The cavo-pulmonary anastomosis is often referred to as Glenn shunt today. The concept of cavo-pulmonary shunting, however, was developed independently by many surgeons. While the work of some of them is widely recognized, the pioneering contributions of many others fall into oblivion. Nonetheless, each of them contributed something original and precious to the total sum of our modern knowledge. It seems timely, as we enter the new millennium, to give due credit to those individuals who put their minds and efforts into helping sick children. These people deserve recognition.

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Les beaux esprits se rencontrent.
Great minds think alike.
—Voltaire (1694–1778)
Lettres philosophiques

Development of the cavo-pulmonary anastomosis is an important landmark in surgical treatment of congenital heart disease. The anastomosis is often referred to as the Glenn shunt. It is noteworthy, however, that this anastomosis was developed experimentally and introduced into clinical practice by many surgeons, working independently and probably unaware of each other’s efforts.

Concept of Cavo-Pulmonary Shunt and the First Experimental Studies

The right ventricular bypass was first successfully achieved in 1949 by Rodbard and Wagner [1], who worked at Michael Reese Hospital in Chicago. They experimentally anastomosed the right atrial appendage to the pulmonary artery and ligated the main pulmonary artery and, thus, demonstrated the feasibility of the right ventricular exclusion in chronic experiments on dogs.

However, it was not until 1950, when the concept of cavo-pulmonary shunt was first introduced by Italian surgeon Carlo A. Carlon (Fig 1) and his colleagues [2, 3]. The story of cavo-pulmonary shunt begins on March 27, 1950, at the Second Clinical Congress of the Italian Chapter of the International College of Surgeons held in Padua and Venice, when three Italian surgeons, Carlon, Mondini, and de Marchi, presented their experimental study of cavo-pulmonary shunt. The results of their experimental study on 8 dogs were first published in 1950 in Italian [2] and in 1951 in English [3]. It was Carlo A. Carlon, Professor of Surgery at the University Medical School in Padua, who first advocated that in certain congenital heart defects an “advantage would be served if the blood of the superior vena cava should reach the capillary region of the right lung by way of a convenient anastomosis between the great venous trunk and the arterial system of the right lung...” [3]. Further they wrote: “We are not aware that anyone else has foreseen and studied the problem of oxygenation of the pulmonary blood under venous pressure and without cardiac output” [3]. The anastomoses were made end-to-end between the proximal end of the divided azygos vein and the right pulmonary artery with preatrial ligation of superior vena cava (Fig 2).

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It is unknown why more than a decade elapsed between their experimental studies of 1950s and 1964, when Carlon reported their first clinical experience [4]. Because their initial reports appeared in journals scarcely read by most surgeons, the pioneering work of Carlon and his colleagues soon fell into oblivion. Although today Carlon is seldom given an appropriate credit, it was he who first described the concept of the cavo-pulmonary shunt [5]. It is our belief that the anastomosis between the right pulmonary artery and azygos vein should be referred to as Carlon’s technique. We are taking the liberty to do so below.

The First Experimental Studies

After initial work of Carlon, the experiments on cavo-pulmonary shunts continued by independent groups in Hungary, Russia, and USA.

Cavo-Pulmonary Shunt via Azygos Vein—Carlon’s Technique

In the 1954 volume of the *Yale Journal of Biology and Medicine*, Glenn (Fig 3) and Patino published their first experimental study on cavo-pulmonary shunts [6]. A superior vena cava–right pulmonary artery shunt was performed in 9 dogs using the azygos vein rather than by direct caval anastomosis. The technique applied was very similar to the technique described originally by Carlon. The follow-up angiograms were done as late as postoperative day 13, and demonstrated patent anastomoses. In 1955 the Yale group reported a study of 59 operated dogs with 6 long-term survivors [7]. Chyloous pleural effusion secondary to elevated blood pressure in the superior vena cava contributed to the death of several dogs. Subsequently, this complication also created problems in their clinical material [8]. On June 2, 1957, the Yale group reported an extensive study of 75 dogs. In all but 7 of these the anastomosis of the distal end of the divided right pulmonary artery to the side of the superior vena cava, utilizing the central stump of the divided azygos vein as an anastomatic channel, was made. In the remaining 7 dogs, an end-to-end anastomosis was created central to the azygos vein [9].

The First Direct End-to-End Anastomosis of the Superior Vena Cava to the Right Pulmonary Artery

In 1954 Francis Robicsek (Fig 4) and colleagues from the Department of Heart Surgery of the Post-Graduate Surgical Clinic in Budapest undertook an experimental study [9] and reported their initial results in the 1956 volume of *Acta Medica Scandinavica* [10]. In their study the direct vena cava-to-pulmonary artery anastomoses were done in about 15 minutes without cardiopulmonary bypass [10]. In 1956 Robicsek moved to the USA and, being unaware of the work of Carlon, continued his experiments on cavo-pulmonary anastomosis with Paul W. Sanger in Charlotte, North Carolina. In 1959 they were able to achieve first clinical success.

In 1954 Harris B. Shumacker (Fig 5) performed a few

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*Fig 3. William Wallace Lumpkin Glenn (1914–). Courtesy of Dr Glenn.*
experimental end-to-end anastomoses of the superior vena cava and the right pulmonary artery, and the next year he applied the technique in 2 patients [11, 12]. Many surgeons at that time continued to anastomose the right atrial appendage to the pulmonary artery [11, 12]. In April 1955, Hurwitt said: “... further investigation will be necessary before one may state whether or not anastomosis of the right auricular appendage to the pulmonary artery may be beneficial in a case of tricuspid atresia. The circulatory by-pass of the right heart described by Glenn and Patino, anastomosing the azygos vein to the right pulmonary artery, and the anastomoses between the venae cavae and the pulmonary artery referred to by Shumacker represent provocative experiments in this direction” [12].

It is often mentioned in surgical literature that the first successful clinical cavo-pulmonary shunt was done and reported in Russia. However, very little information is available on what experimental studies preceded this first success. Herein we describe this development in more detail.

In Russia, the idea of the cavo-pulmonary anastomosis was first proposed in September 1955 by Nikolai K. Galankin (1914–1977) and the first experimental success was achieved the same year by Tigran M. Darbinian (Fig 6). In his PhD thesis published on May 14, 1957, Darbinian wrote:

In September 1955, N.K. Galankin suggested and developed in experiments on dogs a new operation—anastomosis between periferal end of superior vena cava and the right pulmonary artery. The operation was proposed for children with tetralogy of Fallot and tricuspid atresia. In 1955, the anastomosis of the superior vena cava was performed by Shumacker in 2 children with pulmonary hypertension. The operations were not successful. In the beginning of 1956, Robicsek, Temesvari, and Kadar performed this operation in 15 dogs and recommended it for patients with decreased pulmonary flow. Thus, the anastomosis between superior vena cava and the right pulmonary artery was developed simultaneously and independently by Galankin, Shumacker, and Robicsek. It is noteworthy that Shumacker performed this operation not for tetralogy of Fallot, but for transposition of great arteries and truncus arteriosus communis, both with pulmonary hypertension.

In 1954, Glenn and Patino partially bypassed the right ventricle in 9 dogs by anastomosing the right pulmonary artery and the azygos vein with ligation of the superior vena cava below the anastomosis. When we started our experiments, the works of Shumacker and Robicsek were not published yet.

Since September, 1955 we performed 46 experiments on dogs. Of those we designed 34 chronic experiments to study the long-term effects of the anastomosis. Six dogs of those 34 died in the operating room, the rest of 28 survived and the long-term effects were studied. The maximal period of study was 1 year.

Based on the idea of Galankin and our experiments on long-term hemodynamic evaluation of the cavo-pulmonary anastomosis, Meshalkin successfully introduced this operation in clinical practice in 1956 for patients with tetralogy of Fallot and tricuspid atresia. That same year
the operation was performed on a number of patients by Vishnevsky and Galankin [13].

In Darbinian’s study, in 33 cases the anastomosis was made end-to-end using Donetsky’s ring (Fig 7); in 13 cases, the anastomosis was made end-to-side and the superior vena cava was side-clamped, in the same way that was described by Glenn (Fig 8).

On December 6, 1998, Darbinian told us a very interesting story on how the research was started:

I began my post-graduate training in the Vishnevsky’s Institute of Surgery in Moscow in 1954. My supervisor was Professor Nikolai K. Galankin. He had many patients with tricuspid atresia, but had no effective means of treatment. In 1955, he said to me: “Listen, why not to try cavo-pulmonary anastomosis on dogs?” He operated on 5 dogs, I assisted him. All dogs died. It took ages to make the anastomosis. We did not make any shunting of blood and the pressure in the cross-clamped superior vena cava was as high as 600 mm of water during the anastomosing. Finally, he gave up, saying that nothing will come of it. He said to me: “Apparently, my idea is wrong, but do not get upset, I will soon invent something else.” He was, indeed, a very keen-witted man. Meanwhile, I made a good friend with Dr Donetsky. The latter headed the laboratory of blood vessel conservation. Donetsky showed me his ring and his technique to connect blood vessels, which took only a few seconds. I talked him into helping me. After Donetsky made a large diameter ring on my request, I decided to give the idea the last try. Once, without saying anything to Galankin, I took Donetsky with me and he assisted me on the sixth dog. The dog survived.

I initially attributed it to the new technique; however, subsequently, when I started the long-term evaluation I noticed that this dog had previously been operated on the left side. The left lung was adherent to the chest wall and did not collapse. Dogs have very tiny pleural membranes in between pleural cavities and may easily develop left pneumothorax after the operation on the right. We drained only the right pleural cavity on the first 5 dogs, while the left lung was partially collapsed. The blood flow via the anastomosis was impeded due to increased pulmonary vascular resistance postoperatively, while the left lung was collapsed!
I rushed to Galankin and told him about my success and my conjecture. He was very happy but he has not operated since that moment, he just smiled and said: “Very well. Go ahead. This will be your PhD thesis.” I started to inject talc into the left pleural cavity and operated about 3 weeks after, so that adhesions could develop and prevent left lung collapse after the operation. All dogs survived.

When I operated on 6 more dogs, Galankin wrote an article, with the meticulous description of the operative technique and angiographic findings of patent anastomoses, to the journal Eksperimentalnaja Khirurgia. The co-editor of the journal was Meshalkin at the Institute of Thoracic Surgery, and all manuscripts were submitted to him. In 4 months our manuscript was returned and the recommendation was given to at least double the number of operations. In the meantime Meshalkin performed 4 clinical operations and presented them at the Moscow Surgical Society meeting. Later on our article of a total of 13 experiments was published. After the initial clinical success of Meshalkin, the operation was performed frequently by Galankin at the Vishnevsky Institute of Surgery.

As early as 1951, Professor A. N. Bakulev, head of the Institute of Thoracic Surgery in Moscow, had proposed the idea of the cavo-pulmonary anastomosis [14, 15]. However, it was not until successful experiments performed by Darbinian that interest in the cavo-pulmonary shunts was revived in Russia. The first articles on cavo-pulmonary shunt in Russian literature were published in 1956 by Galankin and Darbinian [16], soon followed by a clinical report of 24 cases by Evgenii N. Meshalkin (Fig 9) [14].

**The First Clinical Application**

In the United States, the first to perform clinical cavo-pulmonary shunts was Harris B. Shumacker. On November 15, 1954, at the Fortieth Annual Congress of the American College of Surgeons in Atlantic City, Shumacker, discussing the article of Warden, mentioned the experiments in his laboratory, in which the “venae cavae were anastomosed directly to the pulmonary artery” [11, 12]. At the meeting, Shumacker also gave the first account of the clinical application of the cavo-pulmonary shunt: “One was a very sick child who had truncus arteriosus with pulmonary hypertension and large pulmonary trunks coming off the common one. In this case and in one case with complete transposition, we simply performed a superior cava-right pulmonary artery end-to-end anastomosis” [11, 12]. Unfortunately, both children died 8 and 15 hours after the operation. The high pulmonary vascular resistance most likely contributed to death in both cases. Nonetheless, it was proven that “at least for periods of hours, the human heart can function with the right side circumvented” [12]. Although both of Shumacker’s operations failed, it was an important and brave step forward, particularly when it is remembered...
that it took almost 2 more years until Meshalkin performed successful cavo-pulmonary shunts on patients in Russia [14], and 4 years before Glenn [17], Rasmussen [18], and Robicsek and colleagues [19] did so in the United States and Santy and coworkers did so in France [20].

The First Clinical Success
In 1956 in Russia, Meshalkin [14] presented the case summaries of 24 children on whom he performed cavo-pulmonary anastomosis between April and October 1956. Twenty-three of these patients had Fallot tetralogy and 1 had pulmonary atresia. In all but 1 patient the anastomosis was done end-to-end, and in most cases the atrium was closed with the UKL mechanical stapler (Institute for Surgical Instruments, Moscow, Russia). Meshalkin used a technique developed experimentally by Darbinian and Galankin, except he did not apply a temporary azygos-to-right atrium shunt (Fig 10). Three of 24 patients died. The patient Meshalkin operated on at the Institute of Thoracic Surgery in Moscow on April 3, 1956, represents the first successful clinical case of cavo-pulmonary anastomosis reported in the world’s surgical literature. Stapling facilitated the operation and allowed completion of the anastomosis in 5 to 6 minutes in experiments [16], and in 14 minutes in clinic [14, 15]. The initial success of Meshalkin stimulated further extensive studies on both experimental and clinical aspects of the cavo-pulmonary shunting in Russia [21, 22]. Soon the final Russian technique was established, and was used with some modifications by most institutions in the Soviet Union. The anastomosis was created by four techniques: (1) using continuous U-shaped suture; (2) using interrupted single U-shape staples; (3) using Donetsky’s ring; and (4) using circular vascular stapler. The latter two methods had their disadvantages: although with Donetsky’s ring the diameter of the anastomosis was known precisely, it did not allow for normal growth; the circular vascular stapler required an extensive mobilization of the superior vena cava and necessitated the ligation of the azygos vein [23], although the azygos vein is ligated routinely by many surgeons today. On November 24, 1958, Bakulev and Kolesnikov submitted an article describing clinical experience with 41 cases at the Institute of Thoracic Surgery in Moscow [15].

The first clinical report by Glenn [17] was published on July 17, 1958. In the report Glenn described a 7-year-old boy with transposition of the great vessels and decreased pulmonary blood flow who, on February 25, 1958, underwent cavo-pulmonary anastomosis (Fig 8). The child’s condition was improved significantly and an angiogram performed 2 months later demonstrated patent anastomosis. This was followed shortly by a successful operation reported by Sanger, Robicsek, and Taylor [19]. They performed their first clinical operation on January 9, 1959.

Bidirectional Cavo-Pulmonary Shunt
The first bidirectional cavo-pulmonary shunt was performed successfully in a patient and reported in 1961 by Achille Mario Dogliotti and associates in Turin, Italy [24]. In 1964 independently from them, J. Alex Haller from the Johns Hopkins Hospital performed and reported the bidirectional superior vena cava-to-pulmonary artery shunt [25]. Jose Patino and William Glenn used a temporary bidirectional superior vena cava–pulmonary artery shunt in their first experiments in 1950s. They, however, did not report the procedure at that time [26]. The bidirectional shunt as used by Patino and Glenn was not an integral part of the operation but a temporary means of expediting completion of a total bypass as used in their experiments [26]. Independently from Dogliotti, Haller, Patino, and Glenn, the bidirectional superior vena cava–pulmonary artery anastomosis was performed by Gaetano Azzolina in 1968 in Italy [27].

Epilogue
It often occurs in medicine that a syndrome or an operation is named not after those by whom it was first described, but rather after those who convinced the world. William Glenn, was not the first to introduce the concept of cavo-pulmonary anastomosis. He reported neither the first experimental study, nor the first clinically successful operation. However, it was an extensive study undertaken by the Yale University group and prolific writing of Glenn published in the most-read surgical journals that finally convinced the world. By
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