High Arteriovenous (AV) Access Flow and Cardiac Complications

"Cardiovascular mortality in ESRD patients, depending on age, is 10 - 500 times greater than the general population."
Special Report: NKF Task Force on Cardiovascular Disease, AJKD 1999; 32(5)

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in patients with End-Stage Renal Disease (ESRD).[1,2] It accounts for half of the deaths and one-third of hospitalizations of dialysis patients.[3] The gravity of cardiac disease in hemodialysis patients is highlighted in a Seminars in Dialysis 2014 publication entitled "Hemodialysis-Associated Cardiomyopathy: A Newly Defined Disease Entity."[30]

AV Access Flow & Cardiac Function

Although extensively documented in the literature[2-19,22-29], high arteriovenous access flow is also often overlooked as a source of cardiac dysfunction. By bypassing the customary arteriole/capillary beds and establishing a direct high flow connection between the arterial and venous systems, an AV vascular access causes a precipitous drop in peripheral arterial resistance which significantly affects blood flow. In order to maintain blood pressure and improve cardiac output, the body compensates for this immediate drop in resistance by increasing heart rate and stroke volume,[2,4,5] which over time can lead to the development of congestive heart failure (CHF).

WWII Trauma Victims Exhibit CO Increase

The relationship between an AV access and cardiac function was first observed in World War II in soldiers who experienced trauma-induced arteriovenous fistulas[2]. Iwashima *et al* reported a 15% increase in cardiac output by the seventh day after arteriovenous fistula creation[5]. This increased cardiac workload can lead to left ventricular hypertrophy,[4,5] especially in patients with histories of coronary artery bypass surgery.

In 1976, Henry Fee *et al* from UCLA's School of Medicine reported in the *Annals of Surgery* four patients who required corrective surgery for high-output congestive heart failure (HOCHF) secondary to high flow rates through their femoral AV shunts[6]. His recommendation at that time was that intraoperative graft flow rates should not exceed 900 cc/min.

In 1995, Engelberts and Tordoir *et al* from Maastricht University reported a case where excessive shunting in a hemodialysis access fistula led to high-output cardiac failure. They termed it "an easily overlooked diagnosis." Following surgical closure of the fistula, the patient's condition improved, and signs of congestive heart failure subsided."[7] In 1998, Young PR Jr *et al* from Bowman Gray School of Medicine, Wake Forest University, reported two renal transplant patients who developed high-output cardiac failure from brachiocephalic fistulas. Successful transplantation, coupled with fistula ligation, resolved the cardiac complications.[8] Additional case reports[9-13] cemented the relationship between high volume AV access flows and cardiac complications.

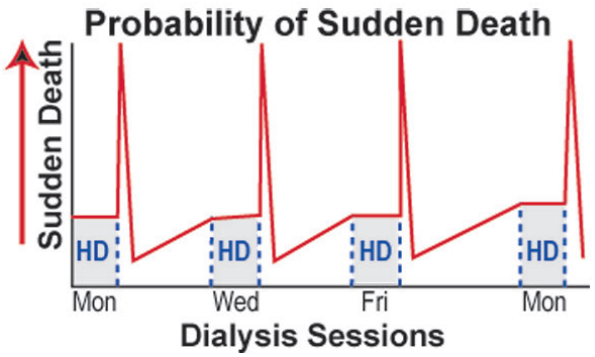

Fig. 1: The graph illustrates the spike in the probability of sudden death immediately following dialysis. "35% of deaths occurred in the first 12-hour interval." Critically low CI levels (<2 L/min/m^2) can occur in patients who do not feel well at the end of a dialysis session. As an AV fistula steals flow from an already limited systemic circulation, low CI can contribute to decreased myocardial perfusion and death.
Bleyer AJ et al, "The Timing and Characteristics of Sudden Death in Hemodialysis Patients" J Am Soc Nephrol 2002;13:SU-PO737.

transonic
THE MEASURE OF BETTER RESULTS.

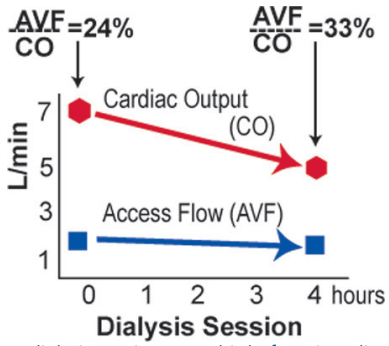

Fig. 2: During a dialysis session, one third of CO is redirected from the systemic circulation to the AV fistula placing patients at cardiac risk.

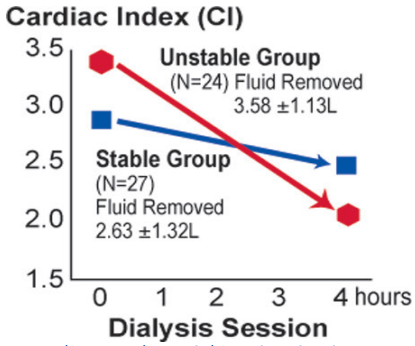

Fig. 3: Inadequate dry weight estimation increases the risk of cardiac failure. Tucker T et al, 2002;13:209A, 213A.

Lowering AVF Flow to Lower Cardiac Output

In 2004, Brian Murray *et al* from State University of NY at Buffalo published the results of the effects of surgical banding a high flow fistula and its effect on access flow and cardiac output.[14] Chemla describes using inflow reduction by diastolization of the anastomoses to treat similar conditions in 17 British hemodialysis patients.[15] Other clinicians report use of similar techniques to reduce high fistula flows and cardiac overload.[16,29]

Access Flow - Cardiac Output (AF/CO) Ratio

MacRae *et al* from the University of Calgary reported the high output cardiac failure associated with high flow AVFs (> 1.5.L/min), particularly in men with upper arm fistulas and previous access surgeries.[2,4,5] In her 2006 comprehensive review, "The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern?", MacRae documents the evidence, to date, on the subject.[2] She also notes that the ratio between access flow and cardiac output is an important clinical indicator. When access flow exceeds 25% of cardiac output, a potential cardiac problem can exist. MacRae suggests that hemodialysis patients be screened for potential high-output cardiac failure using a Qa/CO ratio with patients having a Qa/CO ratio ≥ 30% undergo further testing.[2] Padberg FT Jr, *et al* from New Jersey's School of Medicine also reviewed the existing evidence in the 2008 *Journal of Vascular Surgery*, "Complications of arteriovenous hemodialysis access: recognition and management."[17]

Italian Study Sets 2L/min AVF Flow Cut-off Value

In 2008, Basile *et al* from Miulli General Hospital in Acquaviva delle Fonti, Italy published a study of 96 patients with AV fistulas and cardiac failure.[18] The study showed that upper arm AVFs are associated with an increased risk of high output cardiac failure. It was the first published study with a high predictive power for AV fistula flows greater or equal to 2.0 L/min to result in high-output cardiac failure. In this landmark study, both AV access flow and cardiac output were measured using the Transonic® HD02 Hemodialysis Monitor.

Ye *et al's* 2013 study from Beijing's PUMC hospital, confirmed a 2 L/min threshold for treatment.[19] Ye collected data from 50 non-diabetic AV fistula hemodialysis patients. AVF flow (Qa), stroke volume (SV), cardiac output (CO), cardiac index (CI) central blood volume (CBV) and peripheral resistance (PR) were measured using Transonic's ultrasound dilution technology[16,17]. The conclusion was that "cardiac adaptive changes after long-term AVF include the enlargement of the left ventricle and thickening of the ventricular wall. The risk of cardiac failure significantly increases when the Qa of AVF is more than 2.0 L/min with much higher CO and lower PR."

Pulmonary Hypertension Studies

In two publications, Isrealis Nakhoui *et al* and Abassi Z *et al* investigated and reported on pulmonary hypertension in their ESRD patients. Nakhoui discovered that 48% (20) of his cohort of 40 patients had unexplained pulmonary hypertension (PHT).[22] In reviewing other PHT studies, Abassi's group found that morbidity and mortality from cardiovascular disease were greatly increased in 40% of chronic hemodialysis patients.[23] In a 2009 *Journal of Vascular Access* article from Iran entitled, "Effects of the arteriovenous fistula on pulmonary artery pressure (PAP) and cardiac output in patients with chronic renal failure," data from 50 patients showed a statistically significant positive correlation between fistula flow and PAP and PAP changes ($p < 0.05$). Mean fistula flow was 1322 mL/min in patients without PHT and 2750 mL/min in patients with PHT.[24]

Recent Studies Support High AVF - CO Link

In the 2013 October issue of *Clinical Transplant*, Schier *et al* from Innsbruck University reported the results of a 2005-2010 retrospective study of kidney-transplant recipients. Twenty-five percent of the recipients (29 of 113) needed an AV fistula closure, mostly due to cardiac failure symptoms[25]

Stern *et al* from UNC Kidney Center's Division of Nephrology and Hypertension, in Chapel Hill, NC describes how an increase in preload can lead to increased cardiac output when a large proportion of arterial blood is shunted from the left-sided circulation to the right-sided circulation via the fistula. Patients may present with the usual signs of high-output heart failure including tachycardia, elevated pulse pressure, hyperkinetic precordium, and jugular venous distension. The nephrologist is then faced with the dilemma of preventing progression of heart failure at the expense of losing a vascular access. The authors conclude that treatment should be directed at correcting the underlying problem by surgical banding or ligation of the fistula.[26]

In a 2012 *Seminars in Nephrology* article, "High-output Heart Failure: How to Define It, When to Treat It, and How to Treat It," Wasse *et al* from Emory University succinctly outlines the problem.[27] Dr. Wasse describes the mechanisms by which a dialysis AV access may promote the development of high-output cardiac failure, the risk factors for and diagnosis of high-output heart failure, and recommends management strategies for patients with high-output heart failure.

Conclusion

"A high flow AV access can produce life-threatening cardiac complications. The volume flow level that will induce high-output failure or extremity ischemia will vary with each patient, based on co-morbidities, especially the degree of cardiac disease and peripheral arterial disease. For patients at risk based on such pre-existing conditions, which can be a majority of patients in a given hemodialysis population, the widespread consensus (evidence-based) is that patients with access flows of 2L or higher should be tested and followed for these complications--and have a flow-reduction procedure performed at the earliest signs of cardiac complications or extremity ischemia.

Unfortunately, with the high prevalence of cardiac disease in the HD population, an insidious and silent access flow as a major cause or contributor to a potentially deadly cardiac complication, is often overlooked. Therefore, it is critically important for the practitioner to be aware of the relationship between access flow and cardiac failure, since many of these high-flow patients will have morbidity and mortality that otherwise could have been avoided."

Lawrence Spergel MD FACS

FistulaFirst.org Query

Q. I am seeing congestive heart failure (CHF) in patients with borderline cardiac function and excellent fistulas. We have done compression studies on these patients during a cardiac cath by measuring the ejection fractions, then compressing the fistula with a blood pressure cuff and remeasuring the ejection fraction. The ejection fraction increases and the patient becomes less symptomatic. There was a Transplant International article (France, 2008) stating that they are tying off fistulas in post-transplant patients to decrease left ventricular hypertrophy (LVH). Is anyone else seeing this?

A. In fact, high-output cardiac failure and also pulmonary hypertension are well known complications of high-flow HD access. Although "high flow" is subjective, since every patient has a threshold of access flow that will induce such failure (as well as distal extremity ischemia), Fistula First uses a minimal threshold of 2 L/min flow to refer the patient for cardiac evaluation.

This is an often overlooked cause of LVH & CHF--and any HD patient with a history of CHF or progressive LVH, should absolutely have access flow measured. When unrecognized, many of these patients with recurring CHF will die from their access-induced heart disease, since the cause was not recognized, and only gets worse.

The advent of accurate non-invasive measurement by ultrasound saline dilution has made it possible to measure access flow, which permitted a number of studies confirming the correlation between cardiac output and access flow. Access flow is usually approximately 20% of cardiac output. As access flow increases, so does cardiac output. The only reason that we do not see this problem in many patients, is because only a small proportion of patients have access flow approaching or greater than 2 L/min. Certainly, any patient developing LVH or CHF after starting HD should have the access flow measured. One reason I strongly urge use of access flow surveillance, is because it provides so much information. (Lawrence Spergel, MD, FACS)

(http://www.fistulafirst.org/Professionals/FrequentlyAskedQuestions.aspx#Q5)

References

1. Cardiovascular Disease — An ESRD Epidemic. Am J Kid Dis 1998; 32(5): Suppl 3.
2. MacRae JM *et al,* "The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern?" Sem in Dialysis 2006; 19(15): 349-352. (Transonic Reference # HD7337A)
3. Locatelli F *et al,* "Cardiovascular Disease in Chronic Renal Failure; the Challenge Continues," Nephrol Dial Transplant 2000; 15(Suppl 5): 69-80. (Transonic Reference # HD9643R)
4. MacRae JM, "Vascular Access and Cardiac Disease: Is There a Relationship? Curr Opin Nephrol Hypertens 2006; 15(6): 577-82. (Transonic Reference # HD7382A)
5. MacRae JM *et al,* "Arteriovenous Fistula-associated High-output Cardiac Failure: A Review of Mechanisms, "Am J Kidney Dis 2004; 43(5): 17-22. (Transonic Reference # HD408A)
6. Fee HJ *et al,*"High-output Congestive Heart Failure from Femoral Arteriovenous Shunts or Vascular Access," Ann Surg 1976; 183(3): 321-3. (Transonic Reference # HD9872AHR)
7. Engelberts I *et al,* "High-output Cardiac Failure Due to Excessive Shunting in a Hemodialysis Access Fistula: An Easily Overlooked Diagnosis," Am J Nephrol 1995; 15(4): 323-6. (Transonic Reference # HD9878AHR)
8. Young PR Jr *et al,* "High-output Cardiac Failure Secondary to a Brachiocephalic Arteriovenous Hemodialysis Fistula: Two Cases," Am Surg 1998; 64(3): 239-41. (Transonic Reference # HD9873AHR)
9. Vander Werf BA *et al,* "Cardiac Failure from Bovine Graft Arteriovenous Fistula: Diagnosis and Management," Trans Am Soc Artif Intern Organs 1978; 24: 474-475. (Transonic Reference # HD9883AHR)
10. Kajiwara IS *et al,* "Banding a Hemodialysis Arteriovenous Fistula to Decrease Blood Flow and Resolve High Output Cardiac Failure: Report of a Case." Surgery Today 1994; 24: 734-736. (Transonic Reference # HD9883AHR)
11. Dikow R, *et al,* "Do AV Fistulas Contribute to Cardiac Mortality in Hemodialysis Patients?" Semin Dial 2002; 15: 14-17. (Transonic Reference # HD9882AHR)
12. Anderson CB *et al,* "Cardiac Failure and Upper Extremity Arteriovenous Dialysis Fistulas. Case Reports and a Review of the Literature." Arch Intern Med 1976; 136: 292-297. (Transonic Reference # HD9881AHR)
13. Bailey WB, Talley JD,"High-output Cardiac Failure Related to Hemodialysis Arteriovenous Fistula," J Ark Med Soc. 2000; 96(9): 340-1. (Transonic Reference # HD9874AHR)
14. Murray BM *et al,* "Effect of Surgical Banding of a High-flow Fistula on Access Flow and Cardiac Output: Intraoperative and Long-term Measurements," Am J Kidney Dis 2004; 44(6): 1090-6. (Transonic Reference # HD415A)
15. Chemla ES *et al,* "Inflow Reduction by Distalization of Anastomosis Treats Efficiently High-inflow High-cardiac output Vascular Access for Hemodialysis," Semin Dial 2007; 20(1): 68-72. (Transonic Reference # HD7355AH)
16. Parmar CD *et al,* "Revision Using Distal Inflow for Treatment of Heart Failure Secondary to Arteriovenous Fistula for Hemodialysis, J Vasc Access. 2009; 10(1): 62-3. (Transonic Reference # HD99876AHR)
17. Padberg FT Jr *et al,* "Complications of Arteriovenous Hemodialysis Access: Recognition and Management" J Vasc Surg 2008; 48(5 Suppl): 55S-80S. Review (Transonic Reference # HD9875AHR)
18. Basile C *et al,* "The Relationship between the Flow of Arteriovenous Fistula and Cardiac Output in Haemodialysis Patients," Nephrol Dial Transplant 2008; 23: 282-287. (Transonic Reference # HD7542A
19. Ye WL *et al,* "Long-term Effects of Arteriovenous Fistula on Cardiac Structure and Function in Non-Diabetic Hemodialysis Patients," Zhongguo Yi Xue Ke Xue Yuan Xue Bao 2013; 35(1): 95-101. (Transonic Reference # HD9870AHR)
20. Krivitski NM, Depner TA, "Cardiac Output and Central Blood Volume during, Hemodialysis: Methodology," Adv Ren Replace Ther 1999; 6(3): 225-232. (Transonic Reference # HD8T)
21. Kislouchine VV, Dean DA, "Validation of a Novel Ultrasound Dilution Method to Measure Cardiac Output during Hemodialysis," ASAIO J 1996; 42: M906-M907. (Transonic Reference # HD16V)
22. Nakhoul F *et al,* "The Pathogenesis of Pulmonary Hypertension in Haemodialysis Patients Via Arterio-venous Access," Nephrol Dial Transplant 2005; 20(8): 1686-92. (Transonic Reference # HD9879AHR
23. Abassi Z *et al,* "Pulmonary Hypertension in Chronic Dialysis Patients with Arteriovenous Fistula: Pathogenesis and Therapeutic Prospective," Curr Opin Nephrol Hypertens. 2006; 15(4): 353-60. Review. (Transonic Reference # HD9880AHR)
24. Beigi AA *et al,* "Effects of the Arteriovenous Fistula on Pulmonary Artery Pressure and Cardiac Output in Patients with Chronic Renal Failure," J Vasc Access 2009; 10(3): 160-6. (Transonic Reference # HD9871AHR)
25. Schier T *et al,* "Incidence of Arteriovenous Fistula Closure Due to High-output Cardiac Failure in Kidney-transplanted Patients," Clin Transplant. 2013; 27(6): 858-65 (Transonic Reference # HD9869AHR)
26. Stern AB, Klemmer PJ, "High-output Heart Failure Secondary to Arteriovenous Fistula," Hemodial Int. 2011 Jan 12.
27. Wasse H, Singapuri MS, "High-output Heart Failure: How to Define It, When to Treat It, and How to Treat It," Semin Nephrol 2012; 32(6): 551-7. (Transonic Reference # HD9868AHR)
28. Malhotra K *et al,* "Decompensated High-output Congestive Heart Failure in a Patient with AVF and the Role of Right Heart Catheterization: a Case Study," Hemodial Int. 2012;16 Suppl 1: S58-61. (Transonic Reference # HD9877AHR)
29. Acharya S *et al,* High-output Cardiac Failure Following Insertion of Right Femoral Artery to Left Femoral Vein PTFE Graft for Haemodialysis: a Case Report," Semin Dial. 2009; 22(4): 462-4. (Transonic Reference # 97773A)
30. McIntyre C, Odudu A, "Hemodialysis-Associated Cardiomyopathy: A Newly Defined Disease Entity," Semin Dial 2014; 27(2): 87-97. (Transonic Reference # HD9974R)

transonic
THE MEASURE OF BETTER RESULTS.
www.transonic.com

Transonic Systems Inc. is a global manufacturer of innovative biomedical measurement equipment. Founded in 1983, Transonic sells "gold standard" transit-time ultrasound flowmeters and monitors for surgical, hemodialysis, pediatric critical care, perfusion, interventional radiology and research applications. In addition, Transonic provides pressure and pressure volume systems, laser Doppler flowmeters and telemetry systems.

AMERICAS
Transonic Systems Inc.
34 Dutch Mill Rd
Ithaca, NY 14850
U.S.A.
Tel: +1 607-257-5300
Fax: +1 607-257-7256
support@transonic.com

EUROPE
Transonic Europe B.V.
Business Park Stein 205
6181 MB Elsloo
The Netherlands
Tel: +31 43-407-7200
Fax: +31 43-407-7201
europe@transonic.com

ASIA/PACIFIC
Transonic Asia Inc.
6F-3 No 5 Hangsiang Rd
Dayuan, Taoyuan County
33747 Taiwan, R.O.C.
Tel: +886 3399-5806
Fax: +886 3399-5805
support@transonicasia.com

JAPAN
Transonic Japan Inc.
KS Bldg 201, 735-4 Kita-Akitsu
Tokorozawa Saitama
359-0038 Japan
Tel: +81 04-2946-8541
Fax: +81 04-2946-8542
info@transonic.jp