CLINICAL RESEARCH

Development of catheter-based treatment of patent ductus arteriosus: A medium-sized centre experience

Zakhia Saliba a, Issam El-rassi a, b, *, Dina Helou a, Pauline Abou-Jaoudeh a, Ghassan Chehab a, Linda Daou a, Daniele Khater a, Bernard Gerbaka a, Victor Jebara a

a Saint-Joseph university medical school, Naccache boulevard, Beirut, Lebanon
b Hôtel-Dieu de France hospital, Naccache boulevard, Achrafieh, Beirut, Lebanon

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Summary
Background. — Despite the availability of effective devices, percutaneous closure of patent ductus arteriosus (PDA) can be challenging in some situations.
Aim. — To describe our initial experience of percutaneous PDA closure.
Methods. — Between 2001 and 2007, 73 consecutive patients aged 3 months to 70 years underwent transcatheter PDA closure. An Amplatzer duct occluder (ADO) was chosen for ducts greater than 2 mm (n = 50) and a Detachable coil (DC) for smaller ducts (n = 23).
Results. — The diameter of the ducts ranged from 1 to 7.2 (mean 2.9 ± 1.3) mm. The prostheses were implanted successfully in all patients. The complete closure rate reached 98% in the ADO group and 100% in the DC group at 12 months. Four (5.4%) patients showed asymptomatic device protrusion: three patients (5, 6 and 10 kg) into the aortic isthmus and one patient (7 kg) into the pulmonary artery (PA). One patient (7 kg) experienced transient severe bradycardia due to pulmonary air embolism. Another patient (3.3 kg) had a permanent asymptomatic occlusion of the femoral artery. In a third patient (17 kg), the ADO migrated asymptotically into the descending aorta and was discovered 12 months later.

* Corresponding author. Fax: +9611615300 ext 9706.
E-mail address: issam.rassi@gmail.com (I. El-rassi).

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**Conclusion.** — Even during the learning curve, percutaneous PDA closure can give excellent results. Strict adherence to protocols and careful follow-up assessments are mandatory. In small infants, the use of the ADO may lead to obstruction in the aorta or PA, or to device migration. Cautious surveillance for untoward events is essential, especially in small infants with large ducts.

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**MOTS CLÉS**
Canal artériel ;
Amplatzer ;
Coil ;
Complication ;
Migration

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**Résumé**

**Objectifs.** — Cette étude décrit les débuts de notre expérience dans la fermeture percutanée du canal artériel perméable.

**Méthodes.** — Entre 2001 et 2007, 73 patients consécutifs âgés de trois mois à 70 ans, ont eu une fermeture percutanée du canal artériel. Un Amplatzer duct occluder (ADO) a été utilisé pour le canal supérieur à 2 mm et un Coil détachable (DC) pour le canal inférieur à 2 mm.

**Résultats.** — Le diamètre du canal a varié 1 à 7.2 mm (moyenne 2.9 ± 1.3 mm). Un ADO a été utilisé chez 50 patients (68 %), et un DC chez 23 patients. Les prothèses ont été implantées avec succès chez tous les patients, avec une fermeture complète du canal à 12 mois dans 98 % des cas dans le groupe ADO et 100 % des cas dans le groupe DC. Quatre patients (5.4 %) ont montré une protrusion asymptomatique de la prothèse : dans l’isthme aortique chez trois patients de 5, 6, et 10 kg et dans l’artère pulmonaire chez un patient de 7 kg. Un patient de 7 kg a présenté une bradycardie transitoire sévère, due à une embolie pulmonaire gazeuse. Un autre patient de 3.3 kg a présenté une occlusion asymptomatique de l’artère fémorale. Chez un troisième patient de 17 kg, l’ADO a migré du canal artériel jusqu’à l’aorte descendante, où il fut découvert 12 mois plus tard.

**Conclusion.** — Même au cours de la période d’apprentissage, cette procédure peut avoir d’excellents résultats. L’adhésion stricte aux protocoles et un suivi rigoureux sont nécessaires. Chez les tout petits patients, l’ADO pourrait entraîner une obstruction au niveau de l’aorte ou de l’artère pulmonaire, ou une migration de la prothèse. La recherche minutieuse des complications est essentielle, surtout chez les petits enfants et en cas de large canal.

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**Abréviations**

ADO  Amplatzer duct occluder
DC  detachable coil
PA  pulmonary artery
PDA  patent ductus arteriosus

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**Background**

Patent ductus arteriosus (PDA) is a common congenital heart defect that is usually identified in childhood but sometimes remains unrecognized until late in life. Since the first successful attempt at percutaneous closure by Portsmann in 1967 [1], a number of different devices have been developed and evaluated, and percutaneous PDA closure has now become the treatment of choice in adults and children weighing more than 3 kg. The two devices used most frequently are the Flipper Detachable coil (DC; Cook cardiology, Bloomington, IN, USA) and the Amplatzer duct occluder (ADO; AGA Medical, Golden Valley, MN, USA), the former being indicated for closure of small PDAs and the latter for moderate to large PDAs [2–10].

Despite the availability of these effective devices, some situations remain challenging, especially when small infants and/or large PDAs are involved. Moreover, increasing experience with transcatheter techniques has resulted in interventional cardiologists attempting more frequently to treat patients with PDAs of more complex morphology. Our paediatric cardiology unit was created in 2002 in a medium-sized university hospital with 400 mixed beds (paediatric and adult). Here, we describe our initial experience of percutaneous PDA closure in all consecutive patients during the unit’s first 5 years, emphasizing the difficulties, solutions, complications and outcomes.

**Patients and methods**

All consecutive patients who underwent an attempt at transcatheter PDA closure in our unit between January 2002 and December 2007 were included in this study. The minimum required weight was 3 kg for the use of a DC and 5 kg for an ADO. All babies who weighed less than 3 kg were referred for surgery. All infants who weighed less than 5 kg and required an ADO (based on the finding of a large PDA [> 2 mm] on transthoracic echocardiography) were also referred to the surgeon (five patients during this period). Informed written consent was obtained from all adult patients and children’s parents.

All percutaneous interventions were performed by the same operator (ZS). After obtaining arterial femoral access, an aortogram was performed in the lateral projection to define the morphology and the size of the duct. Arterial femoral access could not be obtained in two infants, in whom the procedure was performed only through the...
femoral vein. A sizing balloon was needed for accurate measurement in two adult patients with large window-like ducts.

An ADO was chosen when the PDA was greater than 2 mm. The only exception to this rule was a 70-year-old patient with a 3 mm PDA; a 6/4 size ADO was not available and two coils were then deployed to close the duct. When an ADO was used, the selected size was usually 2 to 3 mm larger than the minimum ductal diameter and it was deployed transvenously in all cases. A DC was selected for closure of small (<2 mm) PDAs. The size of the DC was 2 to 2.5 times wider than the narrowest ductal diameter and long enough to produce at least two loops inside the ductal ampulla. The DC was implanted transarterially in all but one patient who did not have an arterial access. Our protocol and technical details for duct closure have been described in a previous publication [9].

A repeat aortogram was obtained 10 min after releasing the device, to check for residual shunts and any anomaly in the device position. This post-procedural aortogram was replaced by an immediate echocardiographic assessment in the two patients without arterial access. The procedure was carried out under general anaesthesia in paediatric patients and under local anaesthesia in adults. An intravenous bolus injection of 50 IU/kg heparin was administered after obtaining vascular access. The activated clotting time was not measured. All patients received one prophylactic dose of cephazolin (30 mg/kg) before the procedure.

On the next day, before discharge, the location of the device was noted on a plain chest X-ray, which was checked in most cases by the paediatric resident. A repeat cardiac ultrasound scan was also performed by one of the three paediatric cardiologists — usually the one who had recruited the patients — to check for the presence and degree of any residual shunt and to detect any possible change in the device position. Systematic urine analysis, to check for haemolysis, was also performed in all patients before discharge. Clinical and echocardiographic follow-up assessments were performed 1, 3, 6 and 12 months after the procedure and annually thereafter.

**Results**

Between January 2002 and December 2007, 73 consecutive patients (11 adults) underwent an attempt at transcatheter PDA closure in our unit. Ages ranged from 3 months to 70 years, with a median age of 30 months and a mean age of 6.7 ± 10.5 years. The age distribution of the patients is shown in Fig. 1. The mean weight was 21.5 ± 19.5 kg (range 3.3—85 kg).

An ADO was used in 50 patients (68%) and a DC in the remaining 23 patients; one coil was placed in 22 patients, while one patient required the deployment of two coils. The prostheses were implanted successfully in all patients; no device was wasted during the procedure and no patient was sent for surgery subsequently. Mean fluoroscopy durations for DC and ADO were 6.5 ± 3 (range 3.2–13) min and 13.5 ± 4 (7.5–22) min, respectively.

At the narrowest point, the diameter of the ducts ranged from 1.0 to 7.2 mm, with a mean diameter of 2.9 ± 1.3 mm. In the ADO group, the PDA was conical (type A) in 43 patients, window-like (type B) in three patients, type C in three patients and type D in one patient. In the DC group, the PDA was conical in 17 patients, type E in three patients and type C in three patients.

Patients with an ADO had a mean age of 7.3 ± 8.2 years, a mean weight of 24.3 ± 20.0 kg and were significantly older and heavier than patients with a DC, who had a mean age of 5.3 ± 14.3 years (p < 0.05) and a mean weight of 15.4 ± 16.8 kg (p < 0.05). These differences became even more significant if the 70-year-old patient with a DC was excluded. Fig. 1 shows device use in the different age groups.

In both groups, 6-month follow-up assessments were completed scrupulously and systematically in all patients; follow-up duration ranged from 6.2 months to 6.3 years, with a mean follow-up duration of 3.9 ± 1.8 years. In the ADO group, 20 (40%) patients had complete closure of the PDA confirmed angiographically, immediately after the procedure. The next day, 28 additional patients (making a total of 96%) showed no evidence of residual shunt on colour Doppler flow mapping. By the end of the first month, the rate of complete closure had reached 98% (49 patients) and remained unchanged at the 6-month follow-up assessment. Only one patient had a persistent residual shunt at 12 months; the ADO had migrated asymptomatically to the abdominal aorta.

In the DC group, immediate occlusion of the PDA was achieved in 12 (52%) patients. This rate rose to 74% (17 patients) 24 hours after the procedure and to 91% (21 patients) 1 month later. At 6 months, complete closure was evident in all 23 patients. No patient in either group showed signs of haemolysis on urinalysis.

**Technical difficulties**

Failure to obtain arterial access was encountered in two infants aged 19 and 24 months (9 and 12 kg, respectively). In both, the preprocedural aortogram had to be performed through the PDA using a Multi-Track angiographic catheter.
Figure 2. A. Aortic angiogram in lateral projection showing the ADO (black arrow) protruding into the aortic isthmus (white arrow). B. Repositioning the ADO by balloon inflation (white arrow) into the aorta.

(NuMed, Hopkinton, NY, USA) mounted transvenously on a guide wire. In the first child, a DC was placed through a venous approach; in the second, an ADO was delivered transvenously as usual. In both cases, because access to the aorta was impossible after duct closure, postoperative echocardiography was used to assess the device position after its deployment. In two adults with large window-type PDAs, the measurement of the duct could not be determined precisely by aortography using different projections. Balloon sizing of the duct was therefore performed and the size of the device was chosen according to the measured diameter of the occluding balloon; a 12/10 ADO was used in both cases to occlude a 7.0 mm and a 7.2 mm duct.

Complications

Device-related minor complications occurred only in the ADO group, in four children all aged more than 15 months (5.4%). Three of these patients, weighing 5, 6 and 10 kg, showed a mild aortic narrowing from device protrusion into the aortic isthmus (Fig. 2). The two youngest patients had a systolic gradient less than 10 mmHg across the ADO and no systemic hypertension. The 10 kg patient had an initial gradient of 20 mmHg; the device position was therefore partially adjusted during the same procedure, by pushing it with a balloon catheter from the aorta, reducing the gradient to 10 mmHg (Fig. 2B). In these three patients, the peak velocity across the isthmus on Doppler examination at 3 months was less than 2.5 m/sec, without any systemic hypertension; the 10 mmHg arm-to-leg systolic pressure gradient was absent. In the fourth patient (6 months, 7 kg), who had a minor device-related complication, the prosthesis was seen protruding into the left pulmonary artery (PA), producing an abnormal flow at a peak velocity of 2.7 m/sec (Fig. 3). This patient did not show any dissymmetry in pulmonary vascularisation on a perfusion scan performed 3 months later during the follow-up assessment; at that time, the peak velocity across the protruding device in the left PA had decreased to 2.2 m/sec.

There were three major complications in three (4.2%) other children. One patient (6 months, 7 kg) experienced severe bradycardia due to pulmonary air embolism, following inadvertent retrieval of the delivery cable from...
the sheath after ADO releasing; the child recovered completely within a few minutes after resuscitation. The second complication occurred in an infant (3 months, 3.3 kg) who experienced occlusion of the right femoral artery after the procedure; this baby had a permanent asymptomatic occlusion of the right femoral artery despite the aggressive use of thrombolytic drugs as confirmed by a Doppler study at the 6-month follow-up assessment. Limb growth was normal on follow-up physical examinations; the child showed normal gate at the age of 14 months and the paediatric orthopaedic professional confirmed the absence of dissymmetry between the right and left limbs at the age of 3 years.

The third complication, an ADO migration, was diagnosed 1 year later in a child (24 months, 17 kg); an unusually large residual shunt was noted on all the routine follow-up ultrasound examinations. A chest X-ray was performed finally at 12 months and confirmed the device migration in the abdominal aorta. We believe that the embolization occurred on the day after the procedure, as documented by the predischarge misinterpreted chest X-ray, which did not show the radio-opaque markers of the ADO in the usual position. The device was embedded asymptomatically in the abdominal aorta, facing the coeliac artery. The attempt to remove it percutaneously failed due to its strong adhesion to the aortic wall. There were no related hemodynamic consequences, so it was left in place and successful percutaneous PDA closure was then achieved with another ADO.

Discussion

Excluding premature infants, there are actually very few ducts that cannot be closed safely and effectively using transcatheter techniques [11–14]. With increasing experience, complications and failures have been reduced to a minimum but not abolished completely, especially in small infants with large ducts [2–6,10,13]. In this series, a high rate of procedural success was recorded, regardless of patient age, ductal size or the kind of device used, with an early overall occlusion rate as high as 89%, rising to 98% at the 3-month follow-up assessment. These findings are very similar to those published in larger series [3,5–7,10,13,14]. Most patients had a conical-shaped PDA, which is a rather favourable type, with a well-defined ampulla allowing easy placement and good anchoring of the device without protrusion into any of the adjacent arterial trunks.

Analysing the difficulties and challenges encountered in this series, we think that with more experience, the first two out of the three major complications observed could have been avoided. Pulmonary air embolism leading to transient cardiac arrest occurred in one infant. After detaching the device, the operator assistant retrieved the delivery cable forcefully from the large 7F sheath, which aspirated air into the sheath and consequently into the PA. This was the eleventh patient in our series and for practical reasons we were not as yet using the haemostatic valve. After adequate resuscitation, the patient recovered completely and was discharged 48 hours later with no residual shunt. This avoidable complication shows us once again how essential it is to follow the manufacturer’s instructions fully.

Migration of an 8/6 ADO device was seen in 3-year-old child (18 kg) with a very long (2 cm), bulbous, type D PDA (Fig. 4). This rare complication has been reported previously and is believed to occur immediately after or within 24 hours of the procedure [10,12,13,15,16]. In our patient, the chest X-ray performed 24 hours after the procedure was misinterpreted and the ADO was thought to be in its usual position. The X-ray was not examined by the paediatric cardiologist before discharge and the resident was not sufficiently experienced to express any concern. Retrospectively, we believe that the 8/6 ADO device was undersized in our patient and that the significant residual paraprosthetic shunt noted before releasing the device should have alerted us to this mismatch problem. This residual shunt, although unusually large, was thought to be adjacent to the prosthesis and was watched for 12 months with the hope of spontaneous resolution. This highlights the need for careful and accurate immediate, intermediate and late follow-up assessments. The device is usually impossible to retrieve percutaneously when discovered late after the initial migration and may be left untouched if it remains asymptomatic [5,16,17]. Even with the help of an adult invasive radiologist experienced in the retrieval of endocaval filters, all our attempts at the retrieval of the device from the abdominal aorta were futile. Efforts were then redirected at PDA closure and surgery was contemplated seriously. However, as many solutions have been proposed in cases of D type PDA, we decided to continue with a percutaneous technique, i.e. oversizing the device by two or more sizes or using a vascular plug. We favour generous oversizing of the prosthesis and its deployment within the body of the duct, which allows for incomplete deployment of the disc and hence avoids tearing of the ductal wall (Fig. 4C) [18]. This technique was used 12 months later to close the PDA successfully in this patient, with a 14/12 ADO.

The third major complication was the occlusion of the femoral artery. Although palpated strongly, the femoral pulse may be radiating, making it difficult to locate and catheterize the femoral artery, especially in small infants. Multiple attempts at obtaining arterial access, coupled with the relatively large size of the delivery system (5F) may expose patients to potentially serious vascular complications; reduced pulse or occlusion of the femoral artery are sometimes reported in small infants [3]. In experienced hands, however, vascular access should be obtained easily, especially with the aid of Doppler for more accurate location of the artery. In our series, catheterization of the femoral artery only proved difficult in the early stages of the learning curve and failure to obtain arterial access was encountered in two patients. We do not use Doppler to locate the artery and are not familiar with its advantages in the catheterization laboratory. Adequate heparinization is critical but not sufficient to avoid the complications mentioned above. Although not used in our practice, repeated activated clotting time measurements during the procedure are useful to ensure adequate heparinization.

Another challenge related to age is the adequate measurement of very large window-like ducts in adult patients. Before any duct closure, it is crucial to measure the minimum PDA diameter during systole, as this measurement can be 30% larger than the diastolic dimension [19]. This variation becomes more significant in larger ducts and...
the standard lateral view fluoroscopy projections may not be sufficient for accurate measuring. We were unable to measure a window-type duct in two adults accurately by angiography alone, despite the generous amount of dye injected in different projections. Therefore, a complying sizing balloon (AGA medical corporation, Golden Valley, MN, USA), conceived initially for atrial septal defect calibration, was used to determine the precise duct diameter. The balloon should be used very gently with no tension and retrieved on a guide wire from the aorta across the duct by pushing the wire and freeing the syringe. As a general rule, several types of occluding devices should be available in all sizes when attempting percutaneous closure of a large duct in an adult patient, as the precise size and shape of the PDA may only be uncovered in the catheterization laboratory [11]. Use of the new generation magnetic resonance imaging or multislice computerized tomography has also been proposed in adult patients to delineate the exact morphology of the PDA [4,11,19,20]. To our knowledge, difficulties in measuring the PDA accurately have not been reported in paediatric patients.

Device-related difficulties, such as an inability to position the device in the ductal ampulla, problems related to loading, deployment or retrieval, and malfunction of the device itself or any component of the delivery system, have been reported rarely in large series [2,10,21]. Protrusion of the ADO into the left PA or the aortic lumen occurred in four patients in our series, all inferior to 18 months old and weighing inferior to 10 kg. This is in accordance with other published reports [2,3,5,6,21–23]. In all four patients, rigorous and systematic follow-up assessments were carried out with regard to the obstruction. The isthmic obstruction was evaluated by the gradient across the isthmus, measured invasively initially and then by the peak Doppler velocity and the arm-to-leg systolic pressure ratio. The absence of elevated systemic blood pressure per se is a good sign of a non-obstructed flow. This may be confirmed further by peak Doppler isthmic velocity less than 2.5 m/sec and by equal arm and leg systolic pressures. The concern about a left PA obstruction by an ADO prompted us to perform a perfusion scan that showed normal flow distribution between both lungs.

In some reported cases, the size mismatch between the device and the child has led to serious protrusion into the descending aorta or PA, necessitating device retrieval [22,23]. Correction of the protrusion into the aortic isthmus may be achieved by using a balloon or deploying a stent to push and reposition the device inside the duct. This delicate but feasible technique has been performed successfully by Ewert, Beck et al. and Moore et al. [4,19,22]. Although conical morphology of the PDA is favourable for device accommodation, it does not prevent protrusion into the adjacent vessels; in fact, in this series, all device protrusions occurred in conical-shaped PDAs. While the shape of the device is unique, the PDA anatomy is like a fingerprint; no two are exactly the same and the length of the PDA or the diameter of the aortic ampulla can widely vary in the same anatomy group. Thus, oversizing or undersizing the ADO, especially in small infants and even in conical-shaped PDAs, may lead to obstruction in either the aorta or the PA. Recently, a special ADO device has been developed with a 32-degree angle between the plug and the retention disc, which corresponds better with the anatomic proportions of the PDA and aortic isthmus. In addition, its aortic disc is concave toward the aorta, reducing any possible protrusion into the aortic lumen [2,13].

![Figure 4.](image)

A. Magnetic resonance image showing a type D (bulbous type) PDA, with smaller aortic and pulmonary openings (black arrows) and a larger middle part. B. An aortogram showing a lateral view of the same PDA. C. Lateral view aortogram showing the ADO purposely incompletely deployed (black arrows) within the body of the duct.
Table 1  Difficulties and complications.

<table>
<thead>
<tr>
<th>Difficulty (% of procedures)</th>
<th>Age</th>
<th>Weight (kg)</th>
<th>Size (mm)</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of arterial access (2.7%)</td>
<td>19 months</td>
<td>9.0</td>
<td>1.5</td>
<td>DC</td>
</tr>
<tr>
<td></td>
<td>24 months</td>
<td>12.0</td>
<td>2.6</td>
<td>ADO</td>
</tr>
<tr>
<td>Balloon sizing (2.7%)</td>
<td>23 years</td>
<td>65.0</td>
<td>7.0</td>
<td>ADO</td>
</tr>
<tr>
<td></td>
<td>28 years</td>
<td>67.0</td>
<td>7.2</td>
<td>ADO</td>
</tr>
<tr>
<td>Complication (% of procedures)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device protrusion in aorta (4.1%)</td>
<td>15 months</td>
<td>10.0</td>
<td>4.6</td>
<td>ADO</td>
</tr>
<tr>
<td></td>
<td>4 months</td>
<td>5.0</td>
<td>2.0</td>
<td>ADO</td>
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<tr>
<td></td>
<td>6 months</td>
<td>6.0</td>
<td>4.0</td>
<td>ADO</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
<td>7.0</td>
<td>3.2</td>
<td>ADO</td>
</tr>
<tr>
<td>Loss of femoral pulse (1.4%)</td>
<td>3 months</td>
<td>3.3</td>
<td>1.5</td>
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<td>Pulmonary air embolism (1.4%)</td>
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<td>7.0</td>
<td>2.5</td>
<td>ADO</td>
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<tr>
<td>Device embolization (1.4%)</td>
<td>24 months</td>
<td>17.0</td>
<td>4.0</td>
<td>ADO</td>
</tr>
</tbody>
</table>

Conclusion

With experience, percutaneous PDA closure can give excellent results when the appropriate device is chosen, with no mortality and minimal morbidity rates. Moreover, when protocols are followed carefully, most complications are not life-threatening and are without long-term sequelae. Accurate measurement remains the key for success. This may necessitate balloon sizing in adults, or other imaging radiology tools. Cautious surveillance for untoward events is essential, especially in small infants with large ducts, as they are at higher risk, potentially for both technical and procedural problems. Scrupulous and systematic follow-up assessments are of utmost importance to confirm the medium- and long-term success of the procedure. Future studies should focus on developing smaller delivery systems and creating devices adapted to all ductal morphologies.

Table 1.

Funding

None.

Conflicts of Interest

None.

References


