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REVIEW

Arc of Bühler: the surgical significance of a rare anatomical variation

Adamantios Michalinos[1] · Dimitrios Schizas[2] · Dimitrios Ntourakis[3] · Dimitrios Filippou[1] · Theodore Troupis[1]

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Abstract

Purpose The arc of Bühler, an anastomotic vessel between celiac artery and superior mesenteric artery, is a rare anatomic variation. Various radiologic and surgical procedures can be affected by its existence. We aim to review all available information and identify possible clinical implications.

Methods A systematic review was conducted in accordance to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines. The following terms were utilized in various combinations: "Bühler", "arc of Bühler", "visceral aneurysm", "pancreaticoduodenal arcades".

Results Only 53 cases have been described until today in the literature. The arc of Bühler enhances collateral circulation between celiac artery and superior mesenteric artery alongside with pancreaticoduodenal arcades and dorsal pancreatic artery. Computerized tomography and angiography are the main studies used for its detection and evaluation. Aneurysms of Bühler's arc have been rarely described and seem to share common pathophysiological mechanisms with aneurysms of the pancreaticoduodenal arcades.

Conclusions Various radiologic and surgical procedures such as embolization or pancreaticoduodenectomy are potentially affected by its existence.

Keywords Celiac artery · Superior mesenteric artery · Angiography · Buhler's arc

Introduction

In most of the cases celiac artery (CA) and superior mesenteric artery (SMA) anastomose via pancreaticoduodenal arcades and dorsal pancreatic artery. Gastroduodenal artery (GDA) a branch of the common hepatic artery (CHA) gives rise to superior posterior pancreaticoduodenal artery that anastomoses with inferior posterior pancreaticoduodenal artery, a branch of SMA. This anastomosis takes place behind the head of pancreas and can form partial or complete secondary arcades. First part of the duodenum, posterior surface of the second, third and fourth part of the duodenum as well as head of pancreas receive vascularization from the posterior arcade. Superior anterior pancreaticoduodenal artery (SAPDA), also a branch of GDA, anastomoses with inferior anterior pancreaticoduodenal artery (IAPDA) inside or medial to the groove between duodenum and head of pancreas. Anterior surface of the duodenum, first part of jejunum and head of pancreas are also vascularised from this arcade. Those arcades envelop the pancreas, ensuring adequate collateral circulation between CA and SMA. At least one of these two arcades is always present.

A second major anastomotic arcade is formed between dorsal pancreatic artery (DPA), branch of splenic artery (SA), and SMA or one of its branches (usually the middle colic artery). Those anastomoses are usually present and can potentially substitute CA or SMA in cases of partial and sometimes total occlusion [18, 22, 34].

A less investigated anastomotic route is the arc of Bühler. The arc of Bühler represents an anastomotic vessel between CA and SMA or their branches. Firstly described by Bühler [4] as communication between CA and middle colic artery, it has received little attention until today. Its true incidence

✉ Theodore Troupis
troupistheodore@gmail.com

[1] Department of Anatomy and Surgical Anatomy, School of Medicine, National and Kapodistrian University of Athens, Tetrapoleos 18, 75 Mikras Asias Str, 11527 Athens, Greece

[2] 1st Department of Surgery, Faculty of Medicine, National and Kapodistrian University of Athens, Tetrapoleos 18, 11527 Athens, Greece

[3] Department of Surgery, European University of Cyprus, Diogenis Str 6, 2404 Nicosia, Cyprus

remains unknown as few studies have addressed it in normal or pathologic populations. It is estimated less than 3%. Embryologically the arc of Bühler represents a remnant of ventral longitudinal anastomosis between 10th and 13th segmental arteries [41]. The arc of Bühler can provide an additional collateral route in case of failure of pancreaticoduodenal arcades or DPA and thus its existence is beneficial. However, increased flow can cause aneurysms in a mechanism similar to pancreaticoduodenal arteries aneurysms [3]. Furthermore, its existence implicates interpretation of radiological studies, especially computerized tomography (CT) and angiography as well as surgical interventions in the area, especially pancreaticoduodenectomy.

Purpose of this systematic review is to gather all available information on the arc of Bühler. Our intention is to describe its anatomic, surgical and radiological characteristics as well as its embryologic origin. Furthermore, we intend to explore potential implications of the arc of Bühler in clinical practice and patients' management.

Materials and methods

A systematic review was conducted in accordance to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines [24]. A study protocol was agreed upon and strictly followed by all authors. Identification of eligible studies was performed using Medline, Scopus and Google Scholar databases. The following terms were utilized in various combinations: "Bühler", "arc of Bühler", "visceral aneurysm", "pancreaticoduodenal arcades". One author screened all articles retrieved using the above described searching algorithm. Reference lists of eligible studies were manually assessed to detect any potential relevant article. All article types, including case reports, were considered relevant. No exclusion criteria such as language, sample size or year of publication were used. Flowchart with the study algorithm is presented in Fig. 1.

Results

Study results

The initial search algorithm yielded 1154 citation. Following screening of titles and abstracts and applications of inclusion criteria, 26 studies were found eligible. From 1904 to 2018, 53 cases have been described. 34 cases were included in 7 small series [2, 8, 10, 21, 30, 35, 44] alongside and 19 cases were included in case reports [1, 4, 7, 12, 14, 15, 17, 20, 23, 25, 27–31, 33, 36, 39, 42]. All studies with more than one case are based in imaging techniques, while there was not any cadaveric or surgical study. In 5 out of 19 case reports there is description of aneurysms of Bühler's arc.

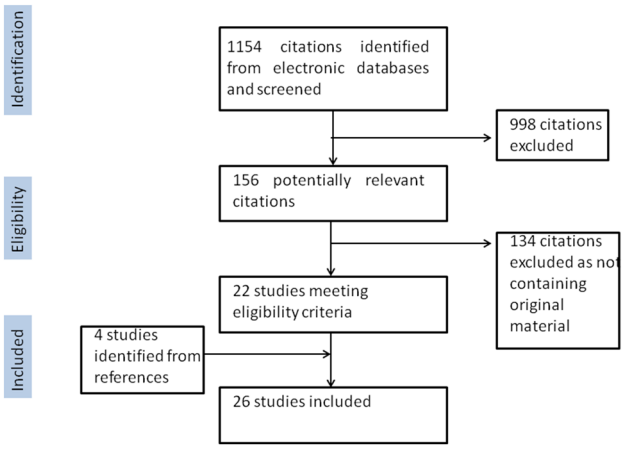

Fig. 1 Study flow chart

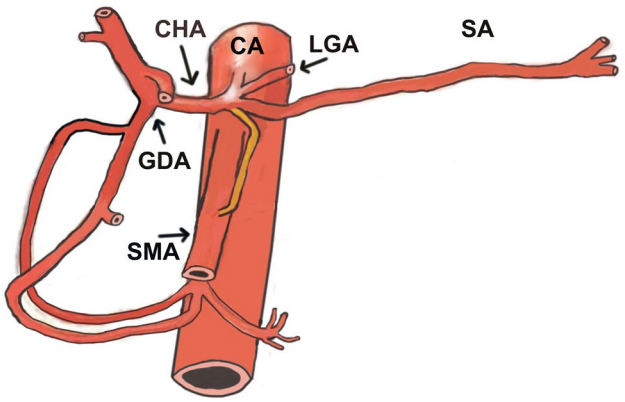

Fig. 2 Highly schematic representation of arc of Bühler anatomy. *CA* celiac artery, *CHA* common hepatic artery, *SA* splenic artery, *LGA* left gastric artery, *GDA* gastroduodenal artery, *SMA* superior mesenteric artery. Yellow branch: arc of Bühler. (Color figure online)

Description, types and incidence

The Arc of Bühler was initially described by Bühler [4] as an anastomotic vessel between CA and middle colic artery, acting usually as an additional collateral between CA and SMA. The arc of Bühler follows a short straight retropancreatic course to the left of the midline in close proximity to SMA. This area is accessed with difficulty and usually after mobilization or transection of the pancreas (Fig. 2) [16].

The arc of Bühler joins together stems of CA with SMA but it can also join their main branches. Out of 53 cases, in 40 cases it joined SMA with CA, in four cases SMA with SA [10, 17, 21], in four cases SMA with CHA [10, 27, 33], in one case CHA with middle colic artery [14], in one case CA with first jejunal artery [10] and in two cases CA with

middle colic artery [4, 21]. Notably in one case the arc of Bühler joined proper hepatic artery with first jejunal artery and during its course gave branches to the first part of the jejunum and the head of pancreas [31]. Bertelli et al. [2] also identified a case with transverse pancreatic artery originating from the arc of Bühler alongside with smaller secondary branches for the pancreas.

Studies including more than one cases are presented in Table 1. Pooled incidence across various studies is 1.71% (range 0.3–4.1%).

Embryology

The Mac Kay arc theory and the Tandler longitudinal anastomosis are the two models used to explain anatomic variations of abdominal aorta branches [6]. According to the Mac Kay arch theory [5, 38], in a 5 mm embryo the distribution of aorta branches is metameric, with each metamere giving rise to 3 pairs of branches, uniting in an arch: The posterior (vertebroparietal) arch gives rise to intercostals and lumbar arteries. The metameric distribution of this set is maintained throughout embryonic development. The lateral (genitourinary) arch gives rise to renal, gonadal and adrenal arteries. The anterior (visceral) arch gives rise to digestive arterial branches. Fusion of the visceral arch branches in a single median digestive artery takes place in the 5–17 mm embryo, as a result of the fusion of the two branches or obliteration of one of them, usually the left. Development and lengthening of the digestive tube causes disappearance or obliteration of some of the metameric branches. Organs development induces development of corresponding arteries and subversion of others. The 10th metameric artery forms the left gastric artery, the 11th metameric artery forms the SA, the 12th metameric artery forms the CHA and the thirteenth the SMA. Ultimately, this process leads to persistence of the CA and its branches (left gastric artery, SA, CHA), omphalomesenteric artery (anlage of SMA), and terminal intestinal artery (anlage of inferior mesenteric artery). Those branches are anastomosed through a longitudinal anastomosis ahead of the aorta, described by Tandler [41]. Persistence of this anastomosis between the left gastric, splenic and common hepatic artery, alongside the disappearance of the connection between the abdominal aorta and the three pre-mentioned arteries lead to the normal CA pattern. A number of morphometric characteristics of the CA, such as height and emergence angle, are defined through details of this process. In the normal pattern, the longitudinal anastomosis between CA, SMA and IMA regresses [43]. The Tandler longitudinal anastomosis theory is commonly used in the literature for the explanation of splanchnic anatomic variations. Still the anastomosis itself has not been observed in embryos, probably due to its early regression [6].

Persistence of Tandler longitudinal anastomoses explains the majority of intermesenteric anastomoses between splanchnic branches. The arc of Bühler is usually described as an embryonic remnant of the longitudinal anastomosis between the CA and SMA (Fig. 3). However, its embryogenesis is closely related to DPA. The DPA is usually a branch of the SA. After a short retropancreatic course it bifurcates behind the pancreas and gives a constant left branch, the transverse pancreatic artery. Its right inconstant branch anastomoses with the anterior pancreaticoduodenal artery, forming the Kirk's arcade, present in 60% of the cases. In 25% of the cases the DPA is a branch of SMA. Maintenance of both "origins" from CA and SMA forms a small vertical retropancreatic anastomosis, the arc of Bühler [6, 14]. Origin of the arc of Bühler from DPA explains those rare cases that it gave branches [2, 31].

In a similar manner, Riolan's arc is a remnant of the anastomosis between the SMA and inferior mesenteric artery. A few cases of direct anastomosis between the CA and left colic artery are explained as persistence of the longitudinal anastomosis, confirming the validity of the above theories [11, 19, 37].

Table 1 Studies with more than one cases

Study	Study population	No. of cases	Modality	Notes
Wicke et al. [44]	280	3	Angiography Cadaveric	
Grabbe and Bücheler [10]	340	14	Angiography	Occlusion of CA: 9 cases Occlusion of SMA: 3 cases
Bertelli et al. [2]	1000	3	Angiography	
McNulty et al. [21]	300	3	Angiography	Occlusion of CA: 2 cases Occlusion of SMA: 1 case
Saad et al. [35]	120	4	Angiography	Asymptomatic population (liver donors)
Ferrari et al. [8]	60	2	MDCT	Asymptomatic population
Ognjanovic et al. [30]	150	5	MDCT	Asymptomatic population

CA celiac artery, *SMA* superior mesenteric artery, *MDCT* multidetector computerized tomography

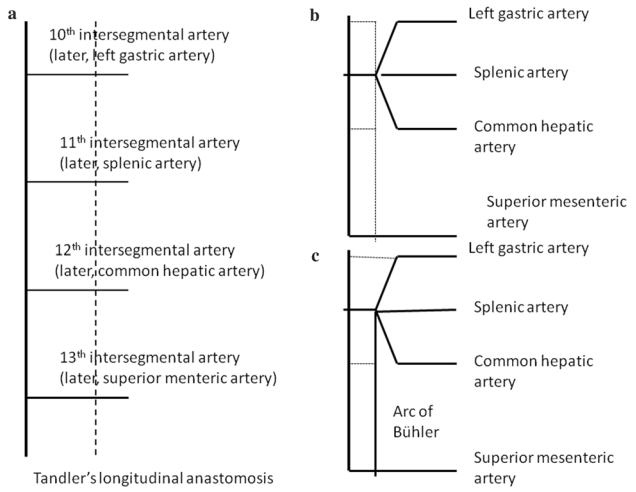

Fig. 3 Highly schematic representation of the arc of Bühler embryogenesis. **a** Embryonal development, 5 mm embryo. **b** Normal pattern. **c** Persistence of longitudinal anastomosis. Straight lines: persistent vessels. Dotted lines: regressed vessels

Physiology, pathophysiology and aneurysms

The arc of Bühler acts as collateral vessel between CA and SMA. Saad et al. [35] suggest than only in half of the cases the arc of Bühler may have an important hemodynamic role, adequately filling the CA and CHA through SMA and vice versa. Notably their study was conducted in asymptomatic population, candidates liver donors. Using as reference a 1.67 mm catheter, they estimated that the diameter of the arc of Bühler ranges between 1.5 and 2.5 mm. In another study, Grabbe and Bücheler [10] estimated that the arc of Bühler diameter ranges between 2 and 7 mm. Considering the above, it seems that flow through the arc of Bühler is negligible in normal situations.

As expected, hemodynamic behavior of the arc of Bühler changes in cases of CA or SMA stenosis or occlusion. In 38 out the 53 described cases included to our study there was almost total or total occlusion of the CA and in one case occlusion of the SMA. Under those circumstances blood flow is drained through CA–SMA collaterals. Although this could restore normal circulation to abdominal viscera, it is also favors aneurysms development [40]. The proposed mechanism is that increased blood flow causes local arterial hypertension, focal arterial wall thickening and true aneurysm formation [9]. Five cases of Bühler's arc aneurysm have been described in the literature (Table 2).

In a unique case, the arc of Bühler acted as a shunt between the CA and SMA causing reduced flow at CHA. Embolization abolished the shunt and restored hepatic arterial flow [42].

Clinical and radiological image

Out of the 53 cases, 7 were symptomatic. Clinical symptoms were vague epigastric discomfort or postprandial pain [13, 17, 21], gastrointestinal bleeding [21], obstructive jaundice [12] and post-endoscopic retrograde cholangiopancreatography bleeding [23]. Notably out of the seven arc of Bühler aneurysms described in the literature, four of them

Table 2 Aneurysms of the arc of Bühler

Study	Aneurysm size	Presentation	Treatment
Kugai et al. [17]	59 years, female Size: 3 cm Occlusion of CA	Epigastric discomfort	Surgery (failed embolization)
Myers et al. [26]	39 years female Size: N/A Occlusion of CA	Asymptomatic	Surgical removal and revascularization with saphenous vein graft
Dubel et al. [7]	54 years, male Size: 2.5 cm Occlusion of CA	Asymptomatic	Embolization
Jeong et al. [13]	41 years, male Size: 2 cm Occlusion of CA	Non specific GI symptoms History of acute pancreatitis	Embolization
Jayia et al. [12]	65 years, female Size: 7 cm	Obstructive jaundice	Embolization
Sugihara et al. [39]	35 years, male Size: 3 cm Occlusion of CA	Median arcuate ligament syndrome	Embolization
Mohapatra et al. [23]	53 years, male Size: N/A Occlusion of CA	Post sphincterectomy bleeding	Embolization

CA celiac artery, *N/A* not amenable, *GI* gastrointestinal

were symptomatic. As it happens in all visceral aneurysms, symptoms are caused either by pressure phenomena or intraluminal bleeding. To the best of our knowledge, no intra or retroperitoneal arc of Bühler aneurysm rupture has been reported until today. Rests of the cases were either finding in angiographies performed for other reason either incidental finding.

The image of an arc of Bühler at angiography is that of an anastomotic vessel between the CA and SMA or their branches, slightly to the left of the midline [10, 44]. The arc of Bühler has also been described in CT, usually as an atypical retropancreatic vessel. However, its definition, including origin, diameter and relationships is better defined with CT angiography or classical angiography [8]. No direct comparisons between various radiologic modalities have been performed until today.

Aneurysm of the arc of Bühler

The most important pathology of the arc of Bühler is aneurysm. Until today, seven cases have been described in the literature (Table 2). Four of these cases were symptomatic, two as non-specific gastrointestinal symptoms [13, 17], one due to pressure phenomena (obstructive jaundice) [12] and one as post-endoscopic retrograde cholangiopancreatography bleeding [23].

Five patients were males and two patients were females. Mean age of the patients was 41 years (39–65). One case was diagnosed during investigation of medial arcuate ligament syndrome [39] and two cases were asymptomatic [7, 26]. Mean size was 3.5 cm (2.5–7 cm). Two patients had possible predisposing factors, von Recklinghausen disease [26] and history of acute pancreatitis [13]. No data regarding whether those aneurysms were true aneurysms or pseudoaneurysms exist.

Notably in six of seven cases CA was occluded. This is in accordance with the pathophysiology of aneurysms of the major collateral vessels between the CA and SMA, pancreaticoduodenal arcades. While atherosclerosis is the main cause for large vessels aneurysms, local hemodynamic circumstances have a pivotal role in visceral artery aneurysms [40]. Increased flow due to CA occlusion or splenic hypertension causes local increase of blood flow inducing arterial wall histological changes such as fibromuscular, atherosclerotic and fibroblastic changes leading to aneurysm formation. The need for revascularization of the occluded vessel to prevent aneurysm recurrence is still debatable [3].

Five of seven cases were treated by embolization. One cases was treated surgically with excision of the aneurysm after two failed embolization attempts [17] while in one case aneurysm resection and revascularization of the CA was performed [26]. No morbidity or mortality were noted. Visceral aneurysms should be treated regardless of their size because risk of rupture is not proportional to their size. Embolization gradually is becoming the method of choice. Although no specific studies exist for Arc of Bühler aneurysm, guidelines for visceral aneurysms seem to apply.

Clinical implications

Retropancreatic space anatomy is essential during performance of pancreatoduodenectomy. This space contains the roots of major vessels such as the CA and SMA, the portal vein, lymphatic and neural tissue. The arc of Bühler resides in this space, and thus its existence has important implications.

Removal of retropancreatic lymphatic tissue is required in pancreatectomies performed for oncological purposes. According to the extent of lymph node dissection, it is characterized either as standard (removal of lymphatic tissue to the right side of SMA) or extended (removal of lymphatic tissue circumferentially to SMA) [32]. Non-removal of this tissue could lead to early recurrence, limiting thus the disease-free and overall survival, and the possible benefits from the operation. Kageyama et al. [15] reported a case where the arc of Bühler existence led them to change dissection lines, so to avoid accidental injury. While this was probably of little importance, as they faced a small lymph-node negative tumor of the ampulla of Vater, their case proves that the arc of Bühler might compromise effectiveness of lymph node dissection.

During pancreaticoduodenectomy, the hepatic circulation must be assessed for patency because ligation of the GDA might deprive liver of its arterial hematosis. In a patient with CA stenosis, hepatic artery reimplantation might be necessary. McCracken et al. [20] reported a case of a patient with CA stenosis who underwent pancreaticoduodenectomy. Luckily this patient had a patent arc of Bühler that maintained arterial hematosis after GDA ligation, cancelling the need for hepatic artery reimplantation.

O'Brien and Ferral [28] and Sugihara et al. [39] reported two cases of patients diagnosed with median arcuate ligament syndrome and patent arc of Bühler. In the first case sufficient flow to CA through the arc of Bühler relieved occlusion of CA, probably palliating the patient's symptoms. In the second case increased flow caused an arc of Bühler aneurysm that was embolized. Flow to the CA was maintained through pancreaticoduodenal arcades.

In a unique case Shah et al. [36] used a patent arc of Bühler as route for chemoembolization in a patient with occluded CA.

Conclusions

The arc of Bühler is a rare anatomic variation, probably underestimated due to difficulties in its detection and diagnosis. Despite its rarity seems to possess an important role

for anatomy, embryology, general and vascular surgery, and interventional radiology. In anatomy and embryology it provides insight into developmental processes that ultimately define adult anatomy. In general and vascular surgery it can cause intraoperative difficulties such as anatomy misidentification or unexpected bleeding. The arc of Bühler can also act beneficially by enhancing collateral circulation, offering solutions in cases of CA or SMA obstruction. In interventional radiology it can provide direct access to SMA through the CA and vice versa for diagnostic and even therapeutic reasons. For those reasons we believe that surgical and radiologic interventions in the area should consider the possible existence of the arc of Bühler and alter, if necessary, their approach. The main pathology of the arc of Bühler is aneurismal dilatation. No specific guidelines exist but such aneurysms can be treated in accordance with the guidelines for all visceral aneurysms.

Despite its importance, knowledge on the Buhler's arc is still incomplete. We believe that further investigation on this rare anatomic variation can offer knowledge in various sectors of laboratory and clinical medicine.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

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