THE PROXIMAL FLOW CONVERGENCE METHOD CAN BE EXTENDED TO CALCULATE REGURGITANT STROKE VOLUME; IN VITRO APPLICATION OF THE COLOR DOPPLER M-MODE

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Recent studies have shown that the flow convergence region proximal to an orifice can be used to quantify flow rate from the color Doppler flow image. Flow is assumed to converge radially toward the orifice. By continuity, orifice flow equals the flow through a hemispherical proximal isovelocity surface area (PISA) with a radius equal to the distance between the orifice and the first color alias encountered as flow accelerates: the velocity at that surface equals the Nyquist limit. Peak Q has been calculated from maximum systolic radius squared. which is proportional to the PISA. However. measures of total regurgitant stroke volume (RVOL) have not been tested. The color Doppler M-mode (CDMM) can display the radius of first aliasing vs time. The purpose of this study was therefore to test the hypothesis that total RVOL can be calculated by integrating the PISA from the CDMM radius squared over the period of flow. Pulsatile flow was pumped through circular orifices (.09 - .25 sq cm). producing RVOLs of 9 - 98 ml/beat. The Nyquist limit was adjusted to maximize the radius. which was measured along the axis of flow. and the radius was squared and integrated from the CDMM trace through the center of the PISA. RESULTS: Calculated RVOLs agreed well with electromagnetic flow values when 5 beats were averaged (y = .92x - .58. r= .99. SEE= 2 ml): for single beats. r= .98. SEE= 4.4 ml. CONCLUSION: The proximal flow convergence method can be extended throughout the pulsatile flow cycle to provide an accurate estimated of RVOL for the orifices studied in vitro. This is achieved by integrating the PISA radius squared from the CDMM tracing. and does not assume orifice area to be constant.

EFFECTS OF ORIFICE SIZE AND SHAPE ON FLOW RATE ESTIMATED FROM FLOW CONVERGENCE REGION IMAGED BY COLOR DOPPLER FLOW MAPPING PROXIMAL TO RESTRICTIVE ORIFICES: AN IN VITRO STUDY.

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Previous studies suggest that regurgitant flow rate (FR) can be estimated using the flow convergence region (FCR) imaged by color flow Doppler proximal to regurgitant orifices. We studied the effects of orifice size and shape on FR estimates in a constant flow model at FRs of 0.70 to 5.6 l/min with maximal jet velocities 1.0 to 6.6 m/sec through 4 circular orifices of 3.4 to 6.8 mm diameter and through 16mm² rectangular and elliptical orifices. Images were obtained with a Toshiba SSH65A, with a 3.75MHz transducer for Nyquist limits (NL) of 54, 41, 27 and 14 cm/sec to determine the radius (R) from the first aliasing surface to the center of the orifice and calculate flow area X velocity of a hemisphere isovelocity surface ($2\pi R^2$ X NL) as a measure of flow rate. For each separate orifice, the estimated FR correlated well with the actual flow rate for every NL used (r=0.87-0.99); however, the regression relationships of FR estimation were different for each NL used ($p<0.05$) with a consistent underestimation of FR, especially for higher NL and larger orifices. The relationship between estimated and actual FR was similar between the different orifices and between the planar axes of rectangular elliptical orifices only when imaged at NL 14 cm/sec, when the FCR radius was more distant from the orifice. The FCR may be used to estimate regurgitant flow rate but accuracy depends on orifice size and shape and the NL used. Using lower NLs to visualize the FCR at greater distances from the orifice overcomes some of these difficulties.

VALIDATION OF A NEW METHOD FOR VALVE AREA CALCULATION USING THE PROXIMAL ISOVELOCITY SURFACE AREA IN PATIENTS WITH MITRAL STENOSIS.

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The flow convergence region proximal to an orifice has been tested as a means of calculating flow rate through regurgitant orifices. However. this method can also potentially be used to derive cardiac output proximal to stenotic orifices and therefore to calculate their areas using the continuity equation. In patients (pts) with mitral stenosis (MS) this proximal convergence region is clearly seen. and this method has the advantage of providing forward flow across the valve regardless of the presence of regurgitation (MR). Therefore. to test the validity of this concept. we studied 30 pts with MS in sinus rhythm using 2D-echo and Doppler color flow mapping. Color flow recordings of mitral inflow were obtained from the apical views and the Nyquist limit was lowered to increase the visualized proximal isovelocity surface area (PISA). PISA was calculated assuming uniform radial flow convergence along a hemispherical surface. corrected by a factor that accounted for the inflow angle formed by the mitral leaflets (hemispherical sector). The PISA radius was measured from the orifice to the first color alias in the proximal convergence region. along an axis parallel to that of flow. Mitral valve area using PISA (MVAp) was calculated as MVAP= PISA*Vn/Vmax (Vn=Nyquist velocity. Vmax= peak velocity by continuous wave Doppler). MVAp was compared with planimetered area (Apl). RESULTS: MVAp correlated well with Apl (MVAp=1.09*Apl-0.16. r=.92 SEE=.19cm2) over a range of .5 to 2.1 cm2. Agreement was similar for 17 pts with MR and 13 without. CONCLUSION: The concept of PISA can be extended to orifice area calculation using the continuity equation. This allows accurate estimation of MS valve area and is not influenced by MR.

NYQUIST LIMIT AND ORIFICE AREA INDEPENDENTLY AFFECT THE ACCURACY OF PROXIMAL ISOVELOCITY SURFACE AREA ESTIMATION OF FLOW RATE: AN IN VITRO STUDY.

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The flow convergence region proximal to an orifice has been used for flow rate (Q) calculation, multiplying the proximal isovelocity surface area (PISA) by the color Doppler Nyquist velocity (v_N). Although it is generally assumed that the isovelocity contours form concentric hemispheric shells, hydrodynamic analysis predicts this should progressively underestimate true flow when the velocity radius is smaller than the orifice diameter, either due to a high Nyquist limit or a large orifice area (A). To test this question, we calculated Q in a dynamic *in vitro* model using the PISA method with v_N = 19 to 36 cm/sec. We used circular orifices (A = 0.3, 1.0 cm²) with Q up to 150 cc/sec. PISA was calculated assuming a hemispheric geometry: PISA=$2\pi r_N^2$, where r_N is the aliasing radius. Flow rate (Q_p) was calculated as Q_p=PISA·v_N and compared with the true flow rate (Q_t) measured by electromagnetic probe. RESULTS: Overall, Q_p agreed well with Q_t: $Q_p = 0.96Q_t - 10.6$, r=0.95, $p<0.0001$, n=50. However, below a true flow of about A·v_N, Q_p was 0, since no aliasing occurred. Multivariate regression showed both orifice area and v_N to have a negative influence on Q_p: $Q_p = 25.1 + 1.2Q_t - 40.4A - 0.9v_N$, r=0.99, $p<0.0001$. CONCLUSION: The assumption of hemispheric geometry is progressively less valid for larger orifices and higher Nyquist limits, particularly at low Q. This should be considered when evaluating flow rate by the PISA method.