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Assessment of Mitral Valve Area from Long Axis and Apical 4-Chamber Echocardigraphic Views: Correlation with Direct Intra-operative Measurements

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ABSTRACT

The standard two-diminishional echocardographic (2-D echo) measurements of Mitral Valve Area (MVA) from the short axis is technically demanding; requires experience and expertise and may not be feasible in some patients. The maximum distance between anterior and posterior mitral leaflet tips as measured from the 2-D Long Axis and Apical 4-chamber views, the Mitral Tip Separation (MTS), has been reported to be valuable for measuring MVA in patients with rheumatic Mitral Stenosis (MS). The aim of this study was to evaluate the use of the simple measurements of maximal 2-D diastolic MTS in determination of MVA via its correlation with the directly measured MVA during open mitral valve surgery in patients with rheumatic MS and to evaluate the reproducibility and sensitivity of this technique. This study comprised 184 patients with rheumatic MS, who were evaluated and subjected to open mitral valve surgery at Cardiothoracic Department, Mansoura University Hospital, in the period from January 1996 to December 2002. For every patient 2-D echo evaluation and estimations of MTS from Long Axis and Apical 4-chamber views, MVA from Short Axis and Doppler estimated MVA were performed at two different setting before surgery. During the open mitral valve surgery, direct measurements of MVA were done with the aid of Hegar dilator. The 2-D diastolic MTS were obtained clearly in all studied patients with minimal (or no) inter-observer variation. The diastolic MTS were obtained easily from the Long Axis views than the Apical 4-chamber views (96.74 vs. 77.17%, $p<0.005$). There a good positive correlations between direct intra-operative measurements of MVA by aids of Hegar dilator and 2-D diastolic MTS ($r = 0.9977$, $p<0.001$). A simple equation can be applied for estimation of MVA when 2-D diastolic MTS values is equal to or less than 1.2 cm as follow: MVA (cm^2) = 1.25 MTS (cm). The maximum diastolic 2-D MTS as measured from the parasternal Long Axis and/or Apical 4-chamber views is simple; reliable; accurate; reproducible; sensitive and easily applied echocardiographic method for determination of MVA in patients with rheumatic MS.

Key words: Rheumatic mitral stenosis, surgical management of mital stenosis, mitral valve area, transthoracic echocardiography, transesophageal echocardiography

INTRODUCTION

Rheumatic fever is the predominant cause of MS and a history of rheumatic fever is present in more than 60% of patients with this disease (Rowe *et al.*, 1960). The pathologic process in RF causes leaflet thickening, calcification and chordal fusion. This results in a funnel-shaped mitral apparatus, in which the mitral orifice is decreased in size (Roberts and Perloff, 1972). The normal Mitral Valve Area (MVA) is 4-6 cm^2. Mitral Stenosis (MS) is considered mild when the area is less than 2 cm^2. It is considered critical when the valve area is less than 1 cm^2 (Braunwald *et al.*, 2001).

Balloon Mitral Valvuloplasty is the procedure of choice for treatment of MS (Kang *et al.*, 2000; Palacios *et al.*, 2002). Surgical intervention for MS is recommended in patients with sever MS and significant symptoms (NYHA class III or IV) when BMV is not available, BMV is contraindicated because of persistent LA thrombus or moderate to sever MR, or when the valve is calcified and surgical risk is acceptable (Otto and Bonow, 2008). Three operative approaches are available for treatment of rheumatic MS: (1) close valvotomy using transatrial or transventricular approach; (2) open valvotomy, i.e., valvotomy carried out under direct vision with the aid of cardio pulmonary bypass (CPB), which may be combined with other repair techniques, such as leaflet resection and (3) MV replacement (Otto and Bonow, 2008). Mitral valve replacement is required for symptomatic patients with combined MS and moderate or sever MR, in those with extensive commissural calcification, sever fibrosis and subvalvular fusion and in those who have undergone previous valvotomy (Otto and Bonow, 2008).

Two-dimensional (2-D) transthoracic echocardiography has been shown to be a reliable, reproducible and accurate method for measuring mitral valve area (MVA) in patients with rheumatic mitral stenosis (MS) without prior surgical commissurotomy (Henry *et al.*, 1975; Nichol *et al.*, 1977; Martin *et al.*, 1979; Egelblad *et al.*, 1983). The planimetric determination of MVA from the parasternal short axis echo view has found to be reliable and accurate when compared to the MVA determined by intraoperative and by Gorlin method (Henry *et al.*, 1975; Wann *et al.*, 1978; Glover *et al.*, 1983). Doppler echocardiography, using the pressure halftime or the continuity equation is an alternative method of estimating MS severity (Hatle *et al.*, 1976; Smith *et al.*, 1986; Kap *et al.*, 1988; Nakatani *et al.*, 1988).

Transesophageal echocardiography was found to be an accurate method of determining the mitral valve orifice area in patients with mitral stenosis (Stoddard *et al.*, 1994; Abdel-hady *et al.*, 1999). However, transeosophageal echocardiography is technically demanding, requires expertise and experience and may not be feasible in measurement of MVA in all patients with MS (Stoddard *et al.*, 1994).

Although, the parasternal short axis echocardiographic view is the most widely employed non-invasive method of evaluating the severity of MS, poor acoustic window may hinder its use in selected cases. Also, it is technically demanding that requires experience and expertise and may not be feasible in some patients (Stoddard *et al.*, 1994).

Measurements of the 2-D maximum diastolic separation between anterior and posterior mitral leaflet tips, the Mitral Tip Separation (MTS), has been reported to be correlated with planimetric MVA, Doppler estimated MVA as well as indirect assessment of MVA by surgeons finger during closed mitral commissurotomy operation (El-Safty *et al.*, 1997, 2000). Early work showed that the addition of numerical value of 0.22 to the measured MTS bring the MVA in cm^2 as that measured from the short axis view (El-Safty *et al.*, 1997). However, subsequent work on a large number of patients (684 patients) showed that the addition of numerical value of 0.24 to the measured MTS bring the MVA in cm^2 (El-Safty *et al.*, 2000).

The aim of this study is to evaluate the accuracy of the simple 2-D measurements of maximal diastolic MTS from the Long Axis and/or Apical 4-chamber views in determination of MVA via its correlation with the directly measured MVA during open mitral valve surgery in patients with rheumatic MS; as well as to evaluate the reproducibility and sensitivity of the technique.

MATERIALS AND METHODS

This is a prospective study conducted at Cardiology unit, Internal Medicine and Cardiothoracic Surgery Departments, Mansoura University Hospital in the period from January 1996 to December 2002.

This study comprised 184 patients with rheumatic Mitral Stenosis (MS) who were prepared and subjected to open mitral valve surgery.

They were 52 males and 132 females, with their ages ranged from 28 to 50 years (33.95±11.64). Among the evaluated patients; 64 were in sinus rhythm; 120 had atrial fibrillation; 38 had pure MS; 92 had MS and associated mild Mitral Regurgitation (MR); 26 had MS and associated mild Aortic Regurge (AR) and 28 had MS and associated both MR and mild AR.

The decisions for open mitral valve surgery among the studied patients were related to the presence of left atrial thrombus (36 patients), presence of mitral valve calcification (50 patients) or extensive leaflets, subvalvular fibrosis (44 patients) or associated MR (54 patients). The type of surgery was related to intra-operative finding, either mitral valve repair (12 patients) or mitral valve replacement (172 patients).

All patients were subjected to the standard full pre-operative clinical; laboratory as well as echocardiographic evaluations.

Exclusion criteria: Based on clinical, Doppler echocardiographic examination and operative situation, we exclude from the study:

- Patients with planimetric MVA >2.0 cm^2
- Patients with MS and associated severe MR
- Patients with MS and associated AR and/r aortic stenosis requiring aortic valve replacement
- Patients with associated systemic hypertension
- Patients in whom MVA measurements during operation were not recorded

Echocardiographic examination: Echocardiographic evaluation were performed for every patient at 2 different setting, 3-5 days apart before operation by 2 different experienced echocardiographers; using the same machine either the Acquason XP5 machine with 3.5 and 2.5 MHz transducer or challenge 7000 with 2.5 and 3.5 MHz transducer. Echocardiographic study was performed following the standard technique with patient in the left lateral decubitus position according to the Recommendation of American Echocardiographic Association (Henery *et al*., 1980).

2-D planimetric MVA: The smallest orifice of the mitral valve was located in the parasternal short axis view by scanning from the left atrium to the left ventricle, taking care to image the mitral orifice when (from) the transducer location that was being perpendicular to the valve at the level of its maximum narrowing and with (at) its optimal gain setting (Weyman, 1982). With aid of playback system of freezed view, the optimal mitral orifice was selected and planimetry of the innermost border of the orifice (Wann *et al*., 1978), bring the value of MVA by aid of the inbuilt computer system in the echo machine.

Doppler-halftime estimated MVA: Continues wave Doppler ultrasound recording of mitral valve flow was made from the Apical 4-chamber views. With the use of auditory and visual monitoring

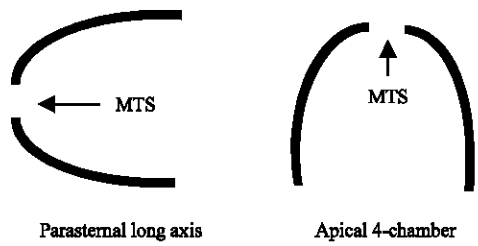


Fig. 1: Measurements of Mitral Tip Separation (MTS) (El-Safty *et al*., 1997, 2000)

to locate the maximum velocity across the mitral valve and with aid of available inbuilt analyzing system in the used machine, tracing the diastolic sloping of the resulted Doppler signal, yield the MVA value (Hatle *et al*., 1976).

A minimum of five optimal quality displayed signals beats were analyzed in patients with atrial fibrillation, while 3 beats were used in patients with sinus rhythm and results were averaged to obtain the MVA in cm^2 (Hatle *et al*., 1976).

The Mitral Tip Separation (MTS): The long axis view was obtained with minimal (simple) transducer adjustment and optimal gain setting, the mitral opening appeared clearly between the anterior and posterior mitral leaflet tips. With the aid of the play-back system in the echo-machine, the maximum separation between the inner margin of Anterior Mitral Leaflet (AML) and Posterior Mitral Leaflet (PML) tips during ventricular diastole was selected and measured from the freezed image. At least 3 Long Axis views were obtained and analyzed in patients with sinus rhythm and 5 views in patients with atrial fibrillation (El-Safty *et al*., 1997, 2000) (Fig. 1).

The Apical 4-chamber view was obtained and with minimal (simple) transducer adjustment and optimal gain setting, the mitral opening appeared between the doomed anterior and posterior mitral leaflet tips. Taking care of the drop out echoes that frequently occurred, (ultrasound beam parallel to leaflet plane) and the continuity of leaflet margin (edge) with fibrotic subvalvular structure; the inner boundary of edge (margin) of both leaflets were localized and the distance between them was calibrated (measured) as done in Long Axis view (Fig. 1) (El-Safty *et al*., 1997, 2000).

When it was available to obtain both Long Axis and Apical 4-chamber views classic for measuring the MTS, the maximal numerical value from either views was considered as the MTS value for that patient. When it was available to obtain only one clear view, classic for MTS measurement, (either Long Axis or Apical 4-chamber), the MTS obtained from that view, was considered the MTS value for that patient (El-Safty *et al*., 1997, 2000).

The first initial MTS (at first examination setting) was taken as a standard MTS value for that patient and used for statistical correlation with other obtainable planimetric MVA and Doppler estimated MVA as well as the intraoperative measurement of MVA by the aids of Hegar dilator during open MV surgery.

The subsequent measured MTS during the 2nd echocardiographic examination setting by another echocardiographer (3-5 days from initial examination) were used to evaluate the reproducibility and sensitivity of the technique. The difference between the initial standard and the second MTS values (either decrease or increase) was calculated in mm for every patient and the percent change from initial value was also calculated and considered as inter-observer variation.

Table 1: Values of MTS; planimetric MVA; Doppler assessed MVA and direct intra operative measurements of MVA of the first consecutive 30 studied patients

Planimetric	Doppler	MTS measurements (cm)			Intraoperative measurement of MVA	
(cm^2)	MVA (cm^2)	Initial exam.	2nd exam.	Inter observer changes	Hegar No.	Area
1.49	1.65	1.28	1.32	±3.17%	16	2.010
0.90	1.00	0.63	0.64	±1.58%	10	0.786
1.51	1.60	1.20	1.24	±3.33%	14	1.540
0.72	0.90	0.62	0.64	±3.22%	10	0.786
0.90	0.80	0.76	0.74	±2.63%	11	0.951
1.65	1.80	1.40	1.48	±5.71%	16	2.010
1.22	1.48	1.30	1.26	±3.07%	15	1.767
2.00	2.10	1.46	1.54	±5.47%	18	2.500
0.70	0.80	0.62	0.064	±3.22%	10	0.786
1.45	1.60	1.22	1.26	±3.27%	15	1.767
1.70	1.80	1.41	1.49	±5.67%	17	2.200
1.60	1.54	1.22	1.24	±3.27%	16	2.010
1.10	1.20	0.90	0.86	±4.44%	12	1.131
1.00	1.05	0.76	0.78	±2.63%	11	0.951
1.20	1.16	0.89	0.86	±3.37%	12	1.131
1.38	1.40	1.07	1.06	±0.93%	13	1.327
1.20	1.14	0.90	0.92	±2.22%	12	1.131
1.46	1.44	1.29	1.34	±3.87%	15	1.767
1.76	1.90	1.38	1.44	±2.90%	18	2.500
1.60	1.54	1.28	1.24	±4.34%	16	2.010
1.18	1.24	0.89	0.86	±3.37%	12	1.131
1.50	1.52	1.26	1.22	±3.77%	15	1.767
1.98	2.00	1.54	1.70	±7.59%	18	2.500
1.48	1.46	1.22	1.24	±1.63%	14	1.540
1.68	1.90	1.42	1.50	±5.63%	17	2.200
1.29	1.30	1.08	1.06	±1.85%	13	1.327
0.92	1.00	0.76	0.74	±2.63%	11	0.951
1.62	1.52	1.23	1.26	±2.4%	15	17067
1.36	1.48	1.06	1.08	±1.88%	13	1.327
1.42	1.54	1.08	1.11	±2.77%	13	1.327

MTS: Mitral tip separation, MVA: Mitral orifice area

Intraoperative measurement of MVA: Mitral valve surgery is carried in these patients using standard cardiopulmonary bypass after ascending aorta and bicaval cannulation. Heart is arrested using cold blood cardioplegia delivered through the aortic root and myocardial preservation is enhanced via systemic cooling (30-32°C) and topical cooling (Duran, 1998). Mitral valve is exposed through standard left atriotomy. After the mitral valve is visualized, the mitral valve orifice is sized by passing Hegar dilators in increasing sizes. The mitral valve area is considered the largest Hegar dilator that fits easily through the mitral valve orifice. The cross sectional area of the Hegar dilator used was considered as the anatomical measurement of MVA for that patient (Table 1).

For statistical analysis the studied patients were classified into different subgroups according to:

Sex:

- Female group (132 patients)
- Male group (52 patients)

Cardiac rhythm:

- Group with sinus rhythm (64 patients)
- Group with atrial fibrillation (120 patients)

Presence of associated other valvular lesions:

- Group with only pure MS (38 patients)
- Group with MS and associated MR (92 patients)
- Group with MS and associated AR (26 patients)
- Group with MS and associated MR and AR (28 patients)

The planimetric MVA:

- Group with MVA of < 1.0 cm^2 (70 patients)
- Group with MVA of 1.0-1.5 cm^2 (62 patients)
- Group with MVA of > 1.5-2.0 cm^2 (52 patients)

The maximum initial diastolic MTS values:

- Group with initial MTS < 1.0 cm (56 patients)
- Group with initial MTS range 1.0-1.2 cm (66 patients)
- Group with initial MTS > 1.2-1.5 cm (48 patients)
- Group with initial MTS > 1.5 cm (14 patients)

RESULTS

Two-D measurements of MTS: The MTS could be obtained and measured for all studied 184 patients from either Long Axis and/or Apical 4-chamber views (Table 2).

MTS measurements from long axis view: From the Long Axis view, The MTS could be obtained and measured in only 178 of our studied 184 patient (96.74%) (Table 2, Fig. 3).

However the frequency of measurement of MTS from Long Axis is more than that measured from Apical 4-chamber (96.74% versus 77.17%, $p<0.05$) (Table 2).

The unavailable measurements of MTS from Long Axis view among 6 patients were related to (1) presence of bad acoustic window (3 patients), (2) dropout echoes from uneven rheumatic fibrotic process (one patient) and (3) uneven margin from fibrotic and calcification projection at site of measurements (2 patients) (Table 3). During conduction of present study when the Long Axis was probably obtained; no difficulties for identifying the MV-opening between the leaflet margins. There were no problems of dropout echoes (as ultrasound beam lies perpendicular to the examining plain) or extension of fibrotic process to subvalvular structure (as the topography of the mitral

Table 2: Frequency of Measurement of 2D- mitral tip separation (MTS) From Long Axis and Apical 4-chambers views among the studied patients with rheumatic mitral stenosis

Groups	Measured MTS (from either views) No.	%	Measured MTS from long axis No.	%	Measured MTS from apical 4-chamber No.	%	Significance between MTS from long axis and apical 4-chamber
Whole group	184	100	178	96.74	142	77.17	$p<0.05$
NSR group	64	100	63	98.93	51	79.67	$p<0.05$
AF group	120	100	115	95.83	91	75.83	$p<0.05$
Female group	132	100	128	96.96	102	77.27	$p<0.05$
Male group	52	100	50	96.51	40	76.92	$p<0.05$
pure MS group	38	100	37	97.37	30	78.95	$p<0.05$
MS and MR group	92	100	89	96.74	70	76.09	$p<0.05$
MR and AR group	26	100	25	96.15	20	76.92	$p<0.05$
MS and MR and AR	28	100	27	96.43	22	78.57	$p<0.05$
MVA<1.0cm^2 group	70	100	69	98.57	57	81.43	$p<0.05$
MVA 1.0-1.5 cm^2 group	62	100	60	96.77	47	75.81	$p<0.05$
MVA>1.5-2.0cm^2 group	52	100	49	94.23	38	73.08	$p<0.05$

MVA: Mitral valve orifice area. AR: Aortic regurgitation. SR: Sinus rhythm.MS: Mitral stenosis. MR: Mitral regurgitation, AF: Atrial fibrillation

Table 3: Limiting factors hindering measurement of mitral tip separation from the Apical 4-chamber and long axis views among the studied 184 patients with rheumatic mitral stenosis

Limiting factors	Long axis No.	%	Apical 4-chamber No.	%
1- Bad acoustic window, hindering obtaining proper echo signals (thoracic cage deformity; crowded ribs; emphysema)	3	1.63	0	0
2- Inadequate to judge the exact site of measurement due to:				
a- Continuation of orifice margin with subvalvular structure.	0	0.00	24	13.04
b- Uneven margin from fibrotic and calcium projection.	2	1.08	2	1.09
3- Drop out echoes at site of measurements (uneven or segmental fibrotic process)	1	0.54	16	8.96
Total	6	3.26	42	22.83

leaflet margin and the subvalvular structure were delineated clearly during examination). In Long Axis the mitral leaflet free margin (tip) appeared more or less as an echogenic line (resembling the T sign of VSD or ASD) (El-Safty *et al*., 2000; Henery *et al*., 1980).

MTS measurements from apical 4-chamber views: Although, the Apical 4-chamber view brought easily in all patients (no limitation of acoustic impedance); measurement of MTS was available in only 142 of the studied 184 patients (77.19%) (Table 2). The unavailable measurements of MTS among 42 patients were related mainly to inadequate judgment for the site of measurement due to (1) extension of fibrotic process to subvalvular structure in 24 patients, (2) dropout echoes at leaflet margin from segmental fibrotic affection in 16 patients and (3) uneven margin from fibrotic and calcium projection in 2 patients (Table 3).

Figure 5a-d show measurements of MTS and MVA of a patient with mitral stenosis.

Table 4: Incidence of percent changes of the Mitral Tip Separation (MTS) values measured during second examination setting in relation to the initial measured values*

Initial MTS values Studied groups	Number	Incidence of percent changes of the second measured MTS** Changes of <5% n	%	Changes of 5-10% n	%	Changes of >10-20% n	%	Significance of changes in the same group
Whole group with MTS of < 1.0 to>1.5 cm	184	106	57.61	70	38.04	8	4.34	p<0.05
Group with MTS of<1.0 cm	56	40	70.14	16	28.17	0	0.00	p<0.05
Group with MTS of 1.0 to 1.2 cm	66	42	63.63	24	36.36	0	0.00	p<0.05
Group with MTS of>1.2 to 1.5 cm	48	22	45.83	26	54.17	0	0.00	p<0.05
Group with MTS of 1>1.5 cm	14	2	4.28	4	28.57	8	57.14	p<0.05
Group with MTS of<1.0 cm	122	82	67.21	40	32.79	0	0.00	p<0.05
Group with MTS of>1.2 cm	62	24	38.71	30	48.39	8	12.90	p<0.05
Significance								
Between sub-groups with MTS of <1.0, MTS of 1.0 to 1.2 0, MTS of >1.2 to 1.5 and MTS of 1>1.5		p<0.05		p<0.05		p<0.05		
Between sub-groups with MTS of < 1.2 0 and MTS of >1.2		p<0.05		p<0.05		p<0.05		

*All 2-D MTS were obtained clearly in all patients during the second examination setting (100% reproducible). **No Changes of > 20% from initial measurements were observed

Reproducibility, validity and reliability of the technique of MTS: When clearly obtained and measured MTS during the first initial examination for any evaluated patient; it was also clearly obtained and measured during subsequent examination by another echocardiographer (3-5 days apart) in all patients (100% reproducible) with minor or no difference in its value (Table 4). Changes up to 5% from initial MTS value was found among 106 patients (57.61%), changes from 5 to 10% was found among 72 patients (39.13%), changes of >10 to was found only among 8 patients (4.34%) (p<0.05) (Table 4).

The changes in subsequent MTS values were related to the initially measured MTS. Patients with their initial MTS of ≤1.5 cm showed changes only up to 10% during subsequent examination. Patients with their initial MTS of >1.5 cm showed changes of up to 10-20 % during subsequent examination (p<0.05) (Table 4).

Correlations between MTS and various method of estimating MVA among the whole studied group: A good positive correlations were present between MTS and direct intra-operative measurements MVA during open MV surgery (r = +0.9408, p<0.001) (Fig. 2), between MTS and the Short Axis estimated MVA (r = +0.9535 p<0.001) (Fig. 3) and between MTS and Doppler estimated MVA (r = +0.854, p<0.001) (Fig. 4).

Correlations between MTS and direct intraoperative measured MVA: A good positive correlations were present between MTS and direct intraoperative measurements MVA during open MV operation among all the studied subgroups: Male Group (r = +0.928, p<0.001); Female Group (r = +0.932, p<0.001); Group with Sinus rhythm (r = +0.9412, p<0.05); Group with AF (r = +0.9714,

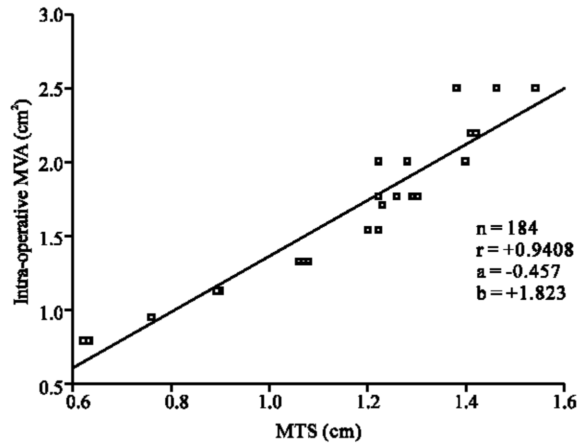


Fig. 2: Correlation between 2-D measured MTS and direct measurements of MVA during open MV-Surgery

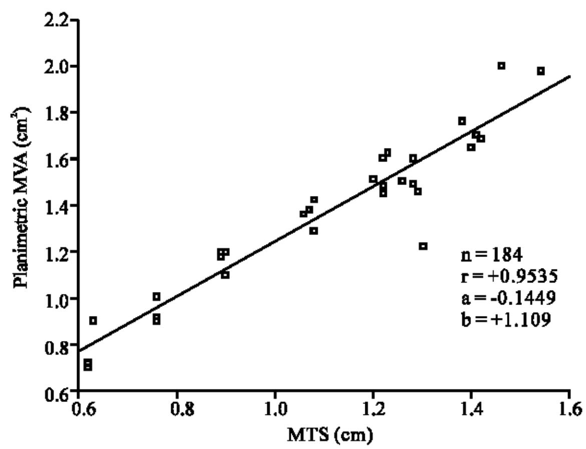


Fig. 3: Correlation between MTS and 2-D planimetric MVA

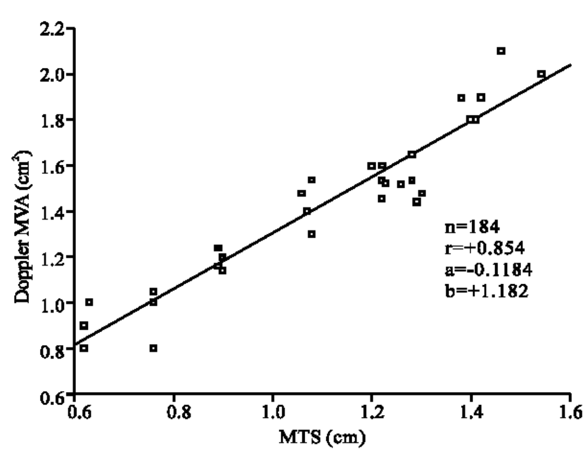
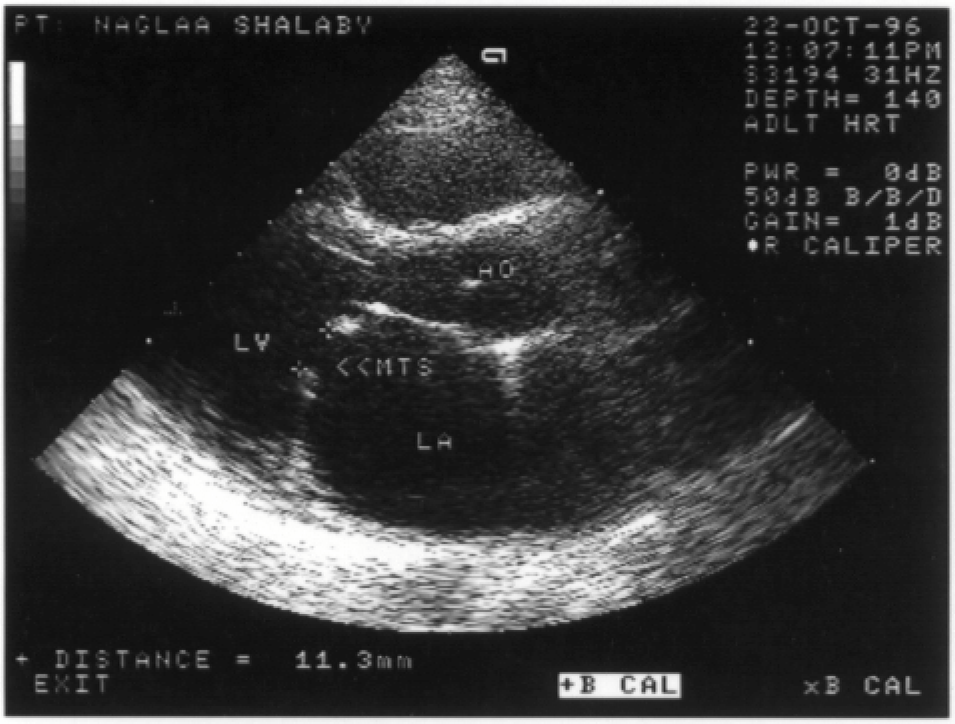


Fig. 4: Correlation between MTS and Doppler estimated MVA

(a)



(b)

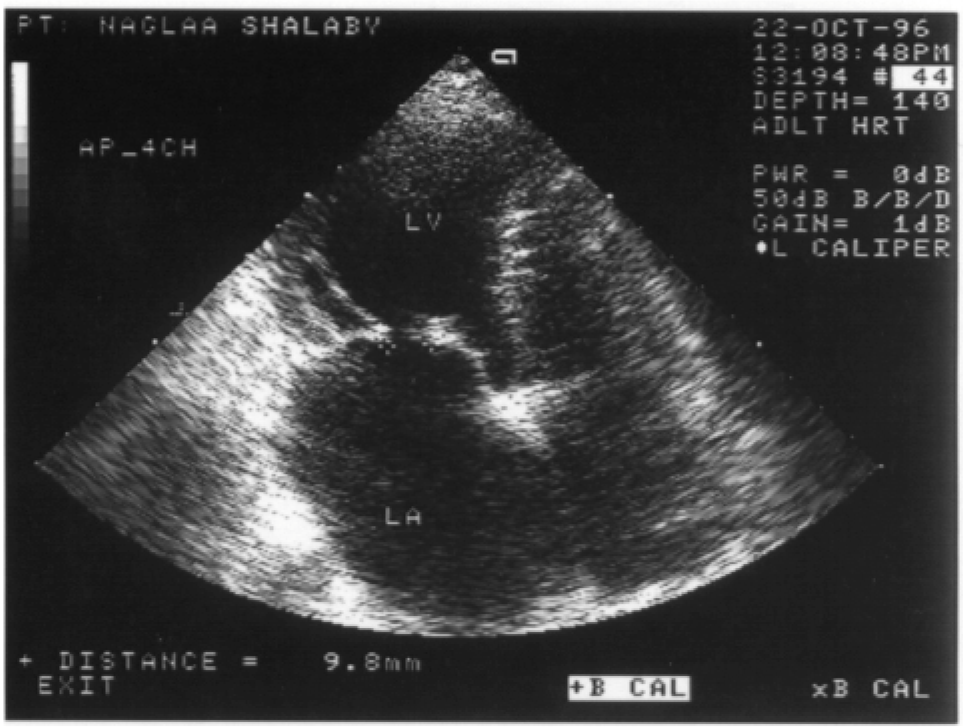


Fig. 5: Continued

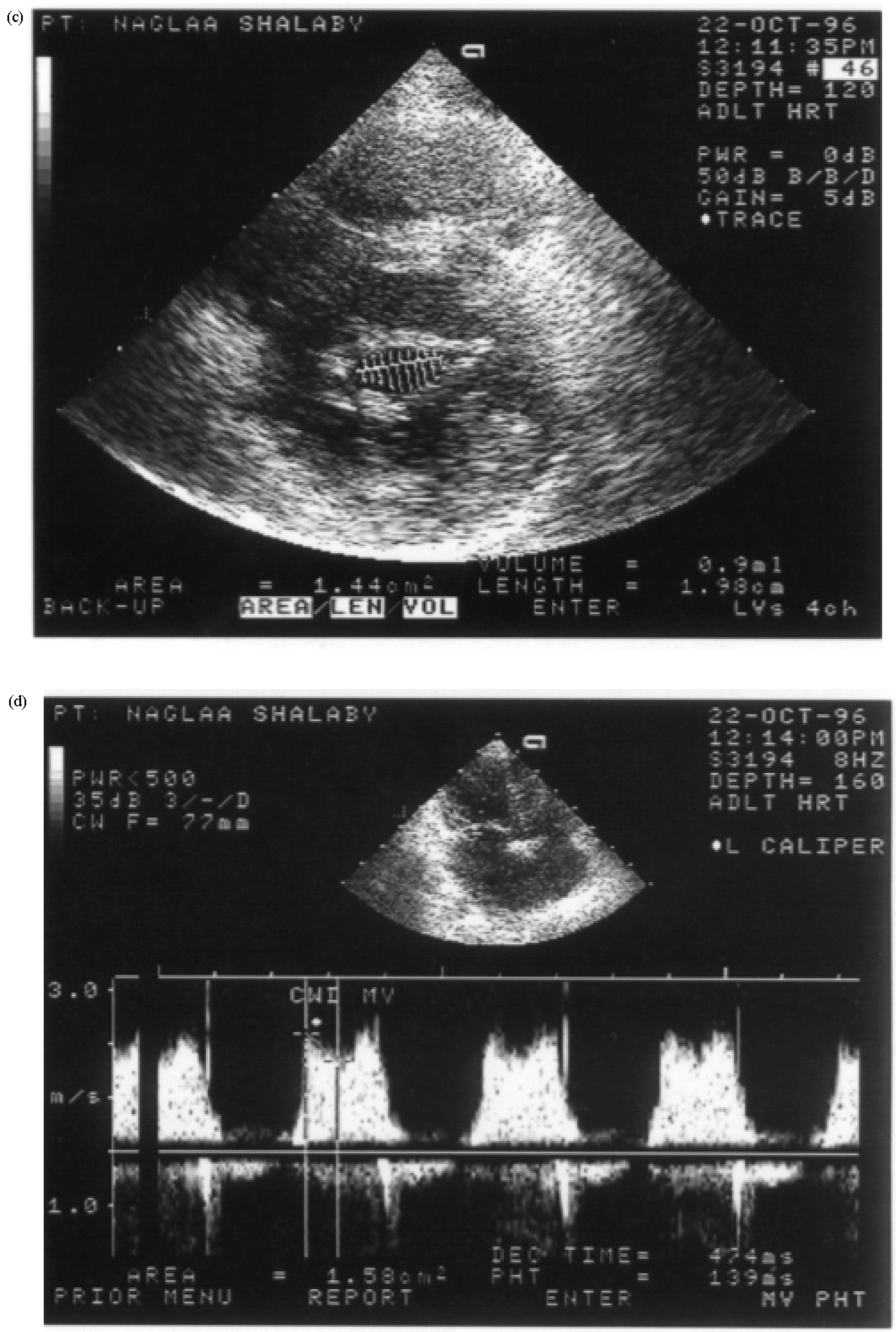


Fig. 5: Measurement of MTS and MVA of a patient with mitral stenosis: (a) Long Axis view, (b) Apical 4-chamber view, (c) short axis-MV level and (d) mitral valve CW Doppler

Table 5: Correlation between Mitral Tip Separation (MTS) and direct intra operative measurements of mitral valve orifice (MVA) area among different subgroup

Studied group	Correlation between mitral tip separation and direct intra operative measurements MVA			
Total group (n = 184)	r = +0.9408	a = -0.457	b = +1.823	p<0.001
Male group (n = 52)	r = +0.928	a = +0.594	b = +2.02	p<0.001
Female group (n = 132)	r = +0.932	a = -0.389	b = +1.962	p<0.001
Group with Sinus rhythm (n = 64)	r = +0.9412	a = -0.406	b = +1.982	p<0.05
Group with Atrial fibrillation (n = 120)	r = +0.9714	a = -0.376	b = +1.74	p<0.001
Group with MVA of <1.0 cm^2 (n = 70)	r = +0.999	a = +0.305	b = +1.204	p<0.001
Group with MVA of 1.0-1.5 cm^2 (n = 70)	r = +0.9453	a = -0.565	b = +1.832	p<0.001
Group with MVA of >1.5-2.0 cm^2 (n = 52)	r = +0.7402	a = +0.3359	b = +1.264	p<0.001
Group with MTS up to 1.2 cm (n = 122)	r = 0.9977	a = +0.003	b = +1.2500	p<0.001
Group with MTS >1.2-1.5 cm (n = 48)	r = 0.7002	a = -0.1500	b = +2.61	p<0.001
Group with MTS >1.5 cm (n = 14)	r = 0.565	a = -0.497	b = +1.58	p<0.001

p<0.001); Group with MVA of <1.0 cm^2 (r = +0.999, p<0.001); Group with MVA of 1.0-1.5 cm^2 (r = +0.9453, p<0.001); Group with MVA of >1.5-2.0 cm^2 (r = +0.7402, p< .00); Group with MTS up to 1.2 cm (r = 0.9977, p<0.001); Group with MTS >1.2-1.5 cm (r = 0.7002, p<0.001 and Group with MTS >1.5 cm (r = 0.565, p<0.001) (Table 5).

The most reliable and perfect correlation between the MTS and the directly measured MVA was present among subgroup with their MTS being up to 1.2 (less or equal 1.2 cm) (r = +0.9977; a = +0.0003 and b = +1.2500, p<0.001) (Table 5).

When the Value of MTS is up to 1.2 cm, A simple equation can be applied for measurement of MVA from knowing only the MTS value as follow:

$$\text{MVA } (cm^2) = 0.0\,003 + 1.2500 \text{ MTS (cm)} \quad \text{(Table 5)}$$

If we ignore the value a from the equation (0.0003), the equation will be simply as follow:

$$\text{MVA } (cm^2) = 1.25 \text{ MTS (cm)}$$

DISCUSSION

Two-dimensional echo is an important noninvasive method of determination of mitral valve orifice area (MVA) in subjects with mitral stenosis (MS). The planimetric determination of MVA from the parasternal short axis echo view has found to be reliable and accurate when compared to the MVA determined by intraoperative and by Gorlin method (Henry *et al.*, 1975; Wann *et al.*, 1978; Glover *et al.*, 1983). However, poor acoustic window may hinder its use in selected patients (Wann *et al.*, 1978). Also, it is technically demanding; required expertise and experience and may not be feasible in some cases (Hatle *et al.,* 1976). Doppler echocardiography; using the pressures halftime or the continuity equation is an alternative method of estimating MS severity (Hatle *et al.*, 1976; Smith *et al.*, 1986; Kap *et al.*, 1988; Nakatani *et al.*, 1988).

From our echocardiographic practice, it was observed that the separation between mitral leaflet tips appeared to be more or less related to the severity of MS. Present study aimed to assess the feasibility, reproducibility and sensitivity of measuring the MVA just from the simple easily obtained Long Axis and Apical 4-chamber echo views.

Our preliminary earlier study (El-Safty *et al.*, 1997, 2000) showed the validity, sensitivity and reproducibility of maximum MTS in calculating MVA in patients with MS. However previous work relate the MTS to either the planimetric MVA, Doppler estimated MVA and the indirect assessment of MVA by surgeon's finger during closed mitral commissurotomy. Our present study correlate MTS values with the directly measured MVA during open MV surgery with aids of Hegar dilator. The study also extended to evaluate the reproducibility of the technique with examination by different echocadiographers.

The technique is completely reproducible and the MTS can be obtained easily during the second evaluation setting by different echocardiographer (100% reproducible) (Table 4).

Also, little variation was observed between the MTS values from both different examination setting that could not affect greatly its value. The variation in MTS values was related to the initial measured value. Small variation up to 10% change was observed among patient with their MTS of up to 1.5 cm. Variation of >20% was observed only among patients with their initial MTS of >1.5 cm ($p<0.05$) (Table 4).

This data denotes that the single measurement of MTS of less than 1.5 cm can be used for estimation of mitral stenosis severity without need for further re-measurements.

Measurement of MTS was obtained easily from the Long Axis view than the Apical 4-chamber view among the whole group (96.74 vs. 77.17%) and all studied subgroups (Table 2). In the Long Axis view, the inner edge of mitral leaflets were clearly defined more or less appeared as the T-sign of VSD and this clear delineation is related to the fact that orientation of the mitral leaflets in Long Axis is perpendicular to the ultrasonic beam and the image is clearly displayed and the mitral leaflet topography can be delineated clearly from the subvalvular structure.

Factors which could limit measurement of MTS from Long Axis view are the (1) bad acoustic window which hinder bringing the classic Long Axis view (1.63%), (2) the segmental fibrotic or sclerotic rheumatic process close to tip margin, where the increased echogenicatory of leaflet distal to the less affected margin could enlarge the measurement (0.54%) and (3) the presence of calcified projection at tip margin (1.08%) (Table 4).

In Apical 4-chamber view the limiting factors for measurement of MTS is inability to judge the exact site for measurement because of (1) drop out echoes at leaflet tip frequently observed (ultrasonic beam parallel to leaflet) (8.96%) and (2) the continuation of fibrotic process of leaflets margin with subvalvular structure (13.04%) and (3) uneven margin from fibrotic and calcium projection (1.09%) (Table 4). However, the Apical 4-chamber view remain the only approach for measurement of MTS among patients with bad acoustic parasternal window, hindering obtaining good Long Axis and short axis view.

The orientation of mitral valve leaflets to ultrasound beam appeared more or less perpendicular to beam in Long Axis view as that in the short axis view, but in Apical 4-chamber view, the orientation of mitral leaflets are distinctly different (parallel to the beam). The axial resolution would be critical in the proper measurement of MVA from short axis and the MTS from Long Axis. Lateral resolution would appear to be a more critical determinant accuracy of measurement of MTS from the Apical 4-chamber view. Lateral resolution is intrinsically inferior to axial resolution and so the frequency of drop out echoes of mitral leaflets edge is more when imaged from Apical 4-chamber view than Long Axis view (El-Safty *et al.*, 1997, 2000).

The technique of measurement of MTS appeared to be sensitive for assessing (and reflecting) severity of mitral stenosis. The MTS showed unexpectedly high (good) positive correlation with (1) direct intraoperative measurements of MV orifice areas during open MV surgery ($r = +0.9408$

$p<0.001$) (Fig. 2) and (2) the other two standard non invasive methods for estimating MVA: the planimetric MVA ($r = +0.9535$, $p<0.001$) (Fig. 3) and the Doppler estimated MVA ($r = +0.856$, $p<0.001$) (Fig. 4).

Good positive correlations were present between the MTS and directly intra-operatively measured MVA among all studied subgroups (Table 5). The most simple and perfect correlation was found among subgroup of patients with their MTS ≤ 1.2 cm ($r = 0.9977$, $a = +00003$; $b = +1.2500$, $p<0.00$). The derived simple and perfect equation: MVA (cm^2) = 1.25 MTS (cm) can be applied satisfactory for calculating the MVA in cm^2 by multiplying numerical value of MTS by 1.25 provided that MTS value is ≤ 1.2 cm.

This equation could be of utmost help during echocardiographic estimation of MVA in patient with bad parasternal acoustic window for obtaining short axis view as well as inability to bring a good clear short axis view by a less experienced and unexpertised echocardiographic operators.

In conclusion MTS is a simple easily obtainable and highly reproducible technique and appeared sensitive for assessing severity of MS regardless patient age, sex; presence of atrial fibrillation. MTS is obtained more easily from the parasternal Long Axis view than the Apical 4-chamber view. It correlated well with direct measurement of MVA during open mitral valve surgery. A simple perfect equation can be applied to calculate the MVA when the measured MTS value is up 1.2 cm as follow: MVA (cm^2) = 1.25 MTS (cm).

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