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ORIGINAL ARTICLE

Establishing an autogenous vascular access program in a Guatemalan comprehensive pediatric nephrology center

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Abstract

Background The Guatemalan Foundation for Children with Kidney Diseases collaborated with Bridge of Life, a not-for-profit charitable organization, to establish a vascular access program. We reviewed our experience with graded surgical responsibility and structured didactic training, creating arteriovenous fistulas (AVF) for Guatemalan children.

Methods Pediatric vascular access missions were completed from 2015 to 2023 and analyzed retrospectively. Follow-up was completed by the Guatemalan pediatric surgeons, nephrologists, and nursing staff. AVF patency and patient survival were evaluated by Kaplan–Meier life-table analysis with univariate and multivariable association between patient demographic variables by Cox proportional hazards models.

Results Among a total of 153 vascular access operations, there were 139 new patient procedures, forming the study group for this review. The mean age was 13.6 years, 42.6% were female, and the mean BMI was 17.3. Radial or ulnar artery-based direct AVFs were established in 100 patients (71.9%) and ten of the 25 transposition procedures. Brachial artery inflow was required in 29 direct AVFs (20.9%). Two patients underwent femoral vein transpositions. Access-related distal ischemia was not encountered. Seven of the AVF patients later required access banding for arm edema; all had previous dialysis catheters (mean = 9, range 4–12). Primary and cumulative patency rates were 84% and 86% at 12 months and 64% and 81% at 24 months, respectively. The median follow-up was 12 months. Overall patient survival was 84% and 67% at 12 and 24 months, respectively. There were no deaths related to AVF access.

Conclusions Safe and functional AVFs were established in a teaching environment within a Guatemalan comprehensive pediatric nephrology center.

Keywords Pediatric · Hemodialysis · AVF · Arteriovenous fistula · Autogenous · Guatemala · Children · Adolescents · Chronic renal failure · Chronic kidney disease · Kidney failure · Vascular access · Medical mission

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Introduction

Among the two billion children worldwide, more than two million are estimated to be affected by chronic kidney disease (CKD), roughly the same number of children with type one diabetes or those with childhood cancers [1]. The global burden of pediatric kidney failure (KF) is difficult to quantify. However, an analysis by Harambat et al. suggests the overall number of children and young adults worldwide with KF and in need of kidney replacement therapy (KRT) to be at least 500,000 [2]. They estimated that hundreds of thousands of children have died in recent years as a result of KF. Childhood KF in high-income countries is uncommon and KRT is almost universally available. In the United States, fewer than 2% of the roughly 750,000 individuals receiving KRT are children less than 21 years of age [3, 4].

Although the National Kidney Foundation Dialysis Outcomes Quality Initiative guidelines have limited recommendations specifically for children [5], the European Society for Pediatric Nephrology Dialysis Working Group has compiled a thorough review with data-driven recommendations from dedicated pediatric nephrology and KRT centers [6]. Kidney transplantation is the preferred therapy for KRT in both children and most adults; however, many barriers exist for establishing pediatric transplantation in developing countries, such as lack of access to transplantation centers, expertise for new programs, care in remote locations, and cost of procedures, in addition to medications and follow-up [7]. Peritoneal dialysis (PD) is frequently chosen for KRT in younger patients when a transplant is not available or not successful. However, hemodialysis remains a commonly utilized therapy for pediatric KRT in the United States and Europe, as well as in many lower- and middle-income countries [6, 8–11].

Long-term survival for children with KF in higher-income countries has dramatically improved in recent years. However, mortality remains roughly 30 times higher than in healthy children and adolescents [12]. Improved outcomes are reported within comprehensive pediatric kidney care centers based on expanded treatment options, clinical facilities, and focused experience with childhood KF issues [6, 13]. Access to specialized pediatric CKD and KF care is often problematic in middle- and low-income countries. However, reports of pediatric KF care in lower-resource settings where comprehensive centers of pediatric KRT care are available find high-quality outcomes despite regional limitations [9, 11, 13, 14].

The Foundation for Children with Kidney Diseases in Guatemala (FUNDANIER) is the only comprehensive center for pediatric CKD, KF, and KRT in Guatemala [11, 14, 15]. Bridge of Life (BOL) is a not-for-profit charitable organization offering worldwide programs focused on renal healthcare; establishing, supporting, and sustaining dialysis treatment facilities; and many other programs such as CKD screenings and treatment for kidney disease [16]. BOL first collaborated with FUNDANIER in 2012 to support the existing KRT program. Most pediatric hemodialysis vascular access was provided by central venous catheters (CVC). BOL support was expanded in 2015 to establish a hemodialysis vascular access program, creating arteriovenous fistulas (AVF) with clinical and structured didactic training.

AVFs offer the most durable hemodialysis vascular access and are associated with lower morbidity and mortality in addition to a lower cost profile when compared to prosthetic grafts and particularly CVCs [6, 13, 17–19]. Children initiating hemodialysis with an autogenous access have superior access patency and overall survival relative to those with a graft or CVC [20–24]. Children with a permanent access rather than a CVC have improved quality of life and fewer symptoms of depression [24]. A multidisciplinary vascular access program incorporating ultrasound assessment is a key element for establishing and maintaining a successful AVF for children receiving chronic hemodialysis [6, 13, 25]. Although it is recommended to establish a functional AVF in appropriate patients before dialysis is initiated, most children still start hemodialysis with a CVC [6, 18]. Children larger than 20 kg in weight requiring hemodialysis and with an expected kidney transplant wait-time of more than 6 months should be evaluated for a permanent vascular access [6]. Although there are few reports of pediatric hemodialysis access outcomes in low- and middle-income countries worldwide, an autogenous access can be constructed in most pediatric patients, despite regional challenges, with outcomes that rival most high-income countries [9–11, 26–29].

We previously reported outcomes of the first three BOL surgical access teaching missions in Guatemala, training local pediatric surgeons with graded surgical responsibility in creating safe and functional AVFs including preoperative evaluations, a full range of access options, and postoperative care [11]. This study analyzes outcomes of this pediatric autogenous vascular access teaching program during an 8-year period and evaluates patient survival according to KRT access and long-term follow-up care within FUNDANIER versus adult dialysis care.

Methods

We retrospectively reviewed our database of hemodialysis vascular access operations performed at the Roosevelt Hospital (University of San Carlos School of Medicine) in Guatemala City during an 8-year period. There were no missions during 2020 due to the COVID-19 pandemic.

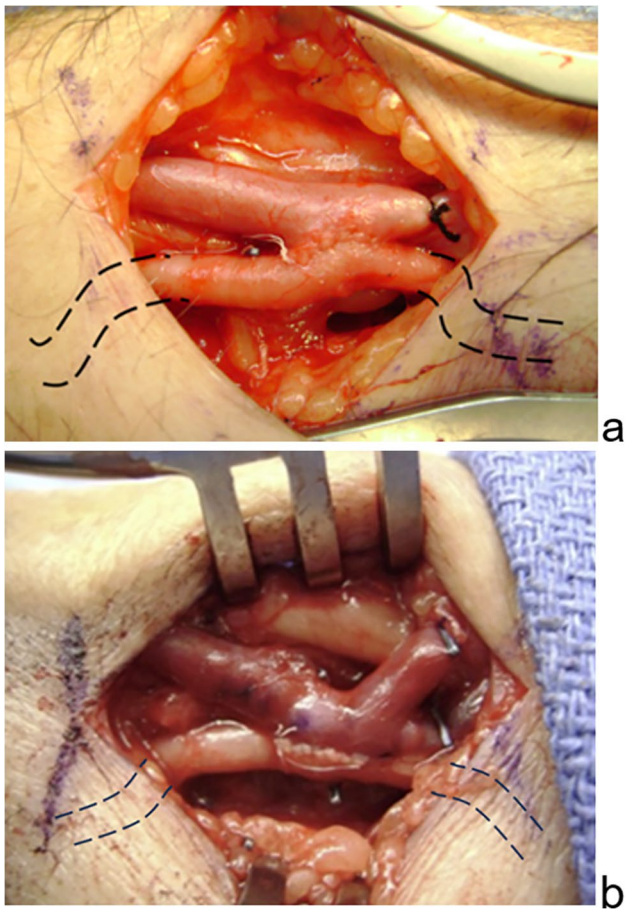


Fig. 1 **a**, **b** Operative radiocephalic arteriovenous fistula photos with radial artery elevation, leaving the cephalic vein undisturbed or with minimal vein mobilization. Dashed lines show the elevated radial artery. Images used with permission from Jennings WC, Glazer SM (2017) J Vasc Surg 65:933–934 and Zamor K, Jennings WC (2023) Avoiding Early Failure in Arteriovenous Fistulas. Textbook of Comprehensive Dialysis Access. 2023, Karl Illig editor. Springer Nature, In press

Each patient underwent preoperative physical examination with duplex vascular ultrasound (US) evaluation by the BOL surgeons and participating Guatemalan fellowship-trained pediatric surgeons along with pediatric nephrology colleagues. A brief US review was often conducted in the operating theater prior to more complex operative procedures, confirming the surgical plan, vessels involved, and incision(s). The anticipated AVF outflow veins had a minimal diameter of 2.0 mm demonstrated on US imaging with a tourniquet in place. US confirmed a compliant vein that was free of any segmental narrowing or thickening. An arterial diameter ≥ 1.5 mm was required for the access creation. An autogenous access creation was anticipated for all patients.

Technical considerations for pediatric AVF vascular access procedures have been reviewed in a recent report [29] and are summarized here. A distal radial cephalic (RC-AVF) was the first choice when adequate vessels were present (Fig. 1a and b). When an RC-AVF was not feasible, a mid-forearm AVF presented the next option when adequate vessels and outflow cannulation length were identified (Fig. 2). Broad elevation of the radial artery was an important component of these more distal AVFs, using cautery to divide small branches well away from the artery. A proximal radial artery (PRA) AVF was chosen when those more distal opportunities were not present [30]. A proximal ulnar artery inflow fistula was selected if the radial artery provided all (or most) arterial supply to the hand. A brachial artery-based AVF was created when these distal options were not possible, limiting the anastomosis size relative to the brachial artery diameter (3–4 mm in length). When a direct AVF was not possible, a transposition procedure with the basilic vein was performed when possible. These operations were completed in staged procedures when the vein was 2–4 mm in diameter with the basilic vein elevated after maturation, 4–5 weeks later [31]. A basilic vein outflow tunneled transposition was often used as a single-stage procedure with a brachial, PRA, or proximal ulnar inflow anastomosis when the vein was > 4 mm. Another option utilized for a single-stage basilic vein access with PRA or ulnar inflow was primary

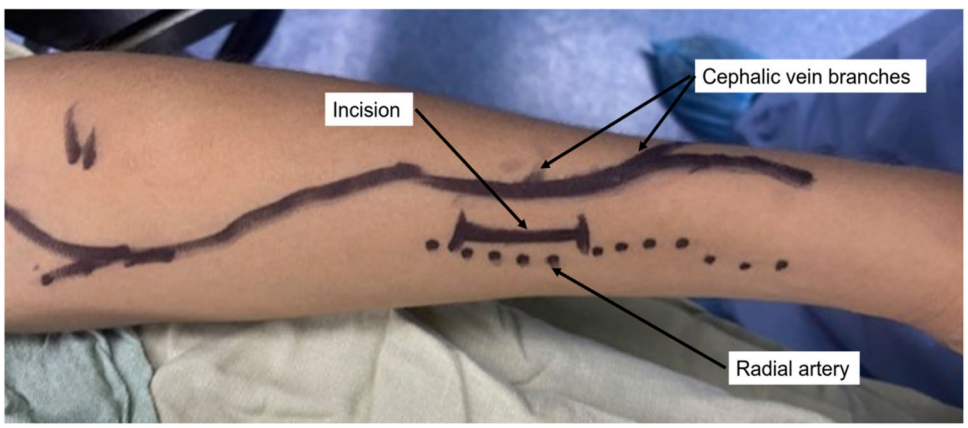


Fig. 2 Constructing a RC-AVF proximal to the common location at the wrist may offer a larger outflow vein at the juncture with a side branch. The surgeon's ultrasound evaluation will identify such an opportunity

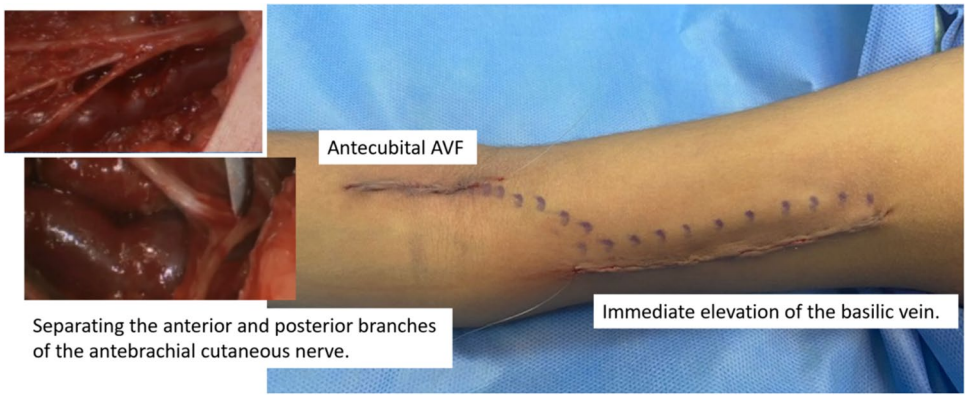


Fig. 3 The photos show an antecubital AVF with outflow into the basilic vein. Immediate elevation of the basilic vein was facilitated by incising the median antebrachial nerve epineurium, allowing separation of the nerve branches

vein elevation, separating the median antebrachial nerve fascicles, if necessary, to allow mobilization and elevation of the basilic vein (Fig. 3). Bi-directional outflow PRA-AVFs were established at the surgeon's discretion when feasible [32].

AVFs were generally created with running suture technique, and suture material varied among surgeons (CV-8 or CV-7, Gore & Associates, Inc., Flagstaff, AZ, USA; Prolene 7–0 or 6–0, Ethicon Inc., Cincinnati, OH, USA; and vascular clips, LeMaitre Inc., Burlington, MA, USA). Interrupted sutures at the heel of the anastomosis were used in some patients for smaller vessels. These access procedures were completed with 3.0 × –5.0 × magnification.

Anesthesia colleagues with the BOL team were active providers in concert with the Guatemalan anesthesia residents and faculty. Endotracheal intubation was avoided in almost all patients with laryngeal mask anesthesia supplemented with long-acting local infiltration agents. Sedation alone with local anesthetic was appropriate for some adolescents. Heparin and prophylactic antibiotics were not used routinely.

The patients were followed in the pediatric dialysis unit and nephrology clinic for AVF maturation. Initial cannulation was allowed in 4–6 weeks with rope-ladder technique. Buttonhole cannulation has not been adopted in Guatemala, however is frequently used in other countries and particularly recommended for pediatric patients [29, 33]. Consultation with BOL surgeons remains available throughout the year when requested.

Children within the FUNDANIER program without a permanent access or past failed AVF(s) created elsewhere were most common. However, occasional patients from other dialysis units with access complications such as aneurysms, high access flow, arm edema, or other issues were also evaluated and treated as indicated. Some individuals with a dysfunctional access created elsewhere were referred for access salvage and required an AVF revision procedure. New patients with access salvage procedures were included in the analysis.

The etiology of KF for individual patients was recorded and evaluated in four groups including (1) congenital anomalies of kidney and urinary tract (CAKUT) such as obstructive uropathy and reflux nephropathy, (2) glomerular disease such as glomerulosclerosis and glomerulonephritis, (3) undetermined, and (4) other uncommon diseases. Obesity was defined by the calculated body mass index (BMI) and grouped as reported by the Centers for Disease Control and Prevention, forming the definition of obesity in this analysis [34].

Primary AVF patency was defined as the time in months from AVF creation with uninterrupted patency and without intervention. Cumulative patency was the time in months from the original AVF creation, regardless of interventions, until the end of the study period, access failure, loss to follow-up, transplantation, or death. A nonfunctional AVF was recorded as a failed access.

Kaplan–Meier plots were constructed by life-table analysis to evaluate patency rates at different time points. Associations of primary and cumulative AVF patency rates with study variables were examined by Cox proportional hazards models, calculating hazard ratio (HR), and 95% confidence intervals (CIs). Data were analyzed using SAS version 9.4 software (SAS Institute, Cary, NC, USA), and the significance of differences was $P < 0.05$.

Results

A total of 153 AVF vascular access procedures were completed by BOL surgeons with Guatemalan pediatric surgical colleagues during the 8-year study period. Fourteen of these were established patients who required secondary operations. New AVF procedures were performed in 139 individuals, forming the study group for this review. The mean

Table 1 Characteristics of the arteriovenous fistulas studied ($n=139$)

Variable	Number (%)
Age, years *(mean ± SD)*	13.58 ± 2.69
BMI *(mean ± SD)*	17.32 ± 2.94
Gender	
Female	58 (41.73)
Male	81 (58.27)
Cause of kidney failure	
Undetermined	94 (71.21)
CAKUT	30 (22.73)
Glomerular disease	5 (3.79)
Other	3 (2.27)
Type of operation	
Radiocephalic	37 (26.62)
Mid-forearm RC	17 (12.23)
ProxRadArt	29 (20.86)
Brachial art	14 (10.07)
Transposition	25 (17.99)
Banding	6 (4.32)
Revision	4 (2.88)
Snuffbox	1 (0.72)
ProxUlnarArt	6 (4.32)
Previous AVFs	
Yes	25 (23.15)
No	83 (76.85)
Site of current dialysis care	
Pediatric	38 (27.34)
Adult	101 (72.66)
Number of catheters, *median (min, max)*	4 (0, 17)
Time of dialysis (months), *median (min, max)*	18 (0, 132)

age was 13.6 years, mean BMI was 17.3, and 60 patients (42.6%) were female. Demographic data are summarized in Table 1. The cause of KF was undetermined in 71.2% of patients with CAKUT identified in 22.7%.

Radial or ulnar artery-based direct AVFs were established in 100 (71.9%) patients, including 37 (26.6%) distal radial artery-based AVFs, 17 (12.2%) mid-forearm AVFs, and 29 (20.9%) PRA-AVFs. Transposition procedures were necessary in 25 children; ten of these were based on the proximal radial or proximal ulnar artery. Brachial artery inflow was required in 29 individuals (20.9%), 15 of these for basilic vein transposition procedures. Among the 25 transpositions, 12 were first-stage procedures that were completed later by the Guatemalan surgical group, generally as basilic vein elevation procedures. Two patients underwent femoral vein transpositions. Prosthetic (PTFE) graft segments were infrequently used for establishing an arterial inflow segment (2), axillary swing site bypass (1), or other revision patch angioplasty repairs (2). There were no infections involving graft material, and no graft segments were used as cannulation sites. Ten patients in the study group were referred from other centers with problematic AVFs created elsewhere. Six of these children required a flow-reduction banding procedure [35], and four underwent a surgical revision for salvage of a dysfunctional AVF.

Primary and cumulative patency rates were 84% and 86% at 12 months and 64% and 81% at 24 months, respectively (Fig. 4). Median follow-up was 12 months with a median duration of cumulative patency of 61 months (50% of the participants had a patent AVF for 61 months). Thirty-one children were eventually lost to follow-up at 1–43 months (mean 6 months), all after transfer from pediatric nephrology care to various adult units.

AVF patency was analyzed for association with individual study demographics (Table 2). Patients with an unknown cause for KF had higher primary AVF patency ($p=0.02$). Ulnar AVF inflow ($n=6$) was associated with lower primary and cumulative patency ($p=0.04$ and $p=0.05$, respectively). Younger age, BMI value, and female gender were not associated with lower patency rates. The number of previous dialysis catheters ranged from none to 17 catheters (median 4). A history of multiple past dialysis catheters was not associated with AVF patency when analyzed overall or by evaluation of the total number of catheters in subgroups. No patient developed access-related distal ischemia.

Seven established patients in the study group later required access banding for arm edema with high AVF flow (one of these also required repair of an aneurysm). High AVF flow and associated elevated access pressure reduction were established by precision banding [35], targeting duplex ultrasound measured brachial artery flow volume post banding of 500–800 ml/min. These individuals had a history of several CVCs (4–12, mean = 9) and had developed arm, shoulder, and/or facial edema. Several patients had resting tachycardia that resolved with access compression (Nicoladoni/Branham sign [35]). Six other children in the study group later required an AVF revision, and one individual with a dysfunctional AVF that could not be salvaged underwent access ligation. These additional 14 operations for established patients were entered in the study group analysis as a failure of primary patency and loss of cumulative patency for the single individual with an AVF ligation. Percutaneous intervention for access salvage has not been readily available in Guatemala, although two patients underwent an attempt at dysfunctional AVF intervention by balloon angioplasty. Both procedures were unsuccessful and without complication.

Overall patient survival was 84% and 67% at 12 and 24 months, respectively. Median survival time was 31 months. There were no deaths related to AVF access. Table 3 shows the analysis for the association of overall survival with the study variables. A longer time period for patients receiving hemodialysis (0–132 months,

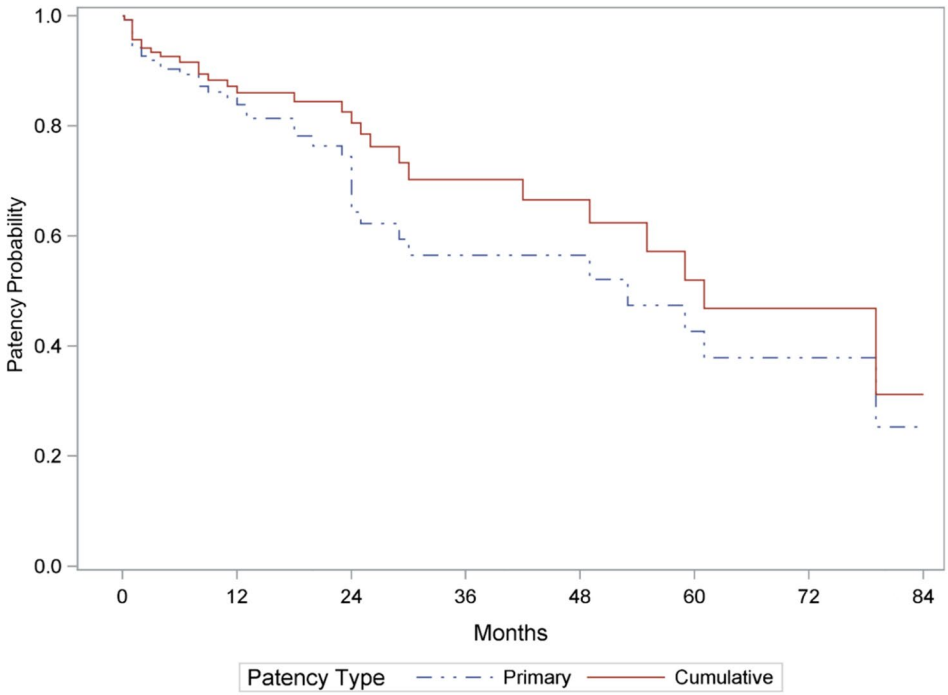


Fig. 4 Kaplan–Meier plot of primary and cumulative AVF patency among the arteriovenous fistulas studied. The standard error for the primary patency curve exceeds 10% at 84 months, making the curve unreliable after that point

Patency Type		Months							
		0	12	24	36	48	60	72	84
Primary	No. at risk	139	74	37	16	13	9	4	2
	Probability of patency	1	0.84	0.64	0.57	0.57	0.43	0.38	0.25
	Standard error	0	0.04	0.06	0.07	0.07	0.09	0.09	0.12
Cumulative	No. at risk	139	75	42	20	16	10	5	2
	Probability of patency	1	0.86	0.81	0.70	0.67	0.52	0.47	0.31
	Standard error	0	0.03	0.04	0.06	0.07	0.09	0.10	0.14

median = 32) was associated with a risk of lower survival ($p = 0.02$). Overall patient survival was not influenced by the presence of a functional AVF, the number of previous dialysis catheters, age, BMI value, or patient transfer into an adult dialysis unit (Table 3 and Fig. 5). Seven patients arrived from outside dialysis centers for AVF procedures with available follow-up of only 1 month or less. These individuals had a successful AVF created but no long-term F/U has been available. Analysis of the data set with these seven patients censored found no significant changes in the patency or survival results.

Discussion

Guatemala has a population of over 17 million people with roughly 50% comprised of indigenous Maya people in rural communities where access to healthcare, including CKD care and dialysis, is limited. The Guatemalan Fundación para el Nino Enfermo Renal (FUNDANIER, Foundation for Children with Kidney Diseases) was established in 2003 and provides kidney care to pediatric and adolescent patients with CKD and KF in Guatemala [14].

Along with our colleagues in Guatemala, we previously reviewed our initial teaching experience while creating permanent vascular access for children in the FUNDANIER comprehensive pediatric nephrology center [11]. At that time, successful peritoneal dialysis and transplantation programs were already established [14, 15]; however, pediatric vascular access expertise was lacking. Non-cuffed temporary dialysis catheters provided almost all hemodialysis access, and the majority were placed through subclavian vein sites, all without US guidance. During the first three missions, 54 new patients had a vascular access constructed with the Guatemalan pediatric surgeons advancing from assistant to primary surgeon by the second and third missions. Physical examination, US skills, and didactic surgical technique sessions were included in the teaching experience. Later, successful surgical interventions required for access dysfunction were completed by one of the trained Guatemalan surgeons. Since that time, central venous dialysis access catheters have been placed through the internal jugular vein with US imaging.

Table 2 Arteriovenous fistula (AVF) patency according to study variables

Variable	Patency type			
	Primary		Cumulative	
	HR (95% CI)	*p*-value	HR (95% CI)	*p*-value
Age	0.893 (0.791, 1.008)	0.0668	0.953 (0.826, 1.099)	0.5087
BMI	0.929 (0.826, 1.046)	0.2250	0.940 (0.821, 1.075)	0.3666
Gender				
Female	0.574 (0.293, 1.125)	0.1057	0.702 (0.329, 1.495)	0.3585
Male	Reference		Reference	
Cause of kidney failure				
CAKUT	Reference		Reference	
Undetermined	0.456 (0.232, 0.896)	0.0227	0.688 (0.307, 1.541)	0.3634
Glomerular disease	0.910 (0.117, 7.110)	0.9286	1.601 (0.195, 13.172)	0.6614
Other	0.588 (0.077, 4.511)	0.6096	1.398 (0.173, 11.270)	0.7529
Type of operation				
Radiocephalic	Reference		Reference	
Mid-forearm RC	0.746 (0.205, 2.718)	0.6571	0.742 (0.153, 3.588)	0.7103
ProxRadArt	0.907 (0.328, 2.508)	0.8514	1.128 (0.355, 3.579)	0.8380
Brachial art	1.733 (0.580, 5.172)	0.3245	2.218 (0.629, 7.819)	0.2153
Transposition	1.402 (0.565, 3.482)	0.4661	1.503 (0.524, 4.306)	0.4484
Banding	–-		–-	
Revision	1.257 (0.159, 9.930)	0.8286	2.03 (0.244, 16.853)	0.5122
Snuffbox	–-		–-	
ProxUlnarArt	3.485 (1.061, 11.451)	0.0396	4.149 (1.024, 16.804)	0.0462
Previous AVFs				
Yes	Reference		Reference	
No	1.700 (0.507, 5.705)	0.3900	1.230 (0.357, 4.246)	0.7428
Site of dialysis care				
Pediatric	Reference		Reference	
Adult	0.530 (0.255, 1.101)	0.0886	0.794 (0.332, 1.900)	0.6046
Number of catheters	1.006 (0.912, 1.109)	0.9065	1.024 (0.920, 1.139)	0.6656
Time of dialysis (months)	0.998 (0.986, 1.009)	0.6917	1.007 (0.995, 1.019)	0.2362

Although healthcare is a constitutionally guaranteed right for Guatemalan citizens, limited government resources make funding problematic. Support through BOL and other donors has allowed improved services and program expansion. Currently, 197 children and adolescents with CKD are cared for through FUNDANIER. Among the patients with KF, 118 receive home PD, 38 are treated with hemodialysis, and 41 have a functioning renal transplant. Since the first successful pediatric kidney transplant at FUNDANIER's program in 2008, 117 children have received a kidney transplant with 84% as living-related donors.

The value of a dedicated center for children with CKD and KF such as FUNDANIER is well established [6, 7, 13, 25, 36, 37]. Several studies have shown that an experienced team of vascular access surgeons, nephrologists, and nurses in addition to US capabilities offers lower catheter rates and improved AVF results [25, 36]. Menon et al. reported the importance of pre-dialysis pediatric care and found such planning dramatically decreased the number of unscheduled dialysis starts with an increased incidence of a functional access in place when hemodialysis was needed [36].

As in the rest of the world, the majority of children treated for KF in Guatemala start dialysis with PD, offering home care for those patients far from population centers. Clearly, financial and housing issues are important in selecting PD for KRT [14] as the cost of PD is usually less than half the cost of hemodialysis per person per year [12, 14]. We recommend that PD patients be evaluated by the access surgeon to map and plan an AVF site if needed later. Higher patient survival has been reported for children on maintenance PD when compared with hemodialysis, although survival rates are often decreased in lower-income countries [37]. PD may have limitations in adolescents. Arhuidese et al. found no mortality difference between PD or hemodialysis for children < 13 years of age. However, PD was associated with

Table 3 Association of overall survival with study variables

Variable	HR (95% CI)	*p*-value
Age	0.980 (0.877, 1.095)	0.7218
BMI	0.919 (0.826, 1.024)	0.1250
Gender		
Female	0.976 (0.547, 1.740)	0.9347
Male	Reference	
Cause of kidney failure		
CAKUT	Reference	
Undetermined	0.877 (0.457, 1.684)	0.6933
Glomerular disease	3.929 (0.836, 18.474)	0.0838
Other	0.742 (0.096, 5.728)	0.7750
Type of operation		
Radiocephalic	Reference	
Mid-forearm RC	0.926 (0.301, 2.848)	0.8940
ProxRadArt	1.167 (0.497, 2.740)	0.7228
Brachial art	0.752 (0.213, 2.663)	0.6591
Transposition	1.397 (0.645, 3.022)	0.3963
Banding	3.007 (0.643, 14.055)	0.1618
Revision	1.037 (0.135, 7.979)	0.9720
Snuffbox	–-	
ProxUlnarArt	0.984 (0.218, 4.434)	0.9829
Previous AVFs		
Yes	Reference	
No	2.480 (0.585, 10.510)	0.2175
Site of current dialysis care		
Pediatric	Reference	
Adult	1.092 (0.541, 2.204)	0.8062
Cumulative AVF patency		
Fail	Reference	
Open	0.870 (0.463, 1.635)	0.6656
Number of catheters	0.999 (0.907, 1.100)	0.9868
Time of dialysis (months)	1.010 (1.001, 1.018)	0.0244

higher mortality risk when compared to hemodialysis in adolescents [20].

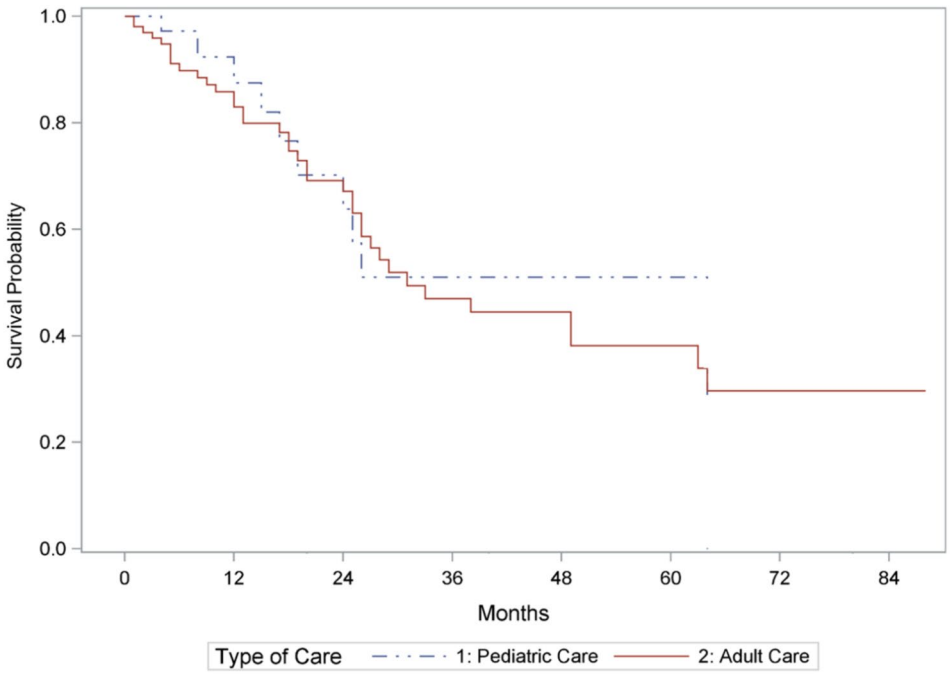
Many children will require hemodialysis access initially or later in their treatment plan. Reports of hemodialysis vascular access experience in pediatric and adolescent patients are limited in number and often comprise accumulated patients from multiple centers in publications from both higher- and lower-income countries [6, 9–11, 13, 26, 27, 29, 38, 39]. These studies demonstrate successful functional AVF patency rates similar to outcomes in vascular access reports of adult patients.

An autogenous access is the preferred choice for long-term hemodialysis access in children and adults, with lower morbidity and mortality, superior long-term patency, and better quality of life when compared with grafts and catheters [6, 13, 21–23, 40]. This study shows our approach to establishing distal AVFs whenever possible and includes techniques particularly helpful in pediatric AVF construction, such as mobilization of the radial artery to minimize the risk of juxta-anastomotic stenosis and recognizing the option of mid-forearm AVFs [29]. These maneuvers help establish moderate flow AVFs, retain more proximal access options, and, along with utilizing the proximal radial artery for inflow in cubital fossa AVFs, minimize the need for a brachial artery inflow anastomosis [30]. All but five patients in our study had previous CVCs (mean = 4, range 0–17). Vascular access intervention for central venous obstruction or stenosis has limited success in the United States and Europe with frequent and early recurrence, and is not practiced in Guatemalan pediatric patients. These children were generally not candidates for PD, and avoiding long-term catheter-based hemodialysis access was critical. Importantly, our experience creating modest flow AVFs in such patients has been successful [41, 42], and the number of past catheters did not impact AVF patency in this study. Those patients developing symptoms were treated by flow reduction procedures with precision banding resulting in AVF salvage [35]. Although we obtained central venous imaging in selected cases, we felt it would not likely add value to patient care for most individuals. Children weighing less than 20 kg are generally treated with PD or catheter hemodialysis access. When resources permit, small children may be candidates for AVF construction using an operating microscope [43]. None of the children in this study group weighed less than 20 kg.

Although adult studies in developed countries show that vascular access grafts outperform catheters when an AVF is not feasible, graft complications are more common when compared with AVFs and grafts are rarely utilized in children [6, 13, 29]. The cost of a prosthetic graft, increased need for interventions, and shorter overall patency make grafts placed for dialysis vascular access particularly unsuited for access in low- and middle-income countries [39]. Serum markers of hemodialysis efficacy in children before and after conversion of a catheter to an AVF or graft access were reviewed by Onder et al., finding significant improvement in all four markers studied with AVF patients. However, these changes were not noted in children converted to a graft access [19].

Primary AVF patency in this report is similar to other pediatric access studies in the United States [26, 29]. However, cumulative patency after 4 years was roughly 25% lower than reported in those studies, presumed in part to be due to a lack of experienced and readily available percutaneous access intervention options. Surgical interventions for dysfunctional AVFs were generally successful, although such revisions were uncommon between BOL missions.

All agree that creating a functional AVF before the start of hemodialysis is ideal but rarely accomplished in the United States, Europe, Guatemala, or elsewhere. For



Type of Care		Months							
		0	12	24	36	48	60	72	84
Pediatric	No. at risk	38	19	11	4	4	1	---	---
	Probability of survival	1	0.88	0.64	0.51	0.51	0.51	---	---
	Standard error	0	0.07	0.11	0.12	0.12	0.12	---	---
Adult	No. at risk	101	61	34	19	14	10	5	3
	Probability of survival	1	0.83	0.67	0.47	0.45	0.38	0.30	0.30
	Standard error	0	0.04	0.06	0.07	0.07	0.07	0.08	0.08

Fig. 5 Kaplan–Meier plot for overall patient survival according to current care site of pediatric versus adult care location. There was no associated survival difference in this analysis. Hazard ratio 1.655 (0.839, 3.265), $p=0.146$

individuals requiring dialysis and where a kidney transplant is realistically anticipated in 6–12 months, a catheter is often placed for dialysis. We recommend these children should also be evaluated for an AVF with an access site plan in place for vessel preservation in case the transplant goal is not met and long-term hemodialysis access is necessary. Children starting hemodialysis with an autogenous access have superior access patency and overall survival when compared to those patients with graft or catheter access [19, 20]. Patient survival varies among high-income countries and is, understandably, lower in middle- and low-income regions of the world [37]. There are few reports of KF survival for children in low- and middle-income countries. Most of these found mortality rates greater than 50% [12], roughly the same as noted in this study after 3 years. The mortality rate found in this study is likely due to multiple factors. The presentation of new pediatric patients with CKD, particularly those with KF, offers a challenge for the treatment capacity of FUNDANIER. In addition to the limitations of the number of available positions for hemodialysis patients, patients' age, families move away, and situations with caregivers change with many children transferred to outside adult dialysis clinics, while other individuals are simply lost to follow-up. The majority of KF patients treated through FUNDANIER had no previous kidney care provided by a nephrologist, dramatically elevating overall mortality risk [37]. Substantial improvement in survival rates for low- and middle-income countries may be gained by slowing the progression of childhood CKD to KF with expanded economic support for treatment and availability of KRT [12].

The most common cause of KF in our study was recorded as undetermined, while CAKUT was the most frequent diagnosis among patients with a known etiology for KF and had the highest likelihood of survival in many reports [37]. Glomerular disease, including glomerulonephritis and glomerulosclerosis, was less common and has been associated with a lower survival rate in lower- and middle-income countries [37, 44].

Obesity has been paradoxically associated with a higher likelihood of survival in adult studies [45]. However, obesity in children appears to hasten the onset and progression of CKD, in addition to an increased risk of death for obese pediatric KF patients [37, 46]. BMI value did not impact patient survival in this study. Several reports found higher survival in older children, with age at dialysis initiation reported as a key determinant of patient survival. Children

less than 5 years of age have been noted to have a particularly elevated mortality risk [37]. Female gender has also been noted to confer a lower survival rate. We found no survival difference in this analysis associated with gender or different age groups.

Bridge of Life has collaborated with FUNDANIER along with other global partners to establish sustainable kidney care programs worldwide, focusing specifically on the treatment and prevention of CKD and KF [16]. Since 2006, BOL's efforts have encompassed over 225 international missions across 34 countries, working with local healthcare providers to establish and support dialysis centers in underserved and lower-income countries. The first of 22 BOL vascular access surgical missions was undertaken in 2012 in collaboration with the nephrology and surgical departments of the University of the West Indies in Kingston, Jamaica. Surgical missions have since expanded to several other sites with approximately 1000 vascular access procedures completed to date. BOL surgeons have a commitment to the creation and teaching of autogenous vascular access procedures, including initial evaluation with US imaging and postoperative care, in addition to the evaluation and treatment of dysfunctional fistulas and complications. US vessel mapping is a key element in recognizing vascular access opportunities and avoiding the creation of an autogenous access unlikely to be successful. BOL and these volunteers bring surgical instruments and all disposable items to minimize any financial impact on the local facility or providers. Other important volunteers are included in addition to surgeons, such as dialysis nurse educators in addition to outreach, screening, ultrasound, and support personnel—all key elements for success. Training includes didactic sessions for local physicians, nurses, and other providers in addition to patient education. Anesthesia colleagues are included for teaching and support in the pediatric and other selected missions. The goals of these surgical vascular access missions are (1) creating safe and functional AVFs while (2) training local surgeons and healthcare providers, leaving a sustainable and lasting influence at each site.

Short-term medical missions (STMMs) are generally recognized as unregulated direct medical service aid from wealthier countries to low- and middle-income countries [47]. Some have questioned the effectiveness and value of these single-visit efforts to provide healthcare to the developing world [48]. Annual expenditures for STMMs from the United States in 2015 were estimated to be $3.7 billion [47]. Potential problems that may arise include such things as inadequate follow-up care and difficulty with informed consent. Local providers may become dependent on STMMs and even displaced by inadvertently dampening local healthcare efforts. However, medical missions with a focus on education, training for local providers, and follow-up planning result in more sustainable and successful outcomes. ReSurge, Partners in Health, Catholic Medical Missions, BOL, and others share this approach [47]. Lundgren et al. developed a surgical exchange program between Sweden and Ethiopia [49], funded to allow trainees from both locations to travel and benefit reciprocally. BOL focuses on working with local practitioners and trainees in addition to sponsoring additional training for some local partner surgeons in the United States and France. BOL has also initiated and facilitated the donation of US devices to mission sites when possible.

Reports of medical mission outcomes are uncommon but important to justify the expenditure of time and resources. Comprehensive follow-up data is often difficult to obtain and requires close collaboration with local healthcare providers. A successful approach in vascular access surgical training in Nicaragua was developed by Lopez et al. with visiting surgical mentorship [50]. The study design included a modular instruction plan providing didactic, clinical, and operative training for two motivated local surgeons over a 2-month period that included one to three surgical procedures, three times per week. The trainee progressed from assistant to primary surgeon supervised by the mentor. Primary failure during the training period was 7%, and after successfully completing this instruction, the two surgeons were integrated into the vascular access service and completed 280 AVFs in the first 5 months.

In addition to the inherent limitations of any retrospective nonrandomized analysis, our study presented challenges in collecting follow-up information and data retrieval due to the wide dispersal of patients as they moved out of the FUNDANIER pediatric nephrology care system, making follow-up difficult or impossible in a significant number of patients. We regret that individual vessel sizes, access flow rates, and the time from AVF creation to catheter removal were not recorded for each patient.

Future plans include a structured educational program with expanded clinical and didactic teaching to improve recognition and treatment of dysfunctional AVFs with emphasis on US skills for surgeons, nephrologists, and dialysis nursing staff. BOL surgeons with Guatemalan colleagues are also initiating a clinical pediatric vascular access course for surgeons in the Central America region.

Conclusions

This study reviews the successful establishment of a pediatric vascular access service for children and adolescents in Guatemala as a critical component in completing a comprehensive center for children with CKD and KF. The experience of multiple experienced vascular access surgeons with those of the Guatemalan surgical team in a graduated

training program resulted in the creation of safe and functional AVFs established in a teaching environment.

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Data availability Study data are available for editorial review.

Declarations

Ethics approval and consent to participate The FUNDANIER ad hoc research ethics committee granted prior approval for this retrospective chart review study. Informed consent was not required. The study was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki.

Conflict of interest The authors declare no competing interests.

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