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Characterization of the cephalic arch and location of stenosis

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Abstract

Purpose—The purpose of this study is to accurately characterize the cephalic arch segments into four domains and to enable more specific evaluation of cephalic arch stenosis (CAS) and determine the frequency of stenosis in each domain.

Methods—After Institutional Review Board (IRB) approval, a retrospective chart review was done to define a population of patients receiving hemodialysis who developed CAS as apparent on clinically indicated radiologic imaging. A standardized approach was devised to categorize four domains of the cephalic arch. Domain I was defined as the peripheral portion of the arch and Domain IV was the distal portion of the cephalic vein near termination with the axillary vein. The magnitude of stenosis as measured by percentage was determined and compared in the four domains.

Results—The most frequent location for stenosis was found in domain IV when compared with domains II or I ($p < 0.01$). The magnitude of stenosis differed across all domains ($p < 0.001$) with the least common place for CAS in domain I. Treatment of CAS included angioplasty in all, thrombectomy in eight, and stent placement in five.

Conclusions—CAS occurs most commonly in the terminal portion of the arch. Four standardized domains have been defined; future work will validate these findings and determine the best intervention for each domain.

Keywords

Cephalic arch; Fistula; Hemodialysis; Stenosis

Introduction

Adequate vascular access is essential to the quality of life and survival of patients undergoing hemodialysis. As the incidence and prevalence of end-stage renal disease

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(ESRD) is increasing, there is a parallel need for adequate arteriovenous fistulas (AVFs) (1–3). The type of AVF with the best outcomes is the radiocephalic fistula (RCF); however, this access commonly fails to mature in elderly patients and those with underlying vascular disease, such as diabetes (4, 5). The primary patency rate of the RCF varies from 18 to 65% (6–8). The second recommended access is the brachiocephalic fistula (BCF). The leading cause of failure of a BCF access is cephalic arch stenosis (CAS). CAS may lead to complications, including head and neck swelling, prolonged bleeding, poor clearance, and in rare cases compartment syndrome (9–11). Treatment of CAS is difficult, as the stenosis in this area tends to recur leading to the need for repeat angioplasty, stents, surgical revision, or eventual access failure (10, 12).

The cause of CAS is unknown. Although the veins of patients with renal failure show wall thickening and intimal hyperplasia compared with the veins of those without renal failure, this does not explain the high occurrence of CAS (13). Contributing factors may include venous valves that are known to occur in the arch, musculo-skeletal constriction in this area, as the cephalic vein transverses the deltopectoral groove and also abnormal wall shear stress as a result of the bend of the vein as the arch enters the axillary vein (12).

A limiting factor in understanding the cause of CAS is lack of a clear and accurate definition to characterize the cephalic arch and location of the stenosis. Past reports broadly define the cephalic arch as the “term given to the final arch of the cephalic vein before it enters the axillary vein to form the subclavian vein” (12). Furthermore, the geometry of the arch and type of stenosis may be variable (14). There are anatomic variants termed “bifid”, in which the arch forms two channels (12). In our own experience, we have found additional variants of trifid circulation and also complex collaterals.

The primary aim of the current study is to standardize the definition of the cephalic arch and the location of the stenosis. The exact definition of the anatomic landmarks and location and degree of stenosis will provide a reference that will enable improved communication among colleagues when discussing this important clinical problem. Likewise, more specifically describing the location of the stenosis will enable better evaluation of treatments options.

Materials and Methods

This study was approved by the Institutional Review Board. We performed a retrospective review of electronic medical records of all patients who had an AVF placed between 2006 and 2013. Patients were included in the study if they had an operative report of a BCF placement and a subsequent clinically indicated venogram with evidence of CAS. Patients were excluded if there was anomalous venous anatomy that precluded standardized segmental labeling and measurement as was defined in this study, such as a bifid arch, a trifid arch, or a chronic cephalic vein occlusion that leads to collateral replacement of the normal cephalic arch. Patients with one or more cephalic arch stents were also excluded if no pre-stent images were available.

Patients meeting inclusion criteria were submitted to a Radiologist for film review. To establish standardized arch segments for accurate and repeatable measurement, we divided

the cephalic arch into four segments. First, a line was drawn through the arch apex perpendicular to the vein wall. Then, the distance from the cephalic-axillary vein junction to the apex was measured. By dividing the distance between the junction and the apex in half, we found the midpoint and inserted a line perpendicular to the arch at that location. The distance from midpoint to apex was used to place a third line perpendicular to the arch at a location equidistant beyond the apex. In the direction of normal blood flow through the cephalic vein, the four segments were labeled as I, II, III, and IV, respectively (Fig. 1). The diameter of the nearest normal cephalic vein peripheral to the arch was used as the standard by which to characterize areas of narrowing to diagnose stenosis. For the purposes of this paper, and in concordance with the DOQI 2006 AVF guidelines (15), we considered significant stenosis to be 50% or more reduction in normal vein diameter. Any and all areas of significant CAS were noted as they appeared in the earliest available venogram.

Demographic data were collected regarding date of birth, height, weight, ethnicity, and medical history related to factors that may affect vascular health, including dialysis and access history, diabetes, hypertension, lupus, coronary artery disease (CAD), peripheral vascular disease (PVD), medication history, and medical information related to factors that contribute to CAS. A patient was considered to have CAD if they had a prior history of myocardial infarction or cardiac catheterization performed showing significant coronary disease. A patient was considered to have PVD if they had a prior history of amputation from ischemic disease or a vascular study showing ankle-brachial index less than 0.9. A patient was counted as a transplant if they had received a renal transplant. A thrombotic event was defined as evidence of venous thrombosis of the AVF. Years to CAS were defined as the time difference between the date of fistula placement and the date of the first clinical presentation of CAS with imaging confirmation.

Patient age, etiology of renal failure, history of diabetes, hypertension, coronary or PVD, history of renal transplant, weight, body mass index (BMI), history of thrombosis, and years to CAS were summarized by mean, standard deviation, and percentages. Fisher's exact test was used to statistically test for an association between each categorical variable and thrombosis. *p* values in all analyses were adjusted according to the Benjamini-Hochberg method and assessed at a 5% false discovery rate. Percent stenosis (represented as an ordinal variable) in the four quadrants was compared via a cumulative link mixed regression effects model with a random term added to adjust for correlated data from the four quadrants within each patient.

Results

Patient characteristics

Sixty-nine patients were included out of 201 patients who had BCF access placed between 2006 and 2013, as they had radiologic images of the cephalic arch with stenosis that were suitable for the measurements made in the methods. The characteristics of these 69 individuals are represented in Table I. We presented the characteristics as All, Diabetes, and No Diabetes, as certain outcomes (such as years to CAS and thrombosis) were predicted to occur more commonly in diabetics, but we did not find this to be the case ($p>0.05$). The mean number of years to development of CAS was 2.93 ± 1.93 and did not differ between

diabetic and nondiabetic individuals. The incidence of the stenosis according to the age of the fistula was determined by classifying the number and percent of individuals who developed detectable CAS during the time intervals 0–1 year (10 individuals 14.5%); 1–2 years (17 individuals 24.6%); 2–3 years (11 individuals 15.9%), or greater than 3 years (31 individuals 44.9%). Sixty-nine subjects were included in the analysis with characteristics represented in Table I. Majority of BCFs (71%) were placed in the left upper arm. Diabetes was the most common cause of ESRD. The most common cause of ESRD was diabetes (43.5%) followed by hypertension (36.2%). The indications for venography included high venous pressure with prolonged bleeding in 5150 individuals, thrombosis in eight, poor clearance in six, pain in the extremity in three, and difficulty with cannulation in one individual. Treatment of the CAS included angioplasty in all, thrombolysis with angioplasty in eight individuals, and angioplasty with stent placement in five individuals. On review of access history, 50.7% of individuals had an episode of thrombosis at some point. The incidence of thrombosis increased in diabetic individuals (58.8%), but did not reach statistical significance when compared with nondiabetic individuals ($p = 0.23$).

Location and magnitude of stenosis

The location of the stenosis, as defined by domains, is summarized in Table II. Domain IV was the most common domain to have evidence of stenosis (72.5%), followed by domain III (56%), domain II (40.6%), and then domain I (17.4%). Pairwise comparison of stenosis incidence in the four domains showed that stenosis was most common in domain IV when compared with domain II or I ($p < 0.01$), in domain III when compared with domain I ($p < 0.001$), and in domain II when compared with domain I ($p = 0.0068$). Domain I has the least number of patients with stenosis as compared with domains II, III, and IV. The location of the stenosis on digital subtraction image analysis represented by the domains is shown in Figure 2. The magnitude of stenosis as measured by percentage is shown in Figure 3. Zero to 50% was defined as no significant measureable stenosis. Domain I had the greatest number of patients in the 0–50% category, with the least number evident in domain IV. The magnitudes differed across all domains ($p < 0.001$).

Discussion

The most common location of CAS is at the distal cephalic vein near termination with the axillary vein. We have developed a uniform approach to define four domains of the cephalic arch and subsequent stenosis. CAS is a common problem and once evident is difficult to treat. As research continues to elucidate the pathophysiology of CAS, and to improve therapy, we believe that a standardized nomenclature for describing arch segmental anatomy is needed. Approaching the evaluation and treatment of CAS by using specific terms for each arch segment may allow for the detection of trends, such as the location of venous valves and other pathology. Defining the cephalic arch in terms of well-defined segmental domains will improve communication among the interdisciplinary teams when discussing treatment options.

For reasons that are still under investigation, the cephalic arch has a relatively high tendency to develop stenosis. Various mechanisms of CAS have been proposed, including venous

adaptation due to changes in sheer stress that promote intimal hyperplasia, and hypertrophic remodeling related to increased postfistula transmural venous blood pressures (16, 17). Venous valves, musculoskeletal compression, and restricted venous mobility in the deltopectoral groove are also likely to contribute to arch pathology in certain cases. Given that venous valves are commonly found in the distal arch (12), they may account for the stenosis frequently found in this region. Alternatively, pressures and flows may be highest in the terminal domain and contribute to the development of stenosis. More research is needed to establish whether certain domains are more likely to experience thrombosis versus stenosis or other complications. Furthermore, as researchers continue to evaluate therapeutic outcomes in separate arch domains, we hope to find whether different interventions provide different longevity or decrease morbidity.

The domains are important, as they give us a clue as to etiology of stenosis (possible valves) and also the different domains may respond differently to angioplasty and/or stent. Reviews have associated the cephalic arch with higher rates of resistance to angioplasty, higher inflation pressures required, greater rupture rates, and more frequent need for stent placement (18–20). Cephalic arch lesions nearly always recur and require multiple interventions (21). Angioplasty is often attempted with resilient stenosis common leading to the need for stent placement. Once stents are placed, there is often intrastent intimal hyperplasia and resultant stenosis and AVF failure. Our hypothesis is that the biology of the vessel and subsequent type of stenosis is different in the four domains. This concept is evident in other vascular trees such as the renal artery. If stenosis occurs in the renal artery and it is proximal, it is often due to atherosclerosis. A distal lesion is often due to fibromuscular dysplasia (22). Optimal treatment may vary by domain. An intervention trial is needed for each domain. By continuing to evaluate cases of arch stenosis by specific domain, we hope to find whether certain domains are more susceptible to certain pathologies, such as thrombus, and whether certain domains respond more robustly to specific therapeutic interventions.

This study has limitations, including the retrospective design, small number of individuals, and error inherent in measurement by a single radiologist. We need three blinded independent observers to validate this method of radiologic measurement. The anastomotic design when a fistula is created has been show to influence wall shear stress and may be a determinate as to which domain the stenosis occurs in. These issues will be addressed in future studies.

In summary, we choose to more accurately characterize CAS by domains. We have developed a simple algorithm for describing the location of the stenosis in the cephalic arch. Future studies are now needed to correlate the location of stenosis with clinical symptoms and intervention options to determine the optimal treatment strategy for each domain.

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Fig. 1.
Normal cephalic arch with domains. Selective DSA image from left brachiocephalic fistula venogram demonstrating a normal cephalic arch with designated domains.

Fig. 2.

Four domains with representative stenosis. Selective DSA image from left brachiocephalic fistula venogram. **(A)** Cephalic arch stenosis in both domains I and IV. **(B)** Stenosis exceeding 50% in domain II. **(C)** Stenosis involving most of domain III. **(D)** Isolated stenosis of domain IV.

Fig. 3. Number of patients in each domain with representative magnitude of stenosis as measured by quartiles. Magnitude of stenosis in domains **I**, **II**, **III**, and **IV**. Zero to 50% represents no stenosis measured.

TABLE I

Characteristics of individuals

	All	Diabetes	No diabetes	p
Age (years)	54.19 ± 17.22	59 ± 14.06	48.67 ± 18.58	0.00*
Right	20 (29%)	9 (26.5%)	11 (31.4%)	
Diabetes	34 (49.3%)	34 (100%)	0 (0%)	
Hypertension	61 (88.4%)	32 (94.1%)	29 (82.9%)	0.26
PVD	17 (24.6%)	12 (35.3%)	5 (14.3%)	0.05
CAD	39 (56.5%)	23 (67.6%)	16 (45.7%)	0.09
Transplant	23 (33.8%)	6 (17.6%)	17 (50%)	0.01
Weight (kg)	86.29 ± 21.8	88.59 ± 21.66	84.06 ± 22.01	0.35
BMI	31.28 ± 7.45	31.66 ± 7.02	30.9 ± 7.92	0.63
Thrombosis	35 (50.7%)	20 (58.8%)	15 (42.9%)	0.23
Years to CAS	2.93 ± 1.93	2.85 ± 1.98	3.02 ± 1.91	0.62

Values are means ± SE or count (%) as appropriate.

BMI = body mass index; CAS = cephalic arch stenosis; CAD = coronary artery disease; PVD = peripheral vascular disease.

* Benjamini-Hochberg method of p-value adjustment was used to control the false discovery rate at 5%.

TABLE II

Cephalic arch stenosis in each domain (counts and percentages)

	Domain I	Domain II	Domain III	Domain IV
All (n = 69)	12 (17.4%) ^{II,III,IV}	28 (40.6%) ^{I,IV}	39 (56.5%) ^I	50 (72.5%) ^{I,II}
Diabetes (n = 35)	9 (26.5%) ^{IV}	15 (44.1%)	17 (50%)	24 (70.6%) ^I
No diabetes (n = 34)	3 (8.6%) ^{II,III,IV}	13 (37.1%) ^{I,IV}	22 (62.9%) ^I	26 (74.3%) ^{I,II}

Values are counts (%) of stenosis for each domain for all individuals, diabetes, and no diabetes.

I, II, III and IV indicate Benjamini-Hochberg method of p-value adjustment, which was used to control the false discovery rate at 5%.