Hemodialysis Annotated References

Theory & Validations (UDT, TTFM)

Ultrasound Dilution (UDT)

Krivitski NM, **"Novel Method to Measure Access Flow during Hemodialysis by Ultrasound Velocity Dilution Technique,"** ASAIO 1995; 41(3): M741-M745. *Theory and bench validation of access flow measurement by ultrasound velocity dilution. Reversal of dialysis lines creates a zone of mixing in the vascular access, allowing the use of dilution technique for access flow measurement. Data show that access flow can be accurately measured by sound velocity dilution technique.*

Depner TA, Krivitski NM, MacGibbon D, **"Hemodialysis Access Recirculation (Rc) Measured by Ultrasound Dilution,"** ASAIO J 1995; 41(3): M749-M753. *"The data suggest that the ultrasound dilution method is both sensitive and accurate."*

Depner TA, Krivitski NM, **"Clinical Measurement of Blood Flow in Hemodialysis Access Fistulae and Grafts by Ultrasound Dilution,"** ASAIO J 1995; 41(3): M745-M749. *"These data show that blood flow in peripheral arteriovenous grafts and fistulas can be measured accurately during hemodialysis using ultrasound velocity dilution."*

Bosman PJ, Koomans HA *et al,* **"Access flow measurements in hemodialysis patients: in vivo validation of an ultrasound dilution technique."** J Am Soc Nephrol. 1996 Jun;7(6):966-9. *"Measurements correlated well with flow rates determined by magnetic resonance angiography and by a technique based on intra-access flow-pressure curves. …Access flow can be measured easily, noninvasively, and reliably by the ultrasound dilution device… The method requires little investment in time making it superior to other methods."*

Krivitski NM, MacGibbon D, Gleed RD, Dobson A, **"Accuracy of Dilution Techniques for Access Flow Measurement During Hemodialysis,"** AJKD 1998; 31(3): 502-508. *"An error in access flow measurement of 20% or more arises from the use of flow reading taken from pump setting rather than a measured flow. The discrepancy between the real flow and pump setting is attributable to needle size, vascular access conditions, or pump calibration."*

Krivitski NM, Depner TA, **"Cardiac output and central blood volume during hemodialysis: methodology,"** Adv Ren Replace Ther. 1999;6(3):225-232. *"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. *"Cardiac output measured by ultrasound velocity dilution during hemodialysis is in good agreement with well established, but invasive, transit time and pump standards."*

Nikiforov UV, Kisluchine VV, Chaus NI, **"Validation of a New Method to Measure Cardiac Output during Extracorporeal Detoxification,"** ASAIO J 1996; 42(5) M903-M905. *"Data suggest agreement between the ultrasound dilution technique and thermodilution. Ultrasound dilution is preferable in patients undergoing extracorporeal detoxification when pulmonary artery catheterization is not required or dangerous."*

Transit-time Ultrasound (TTFM)

Drost CJ, **"Volume Flow Measurement System,"** U.S. Patent # 4,227,407, Cornell Research Foundation, Inc., Ithaca, NY, October 14, 1980. *"Patent for transit-time ultrasound flow measurements: outlines a device and method for direct measurement of volume flow of fluids through a tube, using an interferometric transit-time technique based on an electric signal which is proportional to fluid flow and is, to a high degree, independent of flow profile, conduit geometry, and alignment of the conduit within the probe."*

Drost CJ, **"Homogeneous Full Flow Illumination to Ultrasonic Systems,"** Proceedings of the 31st Annual Conference of Engineering in Medicine and Biology, Bethesda MD: Alliance for Engineering in Medicine and Biology 1978; 20: 183. *"If the signal acquired in ultrasonic blood flow measuring systems could be made to represent the full flow rather than a (spatially often ill defined) portion of one, it is obviously a step closer to instantaneously measuring the total flow independent of flow profile and vessel geometry."*

Drost CJ, **"Vessel Diameter-Independent Volume Flow Measurements Using Ultrasound,"** Proceedings of San Diego Biomed. Symposium, San Diego CA: San Diego Biomed. Soc. 1978; 17: 299-302, 1978. *"Theoretical background for a volume flow measuring technique in which volume flow is measured directly, independent of vessel diameter, vessel shape, flow profile or vessel aluignment within the nonconstrictive probe."*

Hemisch W, **"Blood Flow during Cardiovascular Surgery: Methodological, Technical and Practical Considerations,"** Gefäßchirugie, Springer-Verlag, 1996. *"Comparison of Doppler, electromagnetic and transit-time ultrasound technologies noting that transit time ultrasound is the only method able to measure volume flow inside artificial vascular prostheses."*

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Predictive Power of Arteriovenous Access Flow Measurements

Salman L *et al,* **"A multicenter randomized clinical trial of hemodialysis access blood flow surveillance compared to standard of care - The Hemodialysis Access Surveillance Evaluation (HASE) Study,"** Kidney International Reports (2020), *"The HASE study demonstrated that monthly surveillance using UDT flow measurement has resulted in lower per patient and per visit thrombosis rate as compared to the control group."*

Aragoncillo I *et al,* **"Adding access blood flow surveillance reduces thrombosis and improves arteriovenous fistula patency: a randomized controlled trial,"** J Vasc Access. 2017; 18(4): 352-358. *"QA-based surveillance combining Doppler ultrasound and ultrasound dilution reduces the frequency of thrombosis, is cost effective, and improves thrombosis-free and secondary patency in autologous AV."*

Ashoor IF, Hughson EA, Somers MJ, **"Arteriovenous access monitoring with ultrasound dilution in a pediatric hemodialysis unit."** Blood Purif. 2015;39(1-3):93-8. *"Thrombosis rate dropped from 13.5 per 100 patient-months on HD during the baseline period to 3.5 per 100 patient-months on HD during the surveillance period. Ultrasound Dilution surveillance is very sensitive in detecting hemodynamically significant stenosis and can decrease AV access thrombosis rates."*

Park HS, Kang SH, Chung BH *et al,* **"Effect of intradialytic change in blood pressure and ultrafiltration volume on the variation in access flow measured by ultrasound dilution,"** Kidney Res Clin Pract. 2013; 32(1):16-20. *"Variation in access flow during HD is relatively small. Decreased blood pressure is a risk factor for variation in access flow measured by ultrasound dilution. In most patients whose blood pressures are stable during HD, the access flow can be measured at any time during the HD treatment."*

Chan KE, Hakim RM *et al,* **"Access survival amongst hemodialysis patients referred for preventive angiography and percutaneous transluminal angioplasty,"** Clin J Am Soc Nephrol. 2011 Nov; 6(11):2669-80. *"Huge statistical study (41,132 Medicare patients, 1,342 Fresenius facilities, 48 states) determined, "The benefits of PTA interventions are most seen in newer accesses or accesses with insufficient flow."*

Maoz D, Reinitz R, Schneiderman J *et al,* **"Hemodialysis graft flow surveillance with prompt corrective interventions improves access long-term patency,"** Clin Nephrol. 2009 Jan;71(1):43-9. *"Stringent flow surveillance policy coupled with prompt intervention has proven effective in maintaining AVG long-term patency."*

van Loon M, Tordoir JH *et al,* **"Implementation of a vascular access quality programme improves vascular access care."** Nephrol Dial Transplant. 2007 Jun;22(6):1628-32. *"(24 center, 2300 patients) An AV Access Care Quality Improvement Plan is worthwhile to improve dialysis patients' care and access morbidity."*

Tessitore N *et al,* **"Adding access blood flow surveillance to clinical monitoring reduces thrombosis rates and costs, and improves fistula patency in the short term: a controlled cohort study,"** Nephrol Dial Transplant 2008 23:3578-3584. *"Adding Qa surveillance to monitoring in mature AVFs is associated with a better detection and elective treatment of stenosis, and lower thrombosis rates and access-related costs."*

Wijnen E, van der Sande F *et al,* **"Impact of a quality improvement programme based on vascular access flow monitoring on costs, access occlusion and access failure,"** Nephrol Dial Transplant. 2006 Dec;21(12):3514-9. *"A quality improvement programme based on periodical access flow measurement reduced the number of acute vascular access failures due to thrombotic events and also significantly reduced health care costs in patients with AVG, but not in patients with AVF."*

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Lok CE, Bhola C, Croxford R, Richardson RM, **"Reducing vascular access morbidity: a comparative trial of two vascular access monitoring strategies,"** Nephrol Dial Transplant. 2003 Jun;18(6):1174-80. *"A three-year study, 300-400 patients. Low flow rates detected using Transonic monitoring were associated with increased thrombosis, while stenosis detected using Duplex ultrasonography was not a strong predictor of incipient thrombosis."*

Goldstein SL, Allsteadt A, **"Ultrasound Dilution Evaluation of Pediatric Hemodialysis Vascular Access,"** Kidney Int 2001; 59: *Study supports the use of monthly measurement to prevent access thrombosis in children receiving HD.*

McCarley PB, Ikizler TA *et al,* **"Vascular Access Blood Flow Monitoring Reduces Access Morbidity and Costs,"** Kidney Int 2001; 60:1164-72. *"Vascular access blood flow monitoring along with preventative interventions should be the standard of care in chronic hemodialysis patients. … The comprehensive cost is markedly reduced due to the decreased number of hospitalizations, catheters placed, missed treatments, and surgical interventions."*

Sands JJ, Jabyac PA, Miranda CL, Kapsick BJ, **"Intervention based on monthly monitoring decreases hemodialysis access thrombosis,"** ASAIO J. 1999 May-Jun;45(3):147-50. *"We believe that monthly access flow measurement will ensure the lowest incidence of thrombosis and decrease the cost of access maintenance."*

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Zero Vascular Access Recirculation - A New Reality

MacDonald JT Sosa MA, Krivitski NM, Glidden D, Sands JJ, **"Identifying A New Reality: Zero Vascular Access Recirculation Using Ultrasound Dilution,"** ANNA J 1996; 23(6): 603-608. *"A new method, ultrasound dilution, avoids these problems and supports a new clinical reality--zero access recirculation."*

Alloatti S, Molino A, Bonfant G, Ratibondi S, Bosticardo G M, **"Measurement of Vascular Access Recirculation Unaffected by Cardiopulmonary Recirculation: Evaluation of an Ultrasound Method,"** Nephron 1999; 81(1) 25-30. *"AR determination by USM, avoiding misleading interferences with CPR, is a rapid, easy, and noninvasive method to routinely exclude a potential cause of reduced dialytic efficiency."*

Basile C, Ruggieri G, Vernaglione L, Montanaro A, Giordano R. **"A comparison of methods for the measurement of hemodialysis access recirculation,"** J Nephrol. 2003;16(6):908-913. *"AR in autogenous radiocephalic wrist AVFs was zero when measured by means of the USM."*

Twardowski ZJ, Van Stone JC, Haynie JD, **"All Currently Used Measurements of Recirculation in Blood Access by Chemical Methods are Flawed Due to Intradialytic Disequilibrium or Recirculation at Low Flow,"** Am J Kid Dis 1998; 32(6): 1046-1058. *"The ultrasound dilution method usually gave lower values than the chemical methods, most likely because of overestimation of recirculation by chemical methods."*

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Discrepancy between Prescribed & Delivered HD Pump Flow

Sands J, Glidden D, Jacavage W, Jones B, **"Difference between delivered and prescribed blood flow in hemodialysis,"** ASAIO J. 1996;42(5):M717-M719. *"Delivered and prescribed blood flow (QB) was compared during 208 hemodialysis treatments using the Transonic hemodialysis monitor. Delivered QB averaged 205.6, 300.6, 384.3 ($p < .0001$), and 467.7 cc/min ($p < .0001$) at pump settings of 200, 300, 400, and 500 cc/min."*

Depner TA, Rizwan S, Stasi TA, **"Pressure effects on roller pump blood flow during hemodialysis,"** ASAIO Trans. 1990;36(3):M456-M459. *"Blood pump meter readings greater than 400 ml/min were usually inaccurate because of low Pa."*

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Ward RA, **"Blood Flow Rate: An Important Determinant of Urea Clearance and Delivered Kt/V,"** Adv Ren Replace Ther 2001; 6(1): 75-79. (HD193A) *"For quality assurance purposes, actual blood flow rates should be determined by correcting nominal blood flow rates for pressure effects using empirical relationships or by using an ultrasonic flow meter. Because a poorly functioning blood access may further reduce the effective blood flow rate, blood access performance should also be monitored regularly."*

Mehta HK, Deabreu D, McDougall JG, Goldstein MB. **"Correction of discrepancy between prescribed and actual blood flow rates in chronic hemodialysis patients with use of larger gauge needles,"** Am J Kidney Dis. 2002;39(6):1231-1235. *"This study shows that the use of larger gauge needles can significantly increase d-BFR and PRU as a result of changes in arterial and venous pressures, resulting in a significantly increased dialysis dose at no additional cost."*

Measurements of Recirculation and Delivered Flow in Catheters

Twardowski ZJ, Haynie JD, **"Measurements of hemodialysis catheter blood flow in vivo,"** Int J Artif Organs. 2002;25(4):276-280. *"Pressures & blood flows were measured at pump speeds from 50 to 500 ml/min in increments of 50 ml/min with lines in normal configuration. Blood flow was measured continuously using ultrasound. The correlations between pressures and flows are not linear."*

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