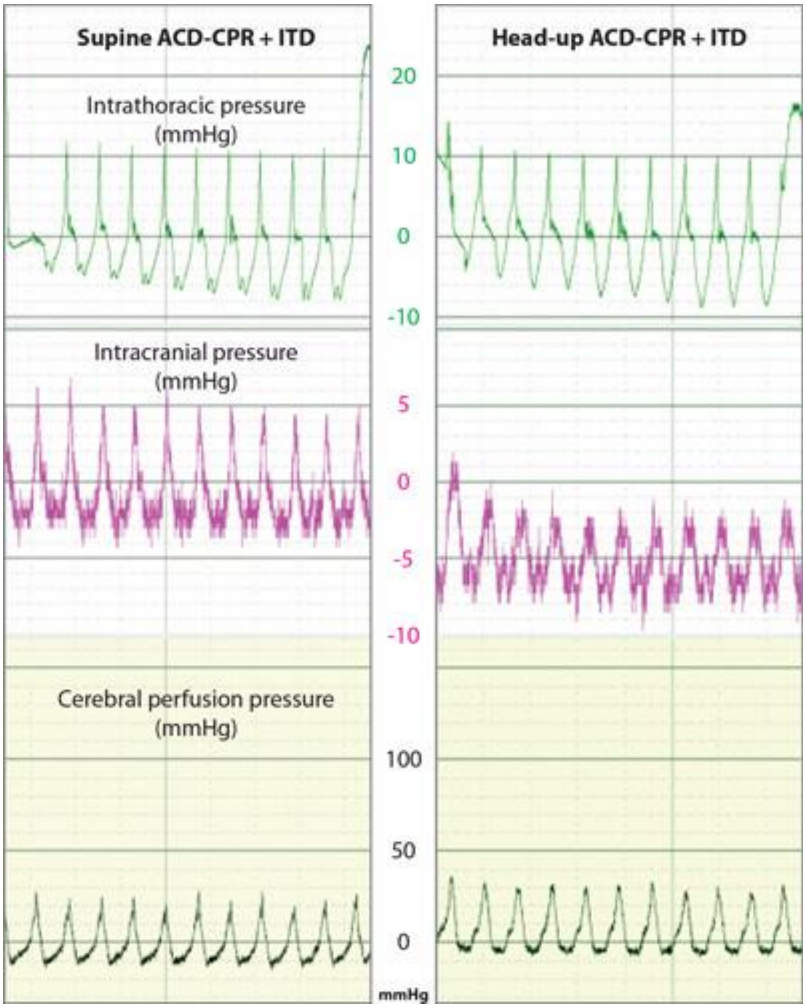

Figure 5: Study results showing lower pressure in the head and thorax, and higher cerebral perfusion pressure in head-up vs. supine CPR[5]

We used fluoroscopy to evaluate the amount of compression that SGAs place on the carotid artery. It appears that some compression does occur, but the precise effect needs to be better defined in the cadaveric model. In any case, we believe cadaveric fluoroscopy is a feasible technique to evaluate the effect of SGAs on flow.

We reconfirmed another finding that was known from Lurie's pig lab. During the trial, it was quite common for the intrathoracic pressure to dip down to -12 cm during ACD-CPR with an ITD; this routinely caused the 10-cm ITDs to pop off. This reinforced the need to use 16-cm and not the 10-cm ITDs.

There were two findings that came up during the research that we didn't expect. The first was that when the torso is raised, there's a temporary elevation of the aortic pressure that lasts for about a minute. This is probably due to the increase venous drainage from the brain with the concomitant decrease in ICP, but may be also partially the result of the drainage of the lung. The latter may result in less resistance to flow across the pulmonary vascular bed and may be one of the reasons that congestive heart failure patients prefer to sit up.

The second, and even more fascinating, finding was that the heart doesn't appear to be where we expected it to be. It was 3–4 cm superior and 3–4 cm to the left of where it was traditionally thought to be. This finding is currently being further researched by one of the investigators using X-ray. If the finding holds up, it's unclear what this will mean to CPR with regard to hand placement and plunger placement when mechanized CPR is being employed.

Conclusion

All of the parameters we evaluated in the lab are qualitatively very similar to those observed in pigs in v fib undergoing CPR in the perfused cadaver model.

This model may have significant potential for further elucidating the physiology of CPR and may be able to be used in the assessment process of new CPR techniques and devices. Further, the model may expedite the translation of CPR science from animals to patients and, hopefully, reduce the need for animal studies.

There remain many unanswered questions about the cadaver model. Included is whether there can be arterial-to-venous flow, something we haven't yet definitively shown.

As noted earlier, it appears that head-up CPR decreases ICP, and increases cerebral and probably coronary flow. It may also have a temporary positive affect on aortic flow. We need further work on the effect of SGA cuff inflation on flow, but we may now have a way to study it.

We don't know what effect, if any, the use of saline rather than blood has on hemodynamics due to the different viscosities. Similarly, we don't know what effect the decrease in elasticity of the cadaverial arterial vessels has on hemodynamics.

The next step is to test the head-up CPR technique in the field. We can do this with the added assurance that the perfusing cadaver model gives us—that it's OK to trial on living human beings.

Evidence-based emergency medicine sometimes comes down to a simple question, like a question about how arrested patients should be brought down in a high-rise elevator in Seoul. Answering this seemingly simple question may end up having a major effect on how we'll be doing CPR in the future. How many other simple questions are lurking out there just waiting to be answered?

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