

Monograph:

Cardiac Function Measurements during Hemodialysis



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- HD03 Cardiac Function Measurements during Hemodialysis
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Cardiac Function References

Theory, Methodology, Validation

- Krivitski NM, "Novel Method to Measure Access Flow during Hemodialysis by Ultrasound Velocity Dilution Technique," *ASAIO J* 1995; 41(3): M741-M745. (Transonic Reference # HD4T) *These data show that access flow can be accurately measured by sound velocity dilution technique.*
- *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) *"We conclude that CO and CBV can be routinely and reliably measured during hemodialysis if precautions are taken to avoid specifically identified sources of error."*
- Kislouchine VV, Dean DA, "Validation of a Novel Ultrasound Dilution Method to Measure Cardiac Output during Hemodialysis," *ASAIO J* 1996; 42(5): M906-M907. (Transonic Reference # HD16V) *"Thus, cardiac output measured by ultrasound velocity dilution during hemodialysis is in good agreement with well established, but invasive, transit time and pump standards."*
- ### Studies and Reviews
- *Malik J, "Heart disease in chronic kidney disease - review of the mechanisms and the role of dialysis access." *J Vasc Access*. 2018 Jan;19(1):3-11. (Transonic Reference # HD18898AHR)
- *Haag S, Friedrich B, Peter A, Häring HU, Heyne N, Artunc F, "Systemic haemodynamics in haemodialysis: intradialytic changes and prognostic significance," *Nephrol Dial Transplant*. 2018;33(8):1419-1427. (Transonic Reference # HD11205AH) *"HD leads to a reduction of CI due to ultrafiltration. Haemodynamic monitoring identifies a significant number of HD patients with cardiac impairment that are at risk for increased mortality."*
- *Balamuthusamy S, Jalandhara N, Subramanian A, Mohanaselvan A. "Flow reduction in high-flow arteriovenous fistulas improve cardiovascular parameters and decreases need for hospitalization," *Hemodial Int*. 2016 Jul;20(3):362-8. (Transonic Reference # HD11223AH) *"Flow reduction in high flow fistulas are associated with decreased LVMI and pulmonary artery pressures. There is also a significant reduction in the risk for hospitalization due to acute HF and an improvement in NYHA heart failure stage."*
- *Chapman FA, Nicdao, MA Kairaitis LK, "The hidden burden of high-flow fistulae in a home haemodialysis programme: outcomes of initiating arteriovenous fistula monitoring in the home haemodialysis population," *Renal Society of Australasia Journal* 2016; 12:1 *"We identified a high prevalence of undetected AVF dysfunction that could result in significant morbidity, particularly related to high-flow AVF that may be clinically silent. We support the use of regular AVF surveillance in the HHD population using ultrasound dilution as a simple and effective way of identifying dysfunctional AVF to allow early intervention and reduced future morbidity."*
- *Basile C, Lomonte C, Vernaglione L 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) *Relationship between Qa of AVFs and CO is complex. ...first study to clearly show the high predictive power for high-output cardiac failure occurrence of Qa cut-off values ≥ 2.0 l/min.*

Basile C, Vernaglione L, Casucci F, Libutti P, Lisi P, Rossi L, Vigo V, Lomonte C, "The impact of haemodialysis arteriovenous fistula on haemodynamic parameters of the cardiovascular system." *Clin Kidney J*. 2016 Oct;9(5):729-34. *"Our observational cross-sectional study describes statistically significant haemodynamic modifications of the CV system associated to an AVF."*

MacRae JM, Pandeya S, Humen DP, Krivitski N, Lindsay RM, "Arteriovenous fistula-associated high-output cardiac failure: a review of mechanisms," *Am J Kidney Dis*. 2004;43(5):e17-e22. (Transonic Reference # HD408A) *Research efforts should focus on the prospective monitoring of high-access flows for insight into high-output cardiac failure.*

MacRae JM, "Vascular access and cardiac disease: is there a relationship?" *Curr Opin Nephrol Hypertens*. 2006;15(6):577-582. (Transonic Reference # HD7382A) *The relationship between vascular access and cardiac disease exists at different levels, ranging from inflammation promoting atherosclerotic disease to vascular remodelling changes of stenosis formation and left ventricular hypertrophy.*

*MacRae JM, Levin A, Belenkie I, "The cardiovascular effects of arteriovenous fistulas in chronic kidney disease: a cause for concern?," *Semin Dial*. 2006;19(5):349-352. (Transonic Reference # HD7337A) *Review of immediate and long-term complications associated with AVF creation, including left ventricular hypertrophy development, high-output cardiac failure, exacerbation of coronary ischemia, and the possible contribution to the development of central vein stenosis.*

Rao NN, Dundon BK, Worthley MI, Faull RJ. "The Impact of Arteriovenous Fistulae for Hemodialysis on the Cardiovascular System," *Semin Dial*. 2016 May;29(3):214-21. (HD10965AHR) *An arteriovenous fistula (AVF) creation causes significant hemodynamic alterations in cardiovascular parameters, and can result in progressive left and right heart failure. Despite successful kidney transplantation, many patients retain a functional AVF indefinitely, which may contribute to ongoing adverse cardiovascular outcomes.*

Tucker T et al, "Central Hemodynamic Profiling (CHP) during Outpatient Hemodialysis (HD)," *JASN* 2002; 13: 209A. (HD268A) *Ultrasound dilution is preferable in patients undergoing extracorporeal detoxification when PA catheterization is not required or dangerous.*

*Schytz PA, Mace ML, Soja AM, Nilsson B, Karamperis N, Kristensen B, Ladefoged SD, Hansen HP, "Impact of extracorporeal blood flow rate on blood pressure, pulse rate and cardiac output during haemodialysis," *Nephrol Dial Transplant* 2015; 30(12): 2075-9. (Transonic Reference # HD11181AH) *Danish study during which cardiac output was measured by the HD03-CO Monitor at the beginning and end of hemodialysis.*

*Válek M, Lopot F, Polakovic V, "Arteriovenous fistula, blood flow, cardiac output, and left ventricle load in hemodialysis patients," *ASAIO J*. 2010; 56(3): 200-3. (Transonic Reference # HD7951A) *Prolonged high access flow (>1,600~2,000 mL/min) can stress the heart causing cardiomegaly (especially left ventricle hypertrophy) and heart failure.*

* References preceding with an * have a Publication Brief

Cardiac Function References cont.

*Hu Z, Zhu F, Zhang N1,2, Zhang C, Pei G, Wang P, Yang J, Guo Y, Wang M, Wang Y, Yang Q, Zhu H, Liao W, Zhang Z, Yao Y, Zeng R, Xu G, "Impact of arteriovenous fistula blood flow on serum il-6, cardiovascular events and death: An ambispective cohort analysis of 64 Chinese hemodialysis patients," PLoS One. 2017 Mar 7;12(3). (Transonic Reference # HD11187A) *Keeping AVF flows in this medium range of 821.12 to 1027.13 ml/min would benefit hemodialysis patients, improve long-term clinical outcomes and lower AVF-induced inflammation.*

Genovesi S, Basile C. et al. "Sudden cardiac death in dialysis patients: different causes and management strategies," 2019 Sep 20]. Nephrol Dial Transplant. 2019;gfg182. (Transonic Reference # HD 10593AHR) *Sudden cardiac death (SCD) represents a major cause of death in end-stage kidney disease (ESKD).*

Stern AB, Klemmer PJ, "High-output heart failure secondary to arteriovenous fistula," Hemodial Int. 2011;15(1):104-107. (Transonic Reference # HD10622AHR) *"When addressing the problem of high-output heart failure, the nephrologist is faced with the dilemma of preventing progression of heart failure at the expense of loss of vascular access. Nevertheless, treatment should be directed at correcting the underlying problem by surgical banding or ligation of the fistula."*

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):551-557. (Transonic Reference # HD10634AHR) *"The presence of an arteriovenous fistula has been shown to have a short-term, adverse effect on cardiac function. Through its effect as a left-to-right extracardiac shunt, the arteriovenous fistula can increase cardiac workload substantially, and, in certain patients, result in a high-output state and resultant heart failure over time."*

Tang CY, Zhu CP, Wang RP, et al. "Effect of Blood Pump Flow and Arteriovenous Fistula Blood Flow on the Blood Pressure and Cardiac Function in Patients Undergoing Maintenance Hemodialysis," Ther Apher Dial. 2019;23(6):556-561. (Transonic Reference # HD11518AH) *"Qb was positively correlated with SBP and MAP. Qa was positively correlated with CO, CI, CBV, and PR but negatively correlated with heart rate."*

Alkhouli M, Sandhu P, Boobes K, Hatahet K, Raza F, Boobes Y, "Cardiac complications of arteriovenous fistulas in patients with end-stage renal disease," Nefrologia. 2015;35(3):234-245. (Transonic Reference HD10618AHR) *"...AVFs have significant and potentially deleterious effects on cardiac functions particularly in the setting of preexisting heart disease."*

Raza F, Alkhouli M, Rogers F, Vaidya A, Forfia P, "Case series of 5 patients with end-stage renal disease with reversible dyspnea, heart failure, and pulmonary hypertension related to arteriovenous dialysis access," Pulm Circ. 2015;5(2):398-406. (Transonic Reference # HD10622AHR) *"In ESRD patients with an arteriovenous dialysis access presenting with heart failure and pulmonary hypertension, revision or closure of the access can markedly improve dyspnea as well as the clinical, echocardiographic, and hemodynamic manifestations of heart failure and pulmonary hypertension."*

Vaes RH, Wouda R, van Loon M, van Hoek F, Tordoir JH, Scheltinga MR, "Effectiveness of surgical banding for high flow in brachial artery-based hemodialysis vascular access," J Vasc Surg. 2015 Mar;61(3):762-6. *"An immediate postbanding access flow >1 L/min and young age are risk factors for recurrent high flow in a banded brachial artery-based HD access during a 1-year follow-up."*

Murray BM, Rajczak S, Herman A, Leary D, "Effect of surgical banding of a high-flow fistula on access flow and cardiac output: intra-operative and long-term measurements," Am J Kidney Dis. 2004 Dec;44(6):1090-6. *Banding resulted in a significant decrease in access flow and cardiac output, which was sustained for up to 1 year postoperatively.*

de Bie MK, van Dam B, Gaasbeek A, van Buren M, van Erven L, Bax JJ, Schaliij MJ, Rabelink TJ, Jukema JW. "The current status of interventions aiming at reducing sudden cardiac death in dialysis patients," Eur Heart J. 2009 Jul;30(13):1559-64. *"Mortality in dialysis patients is extremely high, with an annual death rate of approximately 23%. Sudden cardiac death (SCD) is the single largest cause of death in dialysis patients accounting for approximately 60% of all cardiac deaths and 25% of all-cause mortality. Interventions aiming at reducing cardiovascular mortality, especially SCD, in dialysis patients are therefore extremely important and clinically highly relevant."*

*Rao NN, Stokes MB, Rajwani A, Ullah S, Williams K, King D, Macaulay E, Russell CH, Olakkengil S, Carroll RP, Faull RJ, Teo KSL, McDonald SP, Worthley MI, Coates PT. "Effects of Arteriovenous Fistula Ligation on Cardiac Structure and Function in Kidney Transplant Recipients." Circulation. 2019 Jun 18;139(25):2809-2818. *"Elective ligation of patent AVF in adults with stable kidney transplant function resulted in clinically significant reduction of LV myocardial mass."*

Publication Brief

Cardiac Output and Central Blood Volume During Hemodialysis: Methodology

Krivitski NM, Depner TA, Transonic Systems Inc., Ithaca, NY

BACKGROUND

Measuring cardiac output (CO) and central blood volume (CBV) in hemodialyzed patients helps explain the mechanisms and consequences of cardiac disease in hemodialysis patients.

ELIMINATION OF POTENTIAL SOURCES OF CO, CBV MEASUREMENT ERRORS

Errors in CO and CBV measurements can be minimized by the following:

- (1) Decrease pump flow to the level of 250 to 300 mL/min to eliminate access recirculation error.
- (2) Separate cardiopulmonary recirculation from vascular access recirculation to eliminate recirculation error.
- (3) Inject with a quick bolus of saline (4 - 6 seconds) to shorten the transit time of the indicator through the dialysis blood lines and eliminate loss of the indicator from the circulation.

VALIDATION OF METHOD

ANIMAL STUDIES: Compared the flow measurement of a transit-time ultrasound flowprobe on the pulmonary artery with flow measured by an extracorporeal heart pump.¹

CLINICAL: Method compares favorably with thermodilution methods used in intensive care units in humans during detoxification.²

REPRODUCIBILITY (3,488 measurement duplicates repeated within 5 minutes of one another)

- (1) CO: $4.3 \pm 3.8\%$;
- (2) CVB: $4.1 \pm 3.8\%$.

CLINICAL VALUE

- (1) Morbid events (nausea, vomiting, and/or muscle cramps) were prospectively recorded in 73 randomly selected hemodialysis patients.
- (2) CO and CBV were measured near the beginning and near the end of 98 dialysis sessions. Twenty-eight (28) morbid events were identified.

RESULTS

CBV appeared to be a more sensitive indicator of morbid events than CO in 10 sessions, where morbid events took place within 30 minutes of the measurements.

CONCLUSION

- (1) CO and CBV can be routinely and reliably measured during hemodialysis if precautions are taken to avoid specifically identified sources of error.
- (2) Preliminary studies suggest that these measurements may have significant prognostic value.

REFERENCE

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)

¹Kisloukhine VV, Dean DA, "Validation of novel ultrasound dilution method to measure cardiac output during hemodialysis," ASAIO J 1996; 42: M906-M907.

²Niciforov UV, Kisloukhine VV, Chaus NI, "Validation of new method to measure cardiac output during extracorporeal detoxification," ASAIO J 1996; 42: M903-M905.

Publication Brief

The Clinical Relevance and Management of High-Flow Arteriovenous Access

Bucktowarsing B *et al*, Kidney & Hypertension Consultants Inc, Canton, OH.

BACKGROUND:

An arteriovenous (AV) access for hemodialysis reduces risks of infections, hospitalizations, and need for interventions. However, it can cause or aggravate heart failure by increasing blood volume, cardiac contractility, and left ventricular end-diastolic volume in a non-physiologic fashion that can result in an overall increase in cardiac output, possibly leading to left ventricular hypertrophy, diastolic dysfunction, pulmonary hypertension, and high-output cardiac failure. AV accesses with blood flows greater than 1.5 L/min are of high risk. When access flow exceeds 25% to 30% of cardiac output (AF/CO ratio), the risk of developing high-output heart failure increases. Studies suggest that a blood flow AF/CO ratio greater than 0.3 be used to screen for further cardiac testing. Management of high flow accesses can range from a banding procedure (flow reduction) to the need for total abandonment of the AV access.

CONTENT:

- **High-flow AV Access Criteria: Qa >2 L/min, or Qa/CO: 30%, or Qa/Height > 603 mL/min/m**

Four studies cited:

- 1) (MacRae *et al*, 2004-2006) Blood flows >1.5 L/min; when Qa exceeds 25% of CO, the risk of developing high-output heart failure (HOCF) increases. A Qa/CO ratio of 0.30 should be used as a screening tool to perform further cardiac testing.
 - 2) (Basile *et al*, 2008) AV access flows >2.0 L/min result in high-output cardiac failure. Due to higher flows in this area, there is an association between upper arm AV fistula and the development of high output cardiac failure.
 - 3) (YE *et al*, 2013) "Cardiac adaptive changes after long-term arteriovenous fistula (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 peripheral resistance."
 - 4) (Zamboli *et al*, 2018) Indexation of blood flow for height gives a better diagnosis for HOCF.
- **High-flow AV Access Physiologic Basis:** Cardiac Output = Heart Rate X Stroke Volume (a function of peripheral vascular resistance). Peripheral vascular resistance drops with creation of an AV access, but blood volume, cardiac contractility, and left ventricular end-diastolic volume increase in a non-physiologic fashion that results in an overall increase in CO. When blood flows through an AV access, it bypasses the capillary beds to cause blood to return to the heart at non-physiologic pressures and velocities. The resultant higher filling pressures cause significant atrial stretch, which results in higher CO.
 - **Modification of High-flow AV Access:** Multiple techniques are used to reduce Qa by increasing resistance at the inflow level. Banding, the simplest, most common flow-reducing procedure, requires achieving a fine balance between a band that is tight enough to be effective and not too tight to risk the patency of the access. [Precision banding using intraoperative flow measurements support banding as an effective treatment with a low risk of access failure.](#) Flow reduction revision using distal inflow involves ligation of the fistula at its origin followed by reestablishment of flow via a bypass from either the proximal radial or ulnar artery using a vein or graft as conduit.
 - **How Common are Cardiac Complications Related to AV Access?** Limited data: Three studies cited:
 - 1) (Martínez-Gallardo R, *et al*, 2012) Spanish progressive study indicated that of chronic kidney disease patients, 17% developed at least one episode of pre-dialysis heart failure.
 - 2) (Schier T *et al*, 2013) Retrospective study: 7% of 113 transplant recipients previously on hemodialysis with an AV access required access ligation due to persistent symptoms of heart failure. The mean shunt flow of these patients was 2197 mL/min compared to 851 mL/min among patients who did not undergo shunt closure.
 - 3) (Reddy YNV *et al*, 2017) Retrospective study: 137 CKD patients were followed up for a median of 2.6 years after AV access creation. 43% with no prior history developed incident heart failure. 75% percent of these cases had heart failure with preserved ejection fraction.

(Continued on next page)

REFERENCE

Bucktowarsing B, Vin Y, Lerma EV. The Clinical Relevance and Management of High-Flow Arteriovenous Access. *Adv Chronic Kidney Dis*. 2020 May;27(3):214-218. (Transonic Reference List # 11885AHR)

Bucktowarsing(HD11885AHR-pb)RevA2021A4

The Clinical Relevance and Management of High-Flow Arteriovenous Access cont.

• Why Should Nephrologists Be Suspicious of High Flow AV Access?

CO and Cardiac Index drop during first 12 hours after dialysis. A high-flow fistula may steal blood away from an already compromised peripheral circulation, compromising end organ perfusion. Two studies cited:

- 1) (Bleyer *et al* 2006) Study postulates that 35% of sudden deaths occur within the first 12 hour after dialysis. Critically low levels of cardiac index (>2 L/min/m²) can occur during that time period and is aggravated as a high-flow fistula steals blood away from a suboptimal systemic circulation.
- 2) (Tucker *et al* 2002) Study describes how the AF/CO ratio increases after dialysis, mainly driven by a decrease in CO. If an access is already in a "high flow state," this condition becomes exaggerated and can lead to precipitous decline in systemic perfusion, resulting in sudden death.

CLINICAL SUMMARY:

- High-output cardiac failure is a potential complication of arteriovenous (AV) access creation.
- AV accesses, especially upper arm, with blood flow >1.5 L/min are of high risk.
- Blood flow/Cardiac output ratio (AF/CO) of 0.30 is a valid screening tool to perform further cardiac testing.
- If no reversible cause for high-output heart failure is identified, a case can be made for flow reduction (banding) of the AV access.

CONCLUSIONS:

- High-flow AV access can have significant impact on the long-term outcomes of dialysis patient with other comorbidities.
- Complications associated with high-flow AV accesses are very often attributed to other etiologies or to patient related factors, eg, noncompliance.
- Nephrologists and vascular access experts should work together to mitigate the potential harm to patients on dialysis who are afflicted by this condition.

PUBICATIONS CITED:

- Reddy YNV, Obokata M, Dean PG, Melenovsky V, Nath KA, Borlaug BA, "Long-term cardiovascular changes following creation of arteriovenous fistula in patients with end stage renal disease," *Eur Heart J*. 2017;38(24):1913-1923.
- MacRae JM, Pandeya S, Humen DP, Krivitski N, Lindsay RM, "Arteriovenous of arteriovenous fistula in patients with end stage renal disease," *Eur Heart J*. 2017;38(24):1913-1923.
- MacRae JM, Pandeya S, Humen DP, Krivitski N, Lindsay RM, "Arteriovenous fistula-associated high-output cardiac failure: a review of mechanisms," *Am J Kidney Dis*. 2004 May;43(5):e17-22.
- MacRae JM, "Vascular access and cardiac disease: is there a relationship?" *Curr Opin Nephrol Hypertens*. 2006;15(6):577-582.
- MacRae JM, Levin A, Belenkie I, "The cardiovascular effects of arteriovenous fistulas in chronic kidney disease: a cause for concern?" *Semin Dial*. 2006;19(5):349-352.
- Basile C, Lomonte C, Vernaglione L, Casucci F, Antonelli M, Losurdo N, "The relationship between the flow of arteriovenous fistula and cardiac output in haemodialysis patients," *Nephrol Dial Transpl*. 2008;23(1):282-287.
- Ye WL, Fang LG, Ma J, Li XM, "[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 Feb;35(1):95-101. Chinese.
- Zamboli P, Luca S, Borrelli S, *et al*, "High-flow arteriovenous fistula and heart failure: could the indexation of blood flow rate and echocardiography have a role in the identification of patients at higher risk?" *J Nephrol*. 2018;31(6):975-983.
- Martínez-Gallardo R, *et al*, Hospital Infanta Cristina, "Congestive heart failure in patients with advanced chronic kidney disease: association with pre-emptive vascular access placement," *Nefrologia*. 2012;32(2):206-212.
- Schier T, Göbel G, Bösmüller C, Gruber I, Tiefenthaler M, "Incidence of arteriovenous fistula closure due to high-output cardiac failure in kidney-transplanted patients," *Clin Transplant*. 2013 Nov-Dec;27(6):858-65.
- Bleyer AJ, Hartman J, Brannon PC, Reeves-Daniel A, Satko SG, Russell G, "Characteristics of sudden death in hemodialysis patients," *Kidney Int*. 2006;69(12):2268-2273.
- Tucker T, *et al*, "Unrecognized deterioration of cardiac function during hemodialysis," *J Am Soc Nephrol*. 2002;13:213A.

Publication Brief

The Cardiovascular Effects of Arteriovenous Fistulas (AVFs) in Chronic Kidney Disease: A Cause for Concern?

MacRae JM, *et al*, Division of Nephrology, Univ. of British Columbia, Vancouver, British Columbia, Canada.

This paper reviews the hemodynamic and cardiovascular consequences of AVFs in chronic kidney disease.

SUMMARY

Immediate hemodynamic effects of AVF creation	<ul style="list-style-type: none"> • Increase in Cardiac Output (10-20%). • Increase in Sympathetic nervous system activity (increasing contractility). • Increase in Stroke volume and heart rate. • Decrease in Peripheral Resistance.
Hemodynamic changes within one week of AVF creation	<ul style="list-style-type: none"> • Increase in Circulating Blood Volume resulting in increased left atrial, inferior vena cava, and left ventricle end-diastolic volume (LVEDV). • Increase in Neuro-hormones: atrial natriuretic peptide (ANP) and brain natriuretic peptide (BNP) implying atrial and ventricular filling pressure are increased. (ANP is a powerful vasodilator and BNP is correlated with echocardiographic features). <p>Decrease in Plasma renin and aldosterone levels. Decrease in Systemic vascular resistance and systolic/diastolic blood pressure.</p>
Consequences of long-term AVF creation	<p>Left Ventricular Hypertrophy (LVH): An adaptive response to increased cardiac workload caused by volume or pressure overload.</p> <p>High-Output Cardiac Failure</p> <ul style="list-style-type: none"> • Patients with high-flow AVFs are most likely have a greater risk of developing CHF and greater increase in LVEDV. • AVFs in HD patients may contribute to the development of heart failure. • Left ventricle enlargement at the start of HD is very common and progressive left ventricle dilation with hypertrophy continues over time. Most of the left ventricle growth occurs during the first year of dialysis. <p>Exacerbation of Coronary Ischemia</p> <ul style="list-style-type: none"> • AVF placement is associated with increased myocardial O₂ demand that may not be met, especially in patients with established coronary artery disease (CAD) or left ventricle hypertrophy (LVH). • Increased O₂ consumption may have clinical manifestations in dialysis patients who have had CABG. A decrease in coronary perfusion that occurred with the onset of HD was demonstrated by the reduction in graft flow and reversible hypokinesis of the anterior left ventricle wall. • High-flow AVFs with an associated high cardiac output may increase O₂ demand and reduce supply more than a smaller AVF. <p>Central Vein Stenosis</p> <ul style="list-style-type: none"> • The endothelium plays an active role in vascular remodeling by secreting vasoactive substances and growth factors in response to alterations in flow and shear stress. • Increased blood flow due to AVF creation alters the shear stress on the endothelium and promotes production of substances like transforming growth factor (TGF)-β and NO which dilate the vessel lumen. • A majority of central vein stenosis occurs at the junction of the cephalic and subclavian veins. There was a high correlation between the location of a central vein stenosis and ipsilateral AVF. It suggests that altered flow hemodynamics due to a fistula may result in endothelial damage and vascular remodeling, leading to stenosis.

REVIEW'S CONCLUSIONS

- A thorough cardiac assessment should be performed in patients with CAD prior to placing an AVF.
- Regular careful evaluations are necessary in patients with cardiac disease and AVFs.
- Patients with a large AVF and high flow should be followed with serial echocardiography to watch for changes in the LVEDV and monitor for LVH.
- Patients with high flow fistulas (flow greater than 2L/min) and increasing LVEDV are recommended to have a flow reduction procedure on their AVF.
- Patients with preexisting severe ischemic heart disease (class III unstable angina) should avoid AVF placement if the underlying ischemia cannot be treated.
- AVFs are superior to catheters and grafts due to fewer thrombogenic and infectious complications.

Reference:

MacRae JM *et al*, "The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern?" Seminar in Dialysis 2006; 19:349-352 (Transonic Reference # HD7337A)

Publication Brief

Systemic haemodynamics in haemodialysis: intradialytic changes and prognostic significance

Haag S, Artunc F *et al*, Dept. of Internal Medicine, Division of Endocrinology, Diabetology, Vascular Disease, Nephrology and Clinical Chemistry, University Hospital Tübingen, University of Tübingen, German Center for Diabetes Research (DZD), Tübingen, Germany; Nephrological Center, Leonberg, Germany; Institute of Diabetes Research and Metabolic Diseases (IDM) of the Helmholtz Center Munich, Germany.

OBJECTIVE

To evaluate the diagnostic and prognostic significance of hemodynamic monitoring during routine haemodialysis (HD).

METHODS

- In a multicenter study, cardiac index (CI), access flow (AF) and central blood volume index (CBVI) were measured during a single HD session in stable 215 HD patients using the Transonic HD03 Monitor.
- Systemic CI (SCI) was defined as CI corrected for AF.
- In a subset of 82 patients, total end-diastolic volume index (TEDVI) and total ejection fraction (TEF) were derived from dilution curves.
- Data were correlated with clinical parameters, cardiac biomarkers and bioimpedance measurements.
- Mortality (30%-65 patients) was assessed prospectively after a median follow-up of 2.6 years: 38% of all deaths was due to cardiovascular causes.

RESULTS

- At the beginning of a dialysis session, median CI was 2.8 L/min/m², CBVI was 15 mL/kg and Access Flow was 980 mL/min.
- By the end of the HD session, CI had fallen by 10%; CBVI by 9% and AF by 4% respectively.
- During the HD session peripheral resistance (PR) increased slightly.
- Blood pressure fell by -6/-3 mmHg to 128/63 mmHg.
- Independent predictors of CI were age and ultrafiltration rate.
- AF, overhydration and PR were protective.
- TEF at the beginning of HD is the most robust marker for increased mortality, followed by TEDVI and SCI.

CONCLUSIONS

- Haemodialysis leads to a reduction of CI due to ultrafiltration: Access flow (AF) remains constant
- Hemodynamic monitoring identifies a significant number of HD patients with cardiac impairment who are at risk for increased mortality.

TAKE HOME

- First study to collect comprehensive systemic hemodynamic data during HD from a large group (215) of HD patients from four sites and to present data on the data's hitherto unknown prognostic significance.
- Another study by Drs. F. Artunc, Dr. S. Haag and their group at Tübingen using the HD03-CO to show prognostic significance of cardiac parameters measured by the HD03 Hemodialysis Monitor in HD patients.
- The results of the study underscore the prognostic relevance of cardiac function measurements for the survival of HD patients.

REFERENCE

Haag S, Friedrich B, Häring HU, Heyne N, Peter A, Artunc F, "Systemic haemodynamics in haemodialysis: intradialytic changes and prognostic significance," *Nephrol Dial Transplant*. 2018 Mar 26. (Transonic Reference # HD112305A)



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Publication Brief

The impact of haemodialysis arteriovenous fistula on haemodynamic parameters of the cardiovascular system

Basile C, *et al*, Division of Nephrology, Miulli General Hospital, Acquaviva delle Fonti, Italy.

OBJECTIVE

To calculate, using real data, how an AVF influences the load of the left ventricle (LLV).

STUDY

86 HD patients with an arteriovenous fistula (AVF) were enrolled in an observational cross-sectional study: 56 patients had a lower arm AVF; 30 patients had an upper arm AVF.

Measured parameters included:

- Vascular access flow (Qa) and cardiac output (CO) were measured (Hemodialysis Monitor HD02).
- Mean arterial pressure (MAP) was calculated;
- Total peripheral vascular resistance (TPVR) was calculated as MAP/CO ;
- Resistance of AVF (AR) and systemic vascular resistance (SVR) are connected in parallel and were calculated as $AR = MAP/Qa$ and $SVR = MAP/(CO - Qa)$.
- LLV was calculated on the principle of a simple physical model: $LLV \text{ (watt)} = TPVR \cdot CO^2$. The latter was computationally divided into the part spent to run Qa through the AVF (LLVAVF) and that part ensuring the flow $(CO - Qa)$ through the vascular system.

The data were analyzed by the AVF's site (either lower and upper arm).

REPORTED RESULTS

Mean Qa (L/min)	CO (L/min)	MAP (mmHg)	TPVR mmHg·min/L	LLV watt	LLVAVF
1.3 (0.6 SD)	6.3 (1.3)	92.7 (13.9)	14.9 (3.9)	1.3 (0.6)	19.7 (3.1)%

- Qa, CO, LLV and LLVAVF increased significantly and TPVR, AR and SVR decreased significantly in upper arm AVFs compared with lower arm AVFs.
- A third-order polynomial regression model best fitted the relationship between Qa and LLV for the entire cohort of AVFs, both lower and upper arm AVFs.
- LLVAVF calculated as % of LLV rose with increasing Qa according to a quadratic polynomial regression model, but only in lower arm AVFs.
- On the contrary, no statistically significant relationship was found between the two parameters in upper arm AVFs, even if mean LLVAVF was statistically significantly higher in upper arm AVFs.

STUDY'S CONCLUSION

- The cross-sectional study describes statistically significant haemodynamic modifications of the CV system associated to an AVF.
- In lower arm AVFs, a quadratic polynomial regression model best fits the relationship between LLVAVF and Qa.

Reference:

Basile C, Vernaglion L, Casucci F, Libutti P, Lisi P, Rossi L, Vigo V, Lomonte C, "The impact of haemodialysis arteriovenous fistula on haemodynamic parameters of the cardiovascular system," Clin Kidney J 2016; 9(5): 729-34. (Transonic Reference # HD11001AH)

Publication Brief

The hidden burden of high-flow fistulae in a home haemodialysis programme: outcomes of initiating arteriovenous fistula monitoring in the home haemodialysis population

Chapman *et al*, Dept. of Geriatric Medicine, Blacktown Hospital, Sydney West Local Health District, NSW, Australia

BACKGROUND

Home hemodialysis (HHD) is common in Australia where the majority of patients dialyse using an arteriovenous fistula (AVF). AVFs are a potential source of morbidity, for a low fistula flow may result in inadequate dialysis and a high flow may lead to cardiac failure. HHD patients are particularly vulnerable to unrecognized access dysfunction. The primary aim of access surveillance is to identify low-flow AVF due to the associated complications of access thrombosis or access recirculation. However, it is increasingly recognized that patients with high-flow AVFs are at risk for significant negative cardiovascular consequences. Compared to low-flow fistulas, high-flow fistulas are more likely to go clinically unrecognized, as they typically do not cause difficulty with cannulation and do not trigger pressure alarms during dialysis.

OBJECTIVE

To determine high/low flow access dysfunction in HHD patients and its prevalence.

METHODS

- An ultrasound dilution surveillance program was introduced in the HHD population for a three-year period.
- The study group was 141 AVF patients (mean age: 53 years). Cardiac output (CO) was also measured during the first hour of hemodialysis in patients, when possible.
- Patients were referred for further evaluation by a nephrologist and/or vascular surgeon if access recirculation was >5%, access blood flow (Qa) was <500mL/min or >2L/min, cardiac output (CO) was >8L/min, or when the ratio of access flow to cardiac out-put (Qa/CO) was >30%.
- Access intervention decisions were made by the nephrologist and vascular surgeon, depending on an individual's circumstance.
- Measures were statistically compared between different patient subgroups.

RESULTS

- Twenty-nine percent (n=41) of patients were identified with access dysfunction. Thirteen and one half percent (19) had low-flow AVF (access flow (Qa) < 500mL/min), and 22 patients (15.6%) had evidence of high flow (Qa >2L/min, CO >8L/min or Qa/CO >0.3).
- Upper arm AVFs were more likely to be high flow than radiocephalic accesses.
- Most patients with low-flow AVFs underwent stenting (17/19); 10 patients with high-flow AVFs had banding to reduce the size.

CONCLUSION

- The study uncovered a high prevalence of undetected AVF dysfunction in HHD patients that could result in significant morbidity, particularly related to high-flow AVF that may be clinically silent.
- The authors support the use of regular AVF surveillance in the HHD population using ultrasound dilution as a simple and effective way of identifying dysfunctional AVFs to allow early intervention and reduced future morbidity.

REFERENCE

Chapman FA, Nicdao MA, & Kairaitis L, "The hidden burden of high-flow fistulae in a home haemodialysis programme: outcomes of initiating arteriovenous fistula monitoring in the home haemodialysis population," *Renal Soc of Australasia J* 2016; 12(1): March 2016 (Transonic Reference List # HD119070AHR)

Chapman(HD119070AHR-pb)RevA2021A4

Publication Brief

Impact of extracorporeal blood flow rate on blood pressure, pulse rate and cardiac output during haemodialysis.

Schytz PA *et al*, Herlev Hospital, Copenhagen, Denmark.

BACKGROUND

Symptomatic (intradialytic) hypotension occurs in 15-30% of hemodialysis sessions due to a drop in blood pressure. Such hypotension is an independent predictor of cardiovascular morbidity and mortality. When patients experience intradialytic hypotension, it is common practice to reduce the extracorporeal blood flow rate, even though there is limited data on its effect. Reducing the extracorporeal blood flow rate in effect, reduces the efficacy of hemodialysis (KtV).

OBJECTIVE

To evaluate the effect of falling blood pressure during hemodialysis and the potential mechanism(s) involved by investigating the impact of changes in the extracorporeal blood flow rate on blood pressure, pulse rate and cardiac output in hemodialysis patients with arteriovenous-fistulas.

METHOD

- A randomized, crossover trial was performed in 22 hemodynamically stable hemodialysis patients older than 18 who had AV-fistulas;
- Following a hemodialysis session each patient was examined with extracorporeal blood flow rates of 200, 300 and 400 mL/min in random order;
- After 15 min, when steady state was achieved, cardiac output was measured at each extracorporeal blood flow rate by Transonic's HD03-CO Flow-QC® Hemodialysis Monitor.
- Blood pressure and pulse rate were also measured at each extracorporeal blood flow rate.

RESULTS

- The mean age of patients was 71 (± 11) years;
- Systolic blood pressure was significantly higher at an extracorporeal blood flow rate of 200 mL/min as compared with a rate of 300 mL/min, but not as compared with a rate of 400 mL/min;
- At an extracorporeal blood flow rate of 200, 300 and 400 mL/min, diastolic blood pressure, mean arterial pressure, pulse rates and cardiac output remained unchanged.

CONCLUSION

- No consistent trends in blood pressure changes by a reduction in the extracorporeal blood flow rate were demonstrated by the study.
- The study showed no support for a reduction in an extracorporeal blood flow rate when blood pressure falls during intradialytic hypotension.
- None of the patients experienced intradialytic hypotension.
- Further studies are required to evaluate the impact of changes in extracorporeal blood flow rates on blood pressure during intradialytic hypotension.

TAKE HOME

- Cardiac output was measured by the HD03-CO Monitor at the beginning and end of hemodialysis.
- Interesting Danish study.

REFERENCE

Schytz PA, Mace ML, Soja AM, Nilsson B, Karamperis N, Kristensen B, Ladefoged SD, Hansen HP, "Impact of extracorporeal blood flow rate on blood pressure, pulse rate and cardiac output during haemodialysis," *Nephrol Dial Transplant* 2015; 30(12): 2075-9. (Transonic Reference # HD11181AH)



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Publication Brief

Impact of arteriovenous fistula blood flow on serum il-6, cardiovascular events and death: An ambispective cohort analysis of 64 Chinese hemodialysis patients.

Hu Z *et al*, Div. of Nephrology, Tongji Hospital, Huazhong Univ. of Science and Technology, Wuhan, Hubei, China

BACKGROUND

Arteriovenous fistula (AVF) flows impact dialysis adequacy in hemodialysis (HD) patients. A recent study reported that 52.9% of deaths within the first year on hemodialysis were due to cardiovascular and cerebrovascular disease. However, there is limited data for different access flow levels on outcomes related to long-term dialysis patients, especially in Chinese patients.

OBJECTIVE

To perform a five-year ambispective, mono-centric cohort study from 2009 to 2015 in which the association between AVF flows and inflammation, cardiovascular events and deaths in Chinese hemodialysis patients who have a radio-cephalic fistula (AVF) is investigated.

METHOD

- The link between AVF flows and adverse clinical outcomes (cardiovascular events and mortality) was examined in 64 patients (male, 44; female, 20) over a median follow-up of five years .
- AVF flow and cardiac output were monitored by the Transonic HD02 Hemodialysis Monitor every six months. The mean flow and cardiac output were determined by the average of three measurements taken approximately 5-20 minutes apart.

RESULTS

- Twenty-three patients (35.9%) developed at least one episode of cardiovascular disease within two years after AVF creation. Forty-one patients did not.
- Initial flows in the 64 patients ranged from 620 mL/min to 1490 mL/min (mean, 954.5 mL/min)
- AVF flow, IL-6 and hsCRP were significantly higher in patients with cardiovascular disease than in patients without cardiovascular disease.
- Analysis found that the independent and strongest risk factor for cardiovascular disease in HD patients was serum IL-6, which demonstrated a positive association with AVF flow levels in patients.
- IL-6 was significantly increased in the high AVF flow (>1027.13 ml/min) group.
- Patients with median AVF flows (821.12 to 1027.13 ml/min) showed the lowest morbidity and mortality of cardiovascular disease whereas patients with higher flows were associated with a higher risk of cardiovascular disease. Patients with lower AVF flows (≤ 600 ml/min - <821.12 ml/min) had a higher risk of non-cardiovascular disease related death.

CONCLUSION

Keeping AVF flows in this medium range of 821.12 to 1027.13 ml/min would benefit hemodialysis patients, improve long-term clinical outcomes and lower AVF-induced inflammation.

REFERENCE

Hu Z, Zhu F, Zhang N1,2, Zhang C, Pei G, Wang P, Yang J, Guo Y, Wang M, Wang Y, Yang Q, Zhu H, Liao W, Zhang Z, Yao Y, Zeng R, Xu G., "Impact of arteriovenous fistula blood flow on serum il-6, cardiovascular events and death: An ambispective cohort analysis of 64 Chinese hemodialysis patients." PLoS One. 2017 Mar 7;12(3). <https://www.ncbi.nlm.nih.gov/pubmed/?term=mpact+of+arteriovenous+fistula+blood+flow+on+serum+il-6%2C+cardiovascular+events+and+death> OPEN ACCESS (Transonic Reference # HD11187A)



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Publication Brief

Arteriovenous Fistula, Blood Flow, Cardiac Output, and Left Ventricle Load in Hemodialysis Patients

Válek M, Lopot F, Polakovic V, Charles University, Prague, Czech Republic

OBJECTIVE

To investigate an association between vascular access flow (QVA), cardiac output (CO), and load of left ventricle (LLV) using a simple physical model calculation based on real data, specifically in patients with high access blood flow arteriovenous fistula (AVF).

STUDY

- Group 1: 15 patients with high access blood flow (QVA >1,300 mL/min).
- Group 2: 40 unselected patients with access blood flow (QVA range 200-1,400 mL/min) were added to evaluate association of LLV and QVA over a wider range of QVA magnitude.
- QVA, CO, and PR (Peripheral Resistance) were determined by ultrasound dilution technique (HD01) during the first hour of dialysis sessions.

RESULTS

- Differences in LLV, LLV_{AVF} (the part of the overall LLV used to run the flow QVA through the AVF), and $LLV_{SYSTEMIC}$ (the flow through the entire remaining vascular system without the AVF) are highly statistically significant between Group 1 and Group 2. But when related to body surface area (BSA), only the LLV_{AVF}/BSA showed statistically significant difference between the two groups.
- Strong and nonlinear association between QVA and LLV_{AVF} .
- In Groups 1 and 2 taken together, significant correlation was found between QVA and LLV.
- Borderline level of statistical significance was seen between QVA and Cardiac Index (CI) in data from the two groups together.

STUDY'S CONCLUSIONS

- Vascular access blood flow values in normal range do not seem clinically important and should not significantly affect the heart.
- An AVF with very high QVA consumes disproportionately high part of the LLV and may thus have negative effect on myocardium in the long-term perspective.

TAKE HOME POINTS

- Prolonged high access flow (>1,600~2,000 mL/min) can stress the heart causing cardiomegaly (especially left ventricle hypertrophy) and heart failure.
- Transonic® Flow-QC® Cardiac Output Program automatically calculates Cardiac Index (CI) using a patient's weight and height and identifies dramatic decrease in CI to a dangerous level which indicates potential cardiac problems, inappropriate dry weight estimation, and/or inadequate medication.

REFERENCE

Válek M, Lopot F, Polakovic V, "Arteriovenous fistula, blood flow, cardiac output, and left ventricle load in hemodialysis patients," ASAIO J. 2010; 56(3): 200-3. (Transonic Reference # HD7951A)

Publication Brief

Heart disease in chronic kidney disease - review of the mechanisms and the role of dialysis access

Malik J, Center for Vascular Access, General University Hospital, First Faculty of Medicine, Charles University, Prague, Czech Republic.

BACKGROUND

Heart failure from cardiovascular complications not only shortens the life (mortality) of end-stage renal disease (ESRD) patients, but also it worsens their quality of life (morbidity) due to shortness of breath, edema, and tiredness. Cyclic changes of fluid load, together with an altered metabolism, are responsible. This review delineates the numerous mechanisms of heart disease and their connection to the dialysis access

OBJECTIVE

To describe the mechanisms involved in cardiovascular complications of ESRD patients, to and underscore a dialysis access's role.

MECHANISMS OF HEART DISEASE:

- 1. Arterial Disease:** accelerated atherosclerosis, medial calcinosis (Möckeberg sclerosis); Both atherosclerosis and medial calcinosis increase arterial stiffness and, thus, the left ventricular afterload which, in turn, increases myocardial oxygen demand, but decreases myocardial oxygen supply. Arterial disease of the feeding artery worsens arteriovenous fistula (AVF) maturation and produces a higher risk of hand ischemia.
- 2. Left Ventricular Hypertrophy (LVH):** increased left ventricular mass. LVH development has a direct detrimental effect on the left ventricular diastolic function.
- 3. Left Ventricular Dilatation (LVD):** Described either by its end-diastolic/end-systolic diameter, or its volume, volume overload represents the most powerful mechanism of LVD. Left ventricular size depends on the time interval since the previous hemodialysis session and on the dry weight setting. Slight LVD was observed after AVF creation, and a more pronounced effect could be seen in patients with hyperkinetic heart failure due to high-flow AVF.
- 4. Regional Wall Motion Abnormalities (RWMAs):** RWMAs develop most frequently as a result of coronary artery disease, but have also been described in hemodialysis patients, especially those with intradialytic hypotension that produces a faster decline of systolic function. Higher arteriovenous access flow volume is associated with lower RWMAs frequency.
- 5. Left Ventricular Systolic Dysfunction:** Systolic function is directly related to contractility and preload (Frank-Starling law) and indirectly to afterload. Chronic left ventricular systolic dysfunction is a marker of increased mortality. AVF creation or percutaneous balloon angioplasty of an AVF stenosis could lead to heart failure due to the sudden need for an increase in cardiac output.
- 6. Left Ventricular Diastolic Dysfunction:** Diastolic dysfunction affects approximately 50% of ESRD patients. LVH produces conditions for the development of diastolic dysfunction in ESRD patients.
- 7. Left atrial dilatation and systolic dysfunction:** The left atrium is the most frequently dilated cardiac chamber. Left atrial dilatation, and its systolic dysfunction, becomes more frequent with ageing and with longer hemodialysis history. AVF creation can lead to left atrial dilatation.
- 8. Right ventricular dilatation and systolic dysfunction:** The right ventricle dilates in response to pressure and volume overload due to pulmonary hypertension and hyperkinetic circulation, typical in hemodialysis patients due to volume overload, anemia, inflammation, and an AVF. Systolic dysfunction is a consequence, but it can also develop in acute pressure overload. Right ventricular dilatation and dysfunction worsens left ventricular function. In patients with pulmonary hypertension, right ventricle dysfunction that has the strongest negative impact on survival.
- 9. Pulmonary hypertension:** (>25 mmHg at rest). Symptoms: shortness of breath, dizziness, fainting, leg swelling, etc. Prevalence in ESRD patients is high, up to 56%. Pulmonary hypertension is associated with increased mortality. Pulmonary hypertension is more frequent in dialysis patients with higher AVF flow. It is partially reversible after flow-reducing access surgery.

Continued on next page.

REFERENCE

Malik J, "Heart disease in chronic kidney disease - review of the mechanisms and the role of dialysis access," J Vasc Access. 2018 Jan;19(1):3-11. (Transonic Reference List # HD118892AHR)

Malik(HD188921AHR-pb)RevA2021A4

Heart disease in chronic kidney disease Cont.

10. Cardiovascular calcification: Frequent in hemodialysis patients. Appears in CKD stage 3. Medial calcinosis brings a higher risk of AVF-related hand ischemia.

11. Pericardial disease: Pericardial effusion with impaired filling of the heart chambers affects ESRD patients with systemic disease.

12. Other Heart Disease Mechanisms:

- Valvular disease: common in ESRD patients.
- Atrial fibrillation: also common in ESRD patients. This arrhythmia worsens ventricular filling and thus contributes to the development of heart failure. Atrial fibrillation also increases the risk of ischemic cerebral stroke and other embolic complications.

TYPES OF HEART FAILURE

- Congestive heart failure: determined by inadequate low cardiac output, compounded by AVF flow volume (AVF represents a systemic steal). The term "effective cardiac output" is calculated by subtracting AVF flow volume from the measured cardiac output.
- Hyperkinetic heart failure: heart failure is a somewhat counterintuitive state characterized by symptoms of heart failure and (very) high cardiac output due to systemic vasodilatation, such as in obesity or liver cirrhosis; or, it can be due to large arteriovenous fistula, such as in ESRD patients. As a result, both ventricles dilate and systolic dysfunction develops, which is sometimes accompanied by secondary mitral and tricuspid regurgitation.

VASCULAR ACCESS CONTRIBUTION

Both creation of an AVF or the treatment of a severe AVF stenosis lead to a sudden profound increase in flow volume, which must be generated by the heart. Physiological consequences include a decrease of afterload and an increase of preload. Further development depends not only on the heart's capacity, but also on the ability of systemic arteries to dilate. In other words, systemic arteries compete with the AVF for cardiac output. The creation of an AVF also lowers systemic blood pressure due to the fall of systemic vascular resistance.

PRACTICAL RECOMMENDATIONS

- Prior to access selection, examine the heart clinically (shortness of breath, chest pain, lung congestion).
- Reserve a permanent dialysis catheter for patients with severe irreversible heart failure, or for those with very short life expectancy.
- When the development of heart failure is suspected, current hydration and flow volume should be examined.
- Be aware of the variability of hemodynamic findings. The major source of variability is the patient's hydration status: patients are usually overhydrated prior to hemodialysis therapy initiation.
- Patients coming with developed ESRD from the street: planning of dialysis access in their overhydration negatively influences all echocardiographical findings, and extreme cases could be improperly condemned to permanent dialysis catheter. Another echocardiography or magnetic resonance image is indicated after the stabilization of dry weight.
- Close cooperation between the nephrologist and a cardiologist experienced in the caveats of CKD patients is encouraged.

Publication Brief

The Effects of Arteriovenous Fistula Ligation on Cardiac Structure and Function in Kidney Transplant Recipients

Rao *et al*, Adelaide Medical School, Univ.of Adelaide, NSW, Australia

BACKGROUND

Cardiovascular morbidity and mortality remain high in recipients of a kidney transplant. However, it is not known whether a persistent, patent arteriovenous fistula (AVF) after transplantation may contribute to ongoing maladaptive cardiovascular remodeling.

OBJECTIVE

To conduct a randomized controlled trial on the effect of AVF ligation on cardiac structure and function in stable kidney transplant recipients and determine whether AVF ligation would reverse maladaptive cardiovascular remodeling following kidney transplant.

METHODS

- Ninety-three kidney transplant recipients (>12 months after transplantation with stable graft function) were screened; 64 met the inclusion criteria and were randomized to a AVF ligation (n=33) or control (n=31) group.
- All participants underwent cardiac magnetic resonance imaging at baseline and at 6 months.
- The primary outcome was the change in left ventricular (LV) mass.
- Secondary outcomes included changes in LV volumes, left and right atrial areas, LV ejection fraction, NT-proBNP (N-terminal pro-B-type natriuretic peptide) levels, cardiac output, cardiac index, ipsilateral brachial flows, and pulmonary artery velocity.

RESULTS

- Fifty-four participants completed the study: 27 in the AVF ligation group and 27 in the control group.
- On the second cardiac magnetic resonance scan, a mean decrease of 22.1 g (95% CI, 15.0-29.1) was observed in LV mass in the AVF ligation group compared with a small increase of 1.2 g (95% CI, -4.8 to 7.2) in the control group.
- Significant decreases in LV end-diastolic volumes, LV end-systolic volumes, cardiac output, cardiac index, atrial volumes, and NT-proBNP were also seen in the AVF closure group.
- No significant changes were observed in LV ejection fraction and pulmonary artery velocity
- No significant complications were noted after AVF ligation.
- No changes in estimated glomerular filtration rate or systolic and diastolic blood pressures were observed between cardiac magnetic resonance scans.

CONCLUSION

Elective ligation of patent AVF in adults with stable kidney transplant function resulted in clinically significant reduction of LV myocardial mass at 6 months. These results have significant implications for the management of cardiovascular risk after kidney transplantation, given that a single intervention could provide substantial cardiovascular benefits.

REFERENCE

Rao NN, Stokes MB, Rajwani A, Ullah S, Williams K, King D, Macaulay E, Russell CH, Olakkengil S, Carroll RP, Faull RJ, Teo KSL, McDonald SP, Worthley MI, Coates PT. "Effects of Arteriovenous Fistula Ligation on Cardiac Structure and Function in Kidney Transplant Recipients," *Circulation*. 2019 Jun 18;139(25):2809-2818. (Transonic Reference List # HD119071AHR)

Rao(HD119071AHR-pb)RevA2021A4

The Problem:

Sudden Cardiac Death & Chronic Kidney Disease

ESKD patients are prone to sudden death, stroke and myocardial infarction.



Sudden Cardiac Death

For millions of people suffering from chronic kidney disease (CKD), sudden cardiac death (SCD), or death from an unexpected circulatory arrest that occurs within an hour of the onset of symptoms, or an unwitnessed, unexpected death in patients known to be well within the previous 24 hours without an obvious non-cardiac cause, is a significant risk. CKD patients have a four to 20 times greater risk of sudden cardiac death (SCD) than do persons in the general population. As their glomerular filtration rates decline indicating progressively lower kidney function, the risk of sudden cardiac death proportionally increases.

Cardiovascular Collapse

Sudden death accounts for 25% of all causes of mortality in end-stage kidney disease (ESKD) patients undergoing hemodialysis. Cardiovascular collapse from congestive heart failure resulting from cardiac overload, anemia, severe hypertension and cardiac dysfunction is a major cause of complications during hemodialysis. In adolescents, CVD mortality rates are about 30 times that of the general population.

Identifying SCD in CKD Patients

Determining the sudden nature of death is problematic particularly among ESKD patients because:

- Most sudden deaths among CKD patients are unwitnessed. Therefore, clinical information collected around that time is often limited;
- ESKD patients are often chronically ill with comorbidities, and are frequently hospitalized.

"Haemodynamic monitoring identifies a significant number of HD patients with cardiac impairment that are at risk for increased mortality."

Haag S, Artunc F et al, Nephrol Dial Transplant. 2018;33(8):1419-1427.

CKD Sudden Death Pathophysiology

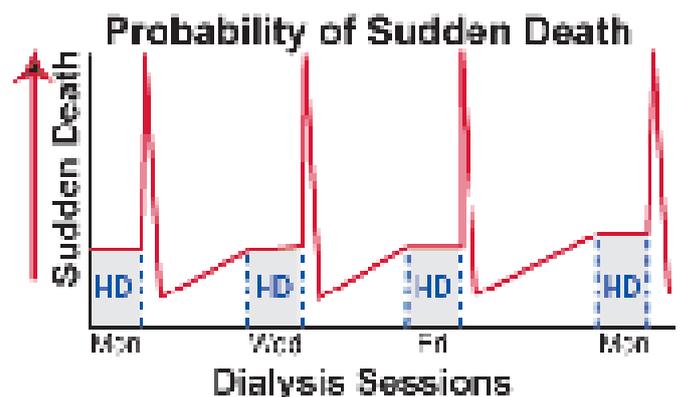
In the general population, coronary heart disease that leads to ventricular fibrillation or sustained ventricular flutter is the major cause of sudden death.

In the case of CKD patients, studies suggest fundamental differences in the causes and pathology of sudden heart disease. In these patients, their coronary artery disease involves multi-vessel arterial stiffening and calcification rather than an ischemic myocardium that might trigger a terminal arrhythmia and death. Rather, CKD patients, especially those on hemodialysis, are subject to a wide array of potential arrhythmic triggers including the following:

- Rapid ultrafiltration rate
- Low calcium during hemodialysis
- Low potassium (hypokalemia) or high potassium (hyperkalemia) levels in the blood

When Does Sudden Death Occur

It has been observed that SCD in CKD occurs most frequently on days when hemodialysis is being administered, particularly on the first day after a three day weekend without dialysis. Moreover, as illustrated in the graph below, the probability of sudden death increases in the time period immediately following dialysis.



The graph illustrates the spike in the probability of sudden death immediately following dialysis. "35% of deaths occurred in the 1st 12-hour interval... 27% of these deaths occurred during dialysis and 33% occurred in the hour after the dialysis treatment (8)." Critically low CI levels (<2 L/min/m²) can occur in patients who do not feel well at the end of a dialysis session.

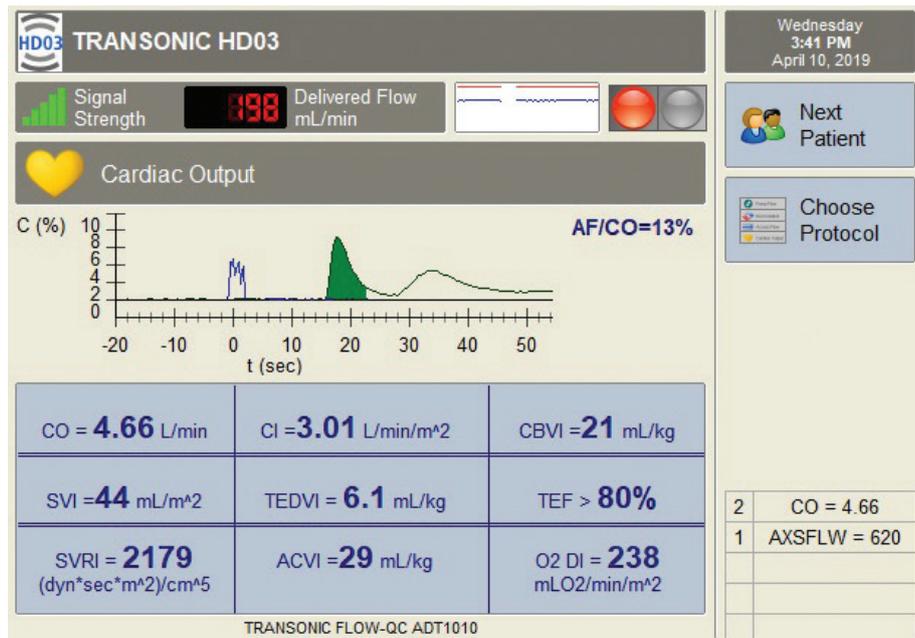
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The Solution:

HD03 Monitoring of Cardiac Function

Forestall cardiovascular complications by routine clinical exams supported by HD03 hemodialysis cardiac function monitoring



Transonic Cardiac Function Monitoring provides a way to integrate cardiac function data into a hemodialysis clinic's treatment protocol in order to forestall the devastating effects of cardiovascular disease. Transonic's proprietary ultrasound indicator dilution technology measures Cardiac Output and reports the following derived cardiac function parameters:

- Cardiac Index (CI);
- Central Blood Volume Index (CBVI);
- Stroke Volume Index (SVI);
- Total End Diastolic Volume Index (TEDVI);
- Total Ejection Fraction (TEF %);
- Systemic Vascular Resistance Index (SVRI);
- Active Circulation Volume Index (ACVI);
- Oxygen Delivery Index (O₂DI);
- Access Flow to Cardiac Output Ratio (AF/CO).

Monitoring of these parameters identifies:

1. Excessively high and prolonged levels of access flow (>1,600-2,000 mL/min) which stress the heart causing cardiomegaly and heart failure. This can be identified by an access flow to cardiac output ratio (AFV/CO) exceeding 25-30%.
2. Low cardiac output (CI < 2 L/min/m²) which places patients at high risk for cardiovascular complications and failure.
3. Significant 20 - 30% decrease of Cardiac Index during hemodialysis to dangerously low levels due to inaccurate dry weight estimation and/or inadequate medication that places patients at high risk for cardiovascular complications and sudden death following a dialysis session.
4. Significant decreases in Central Blood Volume during dialysis that may portend hypotensive episodes.

Summary: Cardiac Function Measurements

HD CARDIAC PARAMETER	TYPICAL RANGE (Observed in 70% of data)	ATYPICAL RESULT*	CLINICAL RELEVANCE	INTERPRETATION & RECOMMENDATIONS
Cardiac Output (CO) (L/min)	5 - 8 L/min	< 2.0; >10 L/min	Increased risk for cardiovascular complications and failure.	CO varies by patient parameters and is used to calculate AF/CO ratio. CO alone should not be used for guidance.
Cardiac Index (CI) (L/min/m ²)	2.2 - 3.8 L/min/m ²	< 2.0 L/min/m ²	If observed at the beginning of the session, indicates significant deterioration of CO function.	Refer to cardiologist for full study. Check for chronic hypoxia.
		20-30% drop in CI during the session indicates inadequate dry weight estimation and/or effects of medication.	Dry weight and medications should be clinically evaluated and updated, if needed, and these measurements should be repeated at beginning & end of session.	
		> 4 L/min/m ²	In approximately 50% of cases, high CI is associated with increased fistula flow. In other cases, high CI is associated with fluid overload or low hematocrit levels.	Determine cause for increased CI. Implement proper treatment: <ul style="list-style-type: none"> • AV access evaluation/intervention; • Adjust dialysis prescription; • Adjust anemia management.
Stroke Volume Index (SVI) mL/m ²	32-56 mL/m ²	< 20 mL/m ²	Usually indicates low preload (hypovolemic status).	Suggest SVI parameters be included in the clinical evaluation.
		> 60 mL/m ²	Usually associated with high fistula flow.	
Total Ejection Fraction (TEF)% ¹	40 - 76%	< 40%	Effective heart performance is decreased. Low value may increase mortality.	Determine if a referral to a cardiologist for additional clinical assessment is appropriate.
Systemic Vascular Resistance Index (SVRI) dynes·sec/cm ⁵ /m ²	1900 - 3200 dynes·sec/cm ⁵ /m ²		In non-hemodialysis adult patients, expected value is 2000-2400 dynes·sec/cm ⁵ /m ² .	Currently, there are no clear guidelines for the expected SVRI. SVRI in dialysis patients may be higher than in the non-hemodialysis population.
Total End Diastolic Volume Index (TEDVI) mL/kg	6 - 11 mL/kg	> 11 mL/kg	Increased TEDVI indicates tendency to cardiomegaly and increased mortality.	Determine if a referral to cardiologist for additional clinical assessment is appropriate.
Central Blood Volume Index (CBVI) mL/kg	13 - 23 mL/kg	< 14 mL/kg	If measurement < 14 mL/kg is taken at beginning of session, patient started on hypovolemic side. If patient is on the lower end at end of session, it is less of an issue.	Special care should be taken during HD session to avoid hypotensive episode.
		> 25 mL/kg	If patient came to session with >25 mL/kg, there is significant fluid overload. If patient ends with >25 mL/kg, insufficient fluid was removed during session.	Assess patient for fluid volume overload. Evaluate if any adjustment for the Dry Weight/Target Weight is indicated. Evaluate if the patient may need additional education/assistance with the fluid restriction included in their diet prescriptions. Repeat study
Active Circulation Volume Index (ACVI) mL/kg	40 - 70 mL/kg	< 45 mL/kg	If measurement of <45 mL/kg is taken at beginning of session, patient started on hypovolemic side. If patient is on the lower end at end of session, it is less of an issue.	Special care should be taken during HD session to avoid hypotensive episode.
		> 65 mL/kg	If patient came to session with >65 mL/kg, there is significant fluid overload. If patient ends with >65 mL/kg, insufficient fluid was removed during session.	Assess the patient for fluid volume overload. Evaluate if any adjustment for the Dry Weight/Target Weight is indicated. Evaluate if the patient may need additional education/assistance with the fluid restriction included in their diet prescriptions. Repeat study.
Oxygen Delivery Index (ODI) mL O ₂ /min/m ²	420 - 500 mL O ₂ /min/m ²	< 400 mL O ₂ /min/m ²	Under O ₂ delivery may be related to low hemoglobin, low CI or high fistula flow.	Refer to nephrologist for evaluation to determine source of issue.
Access Flow/Cardiac Output Ratio %	15-25%	>25-30%	Increased risk for cardiovascular complications and failure. High flow fistula can lead to high output cardiac failure.	For high fistula flows, repeat AF & CO at end of session to re-evaluate ratio. Consider evaluating patient for high output cardiac failure. Consider reducing AF by banding or other surgical procedure.

1.TEF is an aggregate measure of ejection from all 4 heart chambers. It is not interchangeable with EF, an ejection fraction from each of the heart chambers.

* Suggests additional clinical evaluation for clinical relevance.

Measure vascular access flow, save an access. Measure cardiac output, save a life.

Background

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in End-Stage kidney Disease (ESKD) patients whose lives depend on hemodialysis. More common in patients with chronic kidney disease (CKD) than in those without CKD, cardiovascular disease becomes increasingly common as the stage of CKD advances. As one might expect on the basis of CVD prevalence, beneficiaries with CKD underwent substantially more cardiovascular procedures than those without CKD.

Traditional Role

A dialysis care team's traditional role is to administer dialysis. Without adequate dialysis an ESKD patient becomes chronically ill and ultimately dies.

- Transonic HD03's Dialysis Adequacy Monitoring function helps a clinic perform this function more efficiently.
- Transonic's introduction of the first-ever accurate recirculation monitor set a new standard of patients care — 0% recirculation for all hemodialysis patients with vascular accesses. New access devices and temporary catheters are now rated on how well they approach recirculation.
- Dialysis Adequacy tests (recirculation, and comparison of true pump flow with the pump flow setting) diagnose conditions that would cause underdialysis — both common errors such as inadvertently reversed needles, pump miscalibration, incorrect needle size or placement, etc. and severe problems such as manufacturer's tubing defects, or collapsed tubing that could cause blood hemolysis and possible adverse events for the patient.

Transonic: Pioneer of Indicator Dilution Technology

Transonic conceived and pioneered Indicator Dilution Access Flow Measurement. The nephrology community embraced the diagnostic opportunities generated by this test.

- A new role emerged for the dialysis care team and Flow-based Access Patency Management has now become the standard of patient care.
- Hemodialysis vascular access access grafts and fistulas suffer from a progressive narrowing

of the access resulting in a stenosis. If left untreated, this can lead to irreversible failure and thrombosis of the access, and the patient must undergo surgery to create a new vascular access. Transonic pioneered indicator dilution measurement of access flow to track the progression of this disease. This test gives the nephrologist a tool to schedule access interventions proactively to extend the access life.

Cardiac Function Assessment

HD03 Cardiac Function Assessment expands the role of the hemodialysis care team to include management of a patient's cardiovascular health.

Transonic Cardiac Function tests track an ESKD patient's cardiovascular parameters to provide the nephrologist with an on-site diagnosis of early indications of deteriorating cardiac conditions that could lead to CVD.

Transonic's cardiovascular tests can be performed during routine hemodialysis. The tests place a minimal burden on the patient. Test results are trended by Transonic software to allow tracking of cardiovascular status and alarm the nephrologist when significant changes are observed. The nephrologists can then refer a patient with suspected cardiac problems to a cardiologist.

Ultrasound Dilution Technology

Pioneered by Nikolai Krivitski, PhD, DSc, the Ultrasound Dilution technology and the Krivitski Method[®] marries transit-time ultrasound and indicator dilution principles. It leverages Transonic's highly accurate tubing flowsensors for use in any situation involving an extracorporeal blood circuit. Measurements are immediate, and non-invasive. They provide a wide variety of clinically valuable data for healthcare providers.



Nikolai Krivitski

The technology is commonly used with the HD03 Monitor during hemodialysis to measure vascular access flow, recirculation and cardiac function parameters. These measurements can be achieved with the highest accuracy because the technology is able to separate cardiopulmonary recirculation from systemic circulation.

High Arteriovenous (AV) Access Flow and Cardiac Complications: AF/CO Ratio

AV Access Flow & Cardiac Function

High AV 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 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 drop in resistance by increasing its heart rate and stroke volume, which, over time, can lead to the development of congestive heart failure.

Access Flow - Cardiac Output Ratio

Jennifer MacRae *et al* reported that high output cardiac failure is associated with high flow AVFs (> 1.5 L/min), particularly in men with upper arm fistulas and previous access surgeries. In her comprehensive review, "The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern?" MacRae documents the evidence on the subject and reports 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, and patients having a Qa/CO ratio \geq 30% undergo further testing.

Basile Sets 2 L/min AVF Flow Cut-off

In 2008, Basile *et al* published a study of 96 patients with AV fistulas and cardiac failure. 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.

Wasse Summarizes AF/CO Relationship

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

The Clinical Relevance and Management of High-Flow Arteriovenous Access:

Bucktowarsing B, Vin Y, Lerma EV. *Adv Chronic Kidney Dis.* 2020 May;27(3):214-218.

Clinical Summary:

- High-output cardiac failure is a potential complication of arteriovenous (AV) access creation.
- AV accesses, especially upper arm, with blood flow >1.5 L/min are of high risk.
- Blood flow/Cardiac output ratio (AF/CO) of 0.30 is a valid screening tool to perform further cardiac testing.
- If no reversible cause for high-output heart failure is identified, a case can be made for flow reduction (banding) of the AV access.

High-flow AV Access Criteria: Qa >2 L/min, or Qa/CO: 30%, or Qa/Height > 603 mL/min/m

- 1) (MacRae *et al*, 2004-2006) Blood flows >1.5 L/min; when Qa exceeds 25% of CO, the risk of developing high-output heart failure (HOCHF) increases. A Qa/CO ratio of 0.30 should be used as a screening tool to perform further cardiac testing.
- 2) (Basile *et al*, 2008) AV access flows >2.0 L/min result in high-output cardiac failure. Due to higher flows in this area, there is an association between upper arm AV fistula and the development of high output cardiac failure.
- 3) (YE *et al*, 2013) "Cardiac adaptive changes after long-term arteriovenous fistula (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 peripheral resistance."
- 4) (Zamboli *et al*, 2018) Indexation of blood flow for height gives a better diagnosis for HOCHF.

High-flow AV Access Physiologic Basis: Cardiac Output = Heart Rate X Stroke Volume (a function of peripheral vascular resistance). Peripheral vascular resistance drops with creation of an AV access, but blood volume, cardiac contractility, and left ventricular end-diastolic volume increase in a non-physiologic fashion that results in an overall increase in CO. AV access blood flow bypasses capillary beds and returns blood to the heart at non-physiologic pressures and velocities. The resultant higher filling pressures cause significant atrial stretch, which results in higher CO.

Modification of High-flow AV Access: Multiple techniques are used to reduce Qa by increasing resistance at the inflow level. Banding, the simplest, most common flow-reducing procedure, requires achieving a fine balance between a band that is tight enough to be effective and not too tight to risk the patency of the access. Precision banding using intraoperative flow measurements support banding as an effective treatment with a low risk of access failure. Flow reduction revision using distal inflow involves ligation of the fistula at its origin followed by reestablishment of flow via a bypass from either the proximal radial or ulnar artery using a vein or graft as conduit.

Why Should Nephrologists Be Suspicious of High Flow AV Access? CO and Cardiac Index drop during the first 12 hours after dialysis. A high-flow fistula may steal blood away from an already compromised peripheral circulation, compromising end organ perfusion. Two studies cited:

- 1) (Bleyer *et al* 2006) Study postulates that 35% of sudden deaths occur within the first 12 hour after dialysis. Critically low levels of cardiac index (>2 L/min/m²) can occur during that time period and is aggravated as a high-flow fistula steals blood away from a suboptimal systemic circulation.
- 2) (Tucker *et al* 2002) Study describes how the AF/CO ratio increases after dialysis, mainly driven by a decrease in CO. If an access is already in a "high flow state," this condition becomes exaggerated and can lead to precipitous decline in systemic perfusion, resulting in sudden death.

Conclusions:

- High-flow AV access can have significant impact on the long-term outcomes of dialysis patient with other comorbidities.
- Complications associated with high-flow AV accesses are very often attributed to other etiologies or to patient related factors, eg, noncompliance.
- Nephrologists and vascular access experts should work together to mitigate the potential harm to dialysis patients afflicted by this condition.

HD03 Hemodialysis Monitor: Access Flow/Cardiac Output Interpretation

Lower Arm AVF (wrist and above)



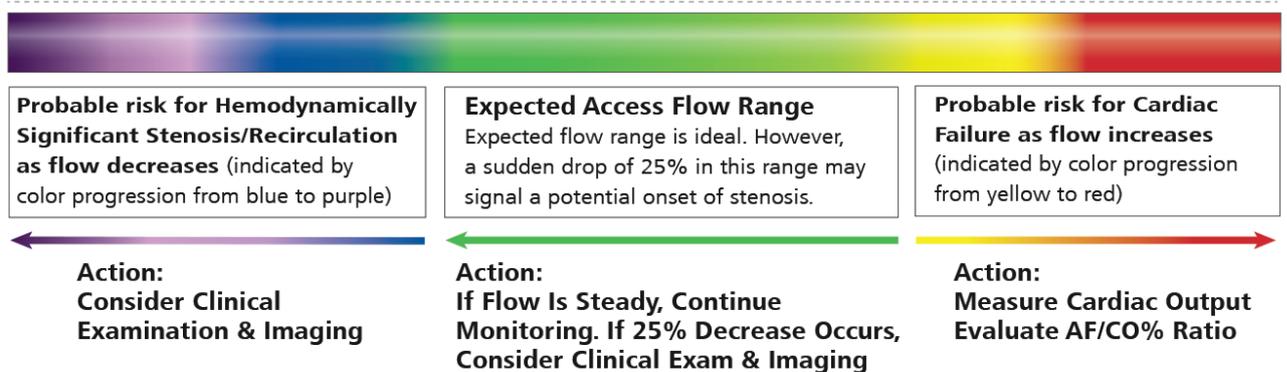
Upper Arm AVF (elbow and above)



AV Graft (forearm loop graft)



CLINICAL INTERPRETATION KEY:



Notes:

- Actual flow levels for AV fistula and graft patients should be customized by the nephrologist.
- A clinical examination (look, listen, feel, arm elevation and augmentation) should be used routinely as part of the pre-cannulation process.
- Transonic access flow measurements are intended to be utilized in conjunction with a clinical examination to detect/confirm indications of access dysfunction.
- Snuffbox or endovascular fistulas may have a lower access flow range depending on the location of the anastomosis and the vessel's outflow configuration.
- Upper arm AV fistulas typically have a higher access flow range due to the larger artery size.
- A potential for cardiac overload exists at flow >1600-3000 mL/min. Cardiac Output parameters can be utilized to measure AF/CO ratio.

Cardiac Output Frequently Asked Questions

Q. Why must the saline injection be pre-warmed to 37°C?

A. The transit time of ultrasound changes with temperature. When CO is measured, the saline bolus travels through the cardiovascular circuit before returning to the arterial line sensor. Saline must be pre-warmed to body temperature so there will be no additional thermal changes added to the saline indicator bolus on its passage through the body.

Q. How can I pre-warm the saline to 37°C?

A. With a saline bag warmer.

Q. How accurately must I pre-warm the saline?

A. The acceptable temperature range for the injected bolus is between 35 and 38°C.

Q. How should I inject the 30mL of saline?

A. It must be injected in one single pass at a fairly rapid rate (4 to 7 seconds for the full volume) into the injection side port of Transonic's Flow-QC tubing. The software automatically identifies injection errors and will post an error message.

Q. How accurate is a Transonic CO measurement?

A. Transonic FDA approval to market CO function rested on comparisons of CO ultrasound dilution measurements with thermodilution (PA) catheters measurements in patients, and with measurements of chronically implanted Transonic A-probes in animal studies. The ultrasound dilution demonstrated an accuracy of 15% (19 out of 20 measurements fall within 15% of actual CO if all calibration and measurement precautions are followed.

B. Why is there a difference in readings between two successive CO measurements?

A. The technology has a repeatability of $\pm 4\%$: this means that noise between successive measurements may give variations in reading with a standard deviation of 4%. A further source of variability comes from the heart itself: CO varies during the course a respiratory cycle, over the course of the dialysis treatment, and when the patient becomes aroused or excited.

Q. How do I know whether the measurement I made was without technical errors?

A. CO must be measured twice in succession especially during baseline studies. If the second CO measurement is within 0.5 L/min or 15% of the first measurement, the average of these two measurements is recorded as the patient's CO. If the difference is larger than 15%, a third measurement should be performed and the measurement that deviates the most can be discarded.

Q. What is the difference between CO and CI?

A. CO varies strongly with body size, sex and physique of the patient: a baby's heart pumps less blood than the heart of an adult. CI is equal to CO, normalized by body surface area. Therefore, CI reflects the patient's condition of the heart, independent of body size.

Q. Why do we recommend setting the pump to 200 mL/min during a CO measurement?

A. From experience we know that at this pump setting you will make a reliable consistent measurement more often. Injecting 30 mL of saline over 6 seconds increases the outflow rate of the venous blood line temporarily by 300 mL/min. Lowering the pump setting reduces the chance of a pump stop during venous pressure elevation, and also reduces the chance that the saline injection would trigger recirculation.

Q. Why must there be 0% recirculation during the CO measurement?

A. For an accurate CO measurement, the full saline bolus must reach the heart: the CO calculation equation includes a bolus volume of 30mL. If recirculation occurs, a part of the bolus will disappear back into the arterial blood line, and the lost saline would cause a measurement error. The monitoring software will recognize recirculation during the CO measurement injection, and warn the user to repeat the measurement at a lower pump flow setting.

Q. Why is a CO measurement not possible with CVCs?

A. Cardiac output measurements require recording a dilution curve in any artery after the introduction of an intravenous indicator. The lack of mixing conditions for the indicator injected through the CVC with the whole cardiac flow prevents CO measurements.

Q. Why do I need to enter the patients' height, dry/idea weight, blood pressure, heart rate and hemoglobin?

A. The Body Surface area is part of the Cardiac Index calculation. Other parameters are also indexed to allow comparison across patient populations/sizes.

Q. Can I save the measurements for later playback?

A. Yes, if you are utilizing a Data Transfers Module (DTM). Once the DTM has been synchronized with the Transonic Administrator Software, the results can then be viewed, trended, and printed as reports.

Q. Why do I need to use the Flow QC tubing set?

A. A safe injection port is needed for a quick injection of the saline bolus. If you were to inject the bolus on another site such as the bubble trap, the injection period would become too long and the program may not be able to separate the timing of the first cardiopulmonary recirculation from which CO is determined from subsequent recirculations of the saline bolus. (The time between start of injection and appearance of the CPR bolus is only 8 to 12 seconds). The Flow-QC tubing provides a controlled, consistent measurement environment. Transonic inspects the ultrasonic and mechanical properties of these tubing sets to guarantee optimum measurement accuracy.



Cardiac Output FAQs cont.

- 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).

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>)