Percutaneous Valved Stent Implantation Above the Coronary Ostia
– A New Transitional Treatment for Acute Aortic Valve Rupture –
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Background: In recent years, some experimental and clinical studies on transcatheter aortic valve implantation (TAVI) have been conducted. TAVI is indicated in patients with calcified pure or predominant aortic stenosis. The risk of this technique is still high. Aortic valved stent implantation above the coronary ostia might avoid blocking the coronary ostia.

Methods and Results: Twenty healthy dogs were selected to establish a canine model of acute aortic valve rupture. The dogs were randomly divided into 2 groups: the rupture model group without any treatment and the valved stent group with percutaneous valved stent implantation above the coronary ostia. The 2 groups of animals were followed up for 3 months. Echocardiography and other tests were performed to assess aortic regurgitation and ventricular function. Acute aortic valve rupture models were successfully established in 16 of 20 dogs. In the rupture model group, the mean aortic regurgitation was 6.8±1.9 ml/s; only 3 of 8 animals survived for 3 months. In the valved stent group, the mean aortic regurgitation was 7.0±2.1 ml/s; valved stents were successfully implanted in 8 animals. Instant post-implantation anatomy showed that the stents were located appropriately. Seven dogs survived for 3 months.

Conclusions: Percutaneous valved stent implantation above the coronary ostia is feasible and effective as a transitional treatment for acute aortic valve rupture. (Circ J 2011; 75: 1872–1877)

Key Words: Aortic valve; Catheter; Coronary ostia; Percutaneous; Porcine

Explosive weapons that are a mainstay of modern warfare can inflict serious injuries by high-energy fragments and shock waves generated by the explosion. The incidence of shock wave-mediated blast injury of the chest has significantly increased, resulting in an increased incidence (up to 9%) of acute cardiac valve rupture. Among them, the incidence of aortic valve injury is the highest, and mainly manifests as acute aortic regurgitation that can be life threatening in severe cases. Generally, the conventional treatment is artificial aortic valve replacement by emergency thoracotomy. However, during warfare, this treatment is very rarely available. On the other hand, the complexity of the injuries in these patients decreases their chances of survival if surgery is delayed by transfer to a hospital. In recent years, some experimental and clinical studies on transcatheter aortic valve implantation (TAVI) have been conducted. TAVI is indicated in patients with calcified pure or predominant aortic stenosis because of the high risk of operation in older patients. It is unlikely that it will be used in patients with pure aortic regurgitation. Under current conditions, the risk of this technique is still high. The 30-day mortality rate reaches 10%, which is mainly due to coronary ostia blockage by the aortic valve stent. Once the coronary ostia are blocked, sudden death might occur. We hypothesized that aortic valved stent implantation above the coronary ostia might avoid blocking of the coronary ostia, and therefore theoretically decrease the mortality rate. However, it might also affect coronary blood flow. No report has been published on such an approach.

In the present study, we established a canine model of acute aortic valve rupture. The experimental animals were randomly divided into a rupture group and a valved stent group with percutaneous valved stent implantation above the coronary ostia. Both groups were followed for up to 3 months to observe the effectiveness of the treatment and to investig-
igate the feasibility of percutaneous valved stent implantation above the coronary ostia as an ideal war emergency transitional treatment for acute aortic valve rupture.

**Methods**

**Valved Stent Construction**

The valved stent was constructed using an artificial valve and a conduit-shaped stent. The artificial valve was fixed inside the conduit-shaped stent, which was sutured with a 5–0 polypropylene thread (Figures 1A and 1B, which show a completed valved stent). The valved stent was preserved in 60% ethanol, sterilized with 75% ethanol for 12 h, and washed 3 times with normal saline prior to placement. The valved stent was crimped by hand and then loaded into a 14-French sheath.

**Animals**

Twenty (8 male and 12 female) healthy dogs weighing an average of 17.7±3.1 kg were used. No abnormalities were found in a preoperative electrocardiogram, thoracic radiographs, and color echocardiography examinations. Animals were fasted and water-deprived for 8 h before surgery. Anesthesia was initiated by intramuscular injection of ketamine (10 mg/kg body weight), followed by intravenous injection of 10 ml of 2.5% pentobarbital sodium. Hair was removed from the precordial region and the inner sides of the extremities. All animals received care in compliance with the Guide for the Care and Use of Laboratory Animals published in 1988 by The National Academies.

**Establishment of a Canine Model of Acute Aortic Valve Rupture and Experimental Grouping**

The bilateral groin area was routinely sterilized and the left femoral artery was cannulated with a 6F leakage-proof vascular sheath. A small orifice was cut at the lateral edge of the pigtail catheter (Cordis, Johnson and Johnson, New Brunswick City, NJ, USA), which was then advanced within the aortic sinus and pressed against the aortic valve leaflets under the guidance of ultrasound. A hard wire was advanced to the small orifice of the pigtail catheter to pierce the aortic valve leaflets under the guidance of ultrasound (Figure 2A). The wire was retained and the pigtail catheter was retracted. A guide catheter was advanced to the perforation in the valve leaflet (Figure 2B). After the removal of the hard wire a Balance Middle Weight (BMW) universal guide wire (Guidant, Santa Clara, CA, USA) was inserted along the guiding catheter to reach the valve leaflet perforation. The balloon was inflated using a pressure of 10 atmospheres (Figure 2C). The balloon, catheter and guide wire were retracted. Angiography revealed obvious reflux through the valve leaflet perforation (Figure 2D). Color Doppler echocardiogram was immediately used to evaluate the aortic valve regurgitation and the left ventricular ejection fraction (LVEF). After the canine model of acute aortic valve rupture was established, the animals were randomly divided into 2 groups (Table). One was the model group, in which the left femoral artery sheath was retracted and the left femoral artery was compressed to stanch bleeding. The other group was the valve stent implantation group, in which the left femoral artery sheath was retained and the stent-valve implantation was performed above the coronary artery opening.

**Valved Stent Implantation and Postoperative Treatment**

After the skin was sterilized in the inguinal region, an incision was made through the right inguinal skin and subcutaneous tissue, and the right femoral artery was subsequently exposed and punctured with a 7-French leak-proof sheath. Heparin (1.5 mg/kg) was introduced via the sheath. A 6-French pigtail catheter was introduced through the right femoral artery sheath, and imaging of the left ventricle was performed using a digital subtraction angiography (DSA) apparatus (Siemens, Munich, Germany; Figure 3A). The aortic valve and coronary artery were identified, and their positions were marked according to the imaging results. After the radius of the ascending aorta at the top of the coronary artery was measured, a valve stent of the appropriate size was selected and loaded into a 14-French sheath. A stent size larger than the measured ascending aorta was selected to avoid shifting. The delivery route was established by introducing a steel guide wire into the left ventricle via the pigtail catheter. After the pigtail catheter was removed, a 14-French delivery sheath with an expandable sub was deployed into the ascending
aorta at the top of the coronary artery via a guide wire (Shanghai Shape-Memory Alloys Material, Shanghai, China; Figure 3B). The expandable stub and steel guide wire were then removed and the 14-French sheath carrying the valve stent was connected with the delivery sheath. The stent was inserted into the delivery sheath positioned under the DSA apparatus to the previously marked position of the ascending aorta (Figure 3C). After it was confirmed that the stent had been delivered to the optimal position, the delivery sheath was retracted to release the stent (Figures 3D and 3E). The delivery sheath was subsequently removed and the right femoral artery was sutured. Imaging of the artificial valve was

![Figure 2](image-url)

**Figure 2.** Procedure for establishing the canine model of acute aortic rupture. (A) In the left anterior oblique view, a hardened wire perforated the aortic cusp under the guidance of echocardiography. (B) In the right anterior oblique view, the guide catheter passed the valve perforation under the guidance of the wire. (C) A balloon was located in the valve perforation and expanded with 10 atm pressure. (D) Obvious regurgitation through the perforation was clearly evident on angiography examination.

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LVEF, left ventricle ejection fraction; LVEDV, left ventricular end-diastolic volume; AVR, aortic valve regurgitation. *Compared with model group P>0.05. **Compared with model group P<0.05. †Compared with immediate postoperative in valved stent group P<0.05.
Valve Stent Implantation Above Coronary Ostia

performed by deploying a pigtail catheter via the left femoral artery (Figure 3F). The catheter and right femoral artery sheath were removed. Iohexol, up to 50 ml, was used as the contrast dye in the procedure. All dogs received postoperative intramuscular injections of penicillin (80,000,000 U) and subcutaneous injections of heparin (2,500 IU) for 3 days. Oral aspirin (3 mg/kg body weight) was given for 30 days.

Immediate Postoperative Assessment of Treatment
A color Doppler echocardiography examination was performed immediately after the stent implantation to assess the function of the artificial valve, LVEF and left ventricular (LV) end-diastolic volume. One dog in each group was randomly selected and killed for anatomic assessment of the aortic valve and the implanted position of the valved stent.

Hemodynamic and Imaging Assessment After 3 Months
All surviving dogs in the 2 groups were examined with color Doppler echocardiography, and LV and aortic DSA. The dogs in the valved stent group underwent prosthetic valve angiography and 64-slice computed tomography scan to assess LV function and artificial valve hemodynamics.

Statistical Analysis
All statistical analyses were performed using commercially available software (SPSS version 15.0 for Windows; SPSS, Inc, Chicago, IL, USA). A P-value <0.05 was considered statistically significant. Normally distributed data are reported as mean±standard deviation. Changes in LVEF, LV end-diastolic volume and aortic valve regurgitation were compared using analysis of variance (ANOVA). Moreover, Wilcoxon signed-rank test was performed to compare the difference between the 2 time points postoperation due to non-normally data.

Results

Surgical Outcome
Among the 20 dogs, acute aortic valve rupture was not established in 4 dogs because the guide wire perforated the myocardium and led to cardiac tamponade. The model establishment was successful in the other 16 dogs. These dogs were randomly divided into 2 groups. In the rupture model group, instant aortic valve regurgitation by intraoperative echocardiography was 6.8±1.9 ml/s (range, 4–10 ml/s), 1 dog was dissected immediately after the surgery, 4 dogs died on days 7, 12, 30 and 38, and only 3 dogs survived for 3 months weighing an average of 21.4±3.7 kg (Table). In the valved stent group, instant aortic valve regurgitation by intraoperative echocardiography was 7.0±2.1 ml/s (range, 4–11 ml/s), and implantation was successful in all 8 dogs. One dog was killed immediately after the implantation for anatomic assessment; the other 7 dogs survived for more than 3 months weighing an average of 25.6±2.9 kg (Table).

Immediate Postoperative Assessment of Treatment
In the rupture group, obvious aortic regurgitation and increased heart rates were detected by instant angiography. The anatomic study showed tears and perforations on the aortic cusp without the coronary ostium. The aortic valve rupture model was successfully established. In the valved stent group, aortic regurgitation was more significantly reduced than that before the stent implantation, as shown by angiography and echocardiography.

Figure 3. The valved stent implantation process. (A) Angiography in the left ventricle. (B) The 14F delivery sheath was introduced by the wire to the ascending aorta. (C) The valved stent was inserted into the ascending aorta. (D,E) The stent was released. (F) Angiography on the prosthetic valve.
ZONG GJ et al.

examinations. Anatomic study indicated a stent indentation above the coronary ostia (Figure 4A), tears on the left aortic cusp (Figure 4B), and the ideal position of the valved stent.

Hemodynamic and Imaging Assessment After 3 Months

In the rupture model group, only 3 dogs survived for 3 months, in which the heart was enlarged with significant aortic regurgitation as indicated by angiography. The LVEF was $38.1 \pm 3.0\%$ (range, 35.4–41.3\%), LV end-diastolic volume was $39.1 \pm 4.8$ ml (range, 34.1–43.7 ml) and aortic regurgitation was $11.2 \pm 3.6$ ml/s (range, 7–14 ml/s) on echocardiography (Table). In the valved stent group, all animals survived for 3 months. Angiography showed that the function of the prosthetic valve was normal, and opening and closing well with mild to moderate aortic regurgitation. The position of the stent was ideal. Echocardiography indicated that the LVEF was $51.6 \pm 6.3\%$ (range, 42.5–58.5\%), LV end-diastolic volume was $31.2 \pm 3.4$ ml (range, 28.3–34.5 ml), and aortic regurgitation was $3.1 \pm 1.2$ ml/s (range, 7–14 ml/s) (Table).

Enhanced 64-slice computed tomography scan showed clear valved stent shadows without any dislocation (Figure 5).

**Discussion**

When the aortic valve is ruptured, aortic regurgitation will occur immediately. If thoracic aortic valve replacement is not performed as soon as possible, mortality is almost always assured. In the present study, only 37.5% of the animals in the rupture model group could survive for 3 months without any treatment. Under warfare conditions, emergency aortic valve replacement by thoracic surgery is very unlikely. Therefore, it is meaningful to investigate a transitioning treatment for acute aortic valve rupture to save victims with this type of injury.

**Feasibility of Percutaneous Aortic Valved Stent Implantation Above the Coronary Ostia**

Percutaneous aortic valve replacement is potentially feasible for the goal of a transitioning treatment, because it causes little damage. However, aortic valved stent implantation is complex. If the location is not ideal, it might obstruct the coronary ostia, causing death. Therefore, this technique has a high risk and a low success rate, which is not suitable for emergency treatment on battlefields. Only the coronary ostia are present in the ascending aorta and there is no major branch within 30 mm above the aortic valve. Therefore, it is ideal for valved stent implantation. In addition, the procedure is simple.

The results of the present study indicate the simplicity of valved stent implantation above the coronary ostia. The stent designed for the experiment was braided with super elastic nickel-titanium alloy wires, which allowed the stent to comply better and to attach to the aortic wall easily. Sewing the valve with a valve ring facilitated prosthetic valve construction. Additionally, the stent was connected with the valve ring so that it was fixed precisely and the valve ring was not easily dislocated. The whole valved stent could be crimped and loaded into a 14F sheath. The path of implantation was similar to that of the occluder delivery for congenital heart defect, which is widely used in clinical practice. This technology has been successfully used in clinical practice for more than 10 years, and is both simple and safe. In the present study, all
animals in the valved stent group were successfully implanted with stents (100% success rate). After a 3 month follow up, no valved stent was dislocated. These observations bolster confidence in the use of the technique in war conditions. Valved implantation above the coronary ostia is feasible and safe for acute aortic valve rupture.

Efficacy of Percutaneous Valved Stent Implantation Above the Coronary Ostia
After the valved stent is implanted above the coronary ostia, the aortic valve and the prosthetic valve open simultaneously during cardiac systole and close simultaneously during cardiac diastole. When the prosthetic valve closes, the pressure gradient between the left ventricle and the space between the aortic valve and prosthetic valve is significantly reduced, thus reducing the aortic regurgitation. In the present study, all animals in the valved stent group survived for 3 months. Both angiography and echocardiography examinations confirmed that regurgitation after stent implantation was significantly less than that prior to the stent implantation. Also, regurgitation was significantly reduced compared with that in the rupture group. No adverse effects due to this stent location problem were noted in this dog for the duration of the study period. These observations are evidence that valved stent implantation above the coronary ostia helps reduce aortic regurgitation, which can significantly delay the deterioration of cardiac function and gain time for further surgical valve replacement. Percutaneous valved stent implantation above the coronary ostia is feasible and effective as a transitional treatment for acute aortic valve rupture.

Disadvantage of Percutaneous Valved Stent Implantation Above the Coronary Ostia
The negative aspect of percutaneous valved stent implantation above the coronary ostia is that the position of an artificial valve is not a physiological location, which might affect coronary blood flow. In physiological conditions, coronary blood flow is supplied during the diastolic period. Theoretically, the coronary ostia are located between the prosthetic and aortic valves. During the diastolic period, both valves are closed so that the coronary blood supply is significantly reduced. Therefore, coronary blood can only be supplied during the systolic period. Presently, cardiac function in the valved stent group was also decreased in varying degrees, which might be related to aortic regurgitation on one hand and reduced coronary blood supply on the other hand. But, all animals survived for 3 months, suggesting that the coronary blood supply is adequate for the physiological need for survival, although it is only supplied during the systolic period. We have only done a preliminary study in this aspect. Further studies are necessary to understand the details of the actual conditions of coronary blood flow.

Study Limitations
At present, there is no report on large animal models of acute aortic rupture because it is relatively difficult to establish. In the present study, we used a guidewire to perforate the aortic valve and expanded it with a balloon to cause aortic rupture. The regurgitation was relatively small. In fact, clinical acute aortic rupture might cause more severe regurgitation and an even more dangerous situation. Second, the valved stent was placed in a non-physiological position. It can potentially affect the LV and systemic hemodynamic parameters. In the present study, assessment of coronary blood flow was not enough. Finally, the small sample size in the present study was also an obvious limitation.

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Disclosures
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