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ORIGINAL ARTICLE

Can three-dimensional echocardiography accurately predict complexity of mitral valve repair?

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Abstract

OBJECTIVE: Feasibility of mitral repair is a key factor in the decision to operate for mitral regurgitation. Repair feasibility is highly dependent on surgical experience and repair complexity. We sought an objective means of predicting complexity of repair using three-dimensional (3D) transoesophageal echocardiography.

METHODS: In a cohort of 786 patients who underwent mitral valve surgery between 2007 and 2010, 3D transoesophageal echocardiography was performed in 66 patients with mitral regurgitation prior to the institution of cardiopulmonary bypass. The surgeon reviewed the 2D echocardiographic images for all patients pre-operatively, but did not view the 3D echocardiographic quantitative data or volumetric analysis until after surgery. Repairs involving no or a single-segment leaflet resection, sliding-plasty, cleft closure, chordal or commissural repair techniques were classed as standard repairs. Complex repairs were defined as those involving bileaflet repair techniques, requiring multiple resections or patch augmentation. Disease aetiology included Barlow's disease ($n = 18$), fibroelastic deficiency ($n = 22$), ischaemic ($n = 5$), endocarditis ($n = 5$), rheumatic ($n = 2$) and dilated cardiomyopathy ($n = 2$).

RESULTS: No patient required mitral replacement or had more than mild mitral regurgitation on pre-discharge echocardiography. Anterior and posterior leaflet areas, annular circumference, anterior and posterior leaflet angles, prolapse and tenting heights and volumes were most strongly predictive of repair complexity. As 21 of the 22 patients with bileaflet pathology and multisegment prolapse were complex repairs, we sought to develop a model predicting repair complexity in the remaining patients. The most predictive model with a *c*-statistic of 0.91 included three predictors: multisegment pathology, prolapsing height and posterior leaflet angle. After bootstrap validation, the revised *c*-statistic was 0.88.

CONCLUSIONS: 3D transoesophageal echocardiography provides an objective means of predicting mitral repair complexity in mitral regurgitation due to a range of aetiology.

Keywords: Three-dimensional echocardiography • Mitral valve repair

INTRODUCTION

Repair feasibility is a key factor in the decision to operate for mitral regurgitation: current consensus guidelines recommend repair over replacement wherever possible and earlier surgical intervention if there is a high likelihood of repair [1, 2]. Repair feasibility is highly dependent on lesion complexity and surgeon experience [3]. Accurate preoperative assessment of the mitral valve could potentially improve the likelihood of a successful repair by allowing clinicians to better match surgeon expertise with repair complexity [4]. Although two-dimensional (2D) transesophageal echocardiography provides detailed information about mitral morphology, predicting repair complexity is very subjective. Real-time 3D transesophageal echocardiography provides unique anatomic views, high image quality and in addition offers the ability to perform a detailed volumetric assessment of the mitral valve from which multiple quantitatitve descriptors can be obtained [5]. Previous studies have suggested that 3D echocardiography is better correlated with intra-operative findings during mitral repair than 2D echocardiography [6–8]. In this study, we sought additionally to establish whether quantitative 3D echocardiographic parameters could reliably predict the complexity of mitral repair.

METHODS

Patients

From our prospective database of 786 patients who underwent mitral valve surgery between 2007 and 2010, we identified

66 patients who also had a complete intra-operative 3D transoesophageal echocardiographic assessment prior to cardiopulmonary bypass as well as volumetric valve analysis. Patients with more than moderate mitral valve stenosis (defined as a mitral valve area <1.5 cm^2) were excluded. Patient characteristics are summarized in Table 1. Institutional Review Board approval with a waiver of individual consent was obtained for this study.

Table 1: Patient characteristics according to repair complexity

	Standard repair (*n* = 26, 39%)		Complex repair (*n* = 40, 61%)		*P*-value
Age	56.96	±11.36	53.30	±13.58	0.259
Female	8	31%	16	40%	0.446
Ejection fraction	53.90	±12.83	56.80	±7.23	0.245
Body mass index	27.83	±4.68	26.07	±3.87	0.101
Body mass index < 25	8	44%	15	56%	0.575
Hypertension	20	77%	14	35%	0.001
Dyslipidaemia	11	42%	16	40%	0.852
Coronary artery disease	11	42%	8	20%	0.050
History of myocardial infarction	1	4%	1	3%	0.755
Congestive heart failure	5	19%	5	13%	0.456
Atrial fibrillation	6	23%	9	23%	0.956
Previous cerebrovascular accident	1	4%	1	3%	0.755
Peripheral vascular disease	1	4%	0	0%	0.211
Diabetes mellitus	3	12%	3	8%	0.577
Chronic obstructive pulmonary disease	2	8%	2	5%	0.654
Renal failure	0	0%	1	3%	0.417
Thyroid disease	1	4%	4	10%	0.356
Previous cardiac operation	2	8%	4	10%	0.750

N (standard), number of values available for standard repairs; *N* (complex), number of variables available for complex repairs.

Definitions

Valve aetiology and lesions were determined by the surgeon during intra-operative inspection of the valve. Barlow's disease was defined as a large valve with multisegment prolapse, leaflet and chordal thickening, excess leaflet tissue and chordal elongation or rupture (Fig. 1a) [3]. Fibroelastic deficiency was defined as a thin and deficient leaflet tissue in a relatively small valve with a single-segment prolapse resulting from chordal rupture (Fig. 1b). Ischaemic mitral regurgitation was defined as mitral regurgitation due to the restricted motion of morphologically normal leaflets due to papillary muscle displacement posteriorly as a result of left ventricular dilatation in the setting of coronary artery disease (Fig. 2). Rheumatic disease was defined as mitral regurgitation due to the restricted motion of thickened leaflets, associated with commissural fusion and thickening of the subvalvular apparatus. Endocarditis was defined by the presence of a history of endocarditis or evidence of valvular vegetations. A satisfactory repair was defined as minimal mitral regurgitation on saline testing with adequate depth and symmetry of coaptation [9], and none or minimal residual mitral regurgitation on post-bypass transaoesophagal echocardiography.

Surgical techniques

Mitral valve repairs were performed by a single surgeon (D.H.A.) via median sternotomy or small right thoracotomy. Operative techniques and repair strategies included a triangular resection and/or chordal reconstruction for a single-segment posterior or anterior leaflet prolapse and a quadrangular resection with or without sliding-plasty for a single-segment prolapse and with sliding-plasty for multisegment posterior leaflet prolapse. All repairs were supported by a remodelling annuloplasty ring selected according to the surface of the anterior leaflet and intercommisural distance: true-sized in the case of degenerative disease and down-sized in the case of ischaemic mitral regurgitation. Autologous pericardial patch augmentation was used in selected cases of rheumatic disease. Additional repair techniques

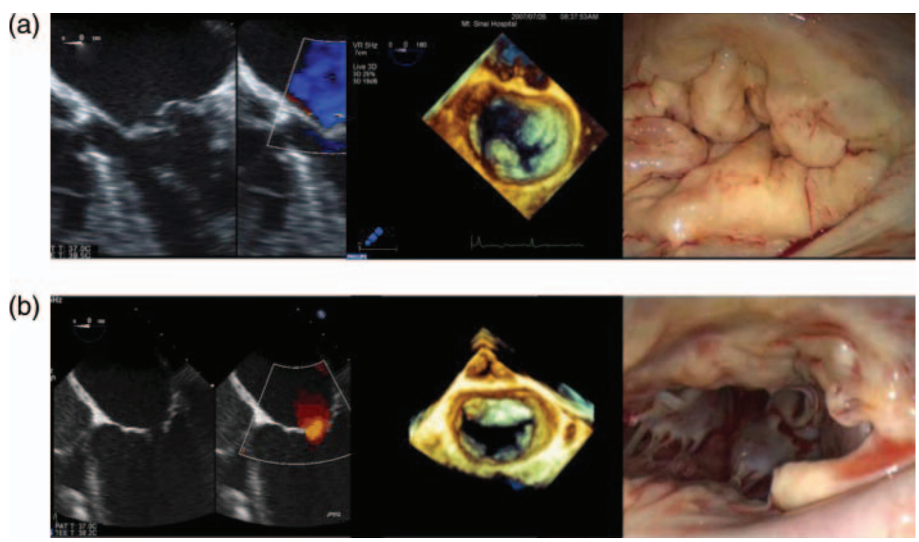

Figure 1: From left to right, 2D transaesophageal echocardiography, 3D echocardiographic reconstruction and intra-operative views of a mitral valve showing (a) Barlow's disease with multisegment bileaflet prolapse in a giant valve and (b) ischaemic mitral disease with posterior leaflet displacement of the posteromedial papillary muscle resulting in restricted motion particularly of the posterior leaflet.

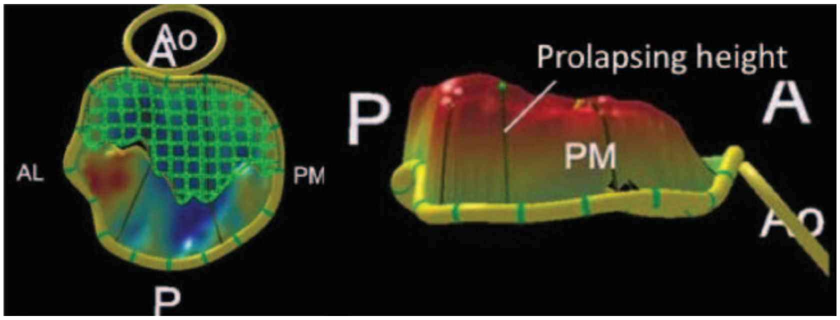

Figure 2: Volumetric quantification of a mitral valve using QLAB® mitral valve quantification software. The left-hand image shows an *en-face* view of a single-segment prolapse (P1) in a patient with fibroelastic deficiency with the anterior leaflet surface area mapped by the green gridlines the mapped surface area of the posterior and anterior leaflets, respectively. The right-hand image shows a transverse section across the mitral valve and the aortic annulus in a patient with a multisegment prolapse due to Barlow's disease. Ao, aortic valve; A, anterior; P, posterior; PM, posteromedial; AL, anterolateral.

included cleft closure, and commissural repair. Adjunctive procedures included tricuspid valve repair (*n* = 48; 73%) (performed for tricuspid regurgitation ≥2 or significant annular dilatation), coronary artery bypass grafting (*n* = 9; 14%), aortic valve replacement (*n* = 7; 11%), and modified maze procedures (*n* = 16; 24%). A maze procedure was performed in all patients with a pre-operative history of atrial fibrillation.

Real-time 3D transoesophageal echocardiography

Intra-operative transoesophageal echocardiography was performed in all patients by a single operator prior to the institution of and following weaning from cardiopulmonary bypass. Imaging was performed using an iE33 ultrasound system (Phillips Medical Systems, Andover, MA, USA), equipped with a fully sampled 3D MTEE transducer, which utilizes approximately 3000 elements, in contrast to the 64 elements currently used in the multiplane TEE probe (Omni III). Images were subsequently reviewed remotely on an Xcelera workstation. Quantification of the mitral valve apparatus was performed using QLAB® software (Phillips Medical Systems, MA, USA) which permits volumetric measurement and analysis of multiple parameters derived from a single *en-face* view of the mitral valve (Fig. 2). Imaging was performed using an iE33 ultrasound system (Phillips Medical Systems, Andover).

Volumetric analysis

Measurements included: (i) the major anatomically oriented 3D axes of the annulus, anteroposterior and anterolateral to posteromedial diameters as well as annular height, (ii) 3D curvilinear leaflet lengths of the anterior leaflet across its central portion from the aortic annulus to the central coaptation border and posterior leaflet length from the central portion of the posterior annulus to its juncture at the anterior leaflet, (iii) anterior and posterior leaflet surface areas, excluding the leaflet contact areas as well as the angle between the aortic annulus (assumed to be planar) and a least-squares fit plane of the mitral annulus. A list of the echocardiographic variables analysed together with the explanation of their abbreviations is presented in Table 3. Figure 2 shows selected parameters of the volumetric analysis.

Data acquisition

At the time of mitral valve repair surgery, all valves were inspected and aetiology, lesions and leaflet dysfunction documented by the surgeon. All repair techniques used were recorded and these data prospectively entered in a mitral valve surgery database which also included clinical outcome data.

Study design

The surgeon reviewed the 2D echocardiographic images for all patients pre-operatively, but did not view the 3D echocardiographic quantitative data or volumetric analysis until after surgery.

All patients were divided into two groups based on the complexity of the mitral repair. The level of complexity was determined by the number or type of repair techniques required to achieve a satisfactory repair as defined below, by two surgeons blinded to all echocardiographic data obtained prior to or during the procedure. Repairs involving no or a single-segment leaflet resection, sliding-plasty, cleft closure, chordal or commissural repair techniques were defined as standard repairs (Group 1). Complex repairs (Group 2) were defined as those involving bileaflet repair techniques, requiring multiple leaflet resections or patch augmentation. All parameters derived from the quantitative volumetric analysis of the mitral valve were then analysed to determine which would reliably predict the complexity of mitral valve repair. Table 3 summarizes the pre-operative patient characteristics according to repair complexity.

Statistical analysis

Normally distributed continuous variables are presented as mean ± standard deviation, and otherwise as median and interquartile range. Categorical variables are shown as percentages. $P < 0.05$ was considered statistically significant. Univariate logistic regression analysis was used, and the significance of the quadratic term was also tested if the predictor was of a continuous scale. None of the predictors required a quadratic term, and subsequently, the area under the receiver operating characterisitic (ROC) curve (also the *c*-statistic) was reported as an index for predictability. For multiple regression analysis, logistic regression with stepwise selection, was performed to select a subset of the quantitative variables for use in discriminating between standard and complex repairs. Canonical discriminant analysis (a form of multivariable analysis used when the dependent variable is categorical and the independent variables metric as in this case) was also employed to generate a predictive model of repair complexity. The analysis was performed by an independent observer who did not participate in either the acquisition of echocardiographic images or the surgical procedure.

RESULTS

Valve analysis

Intra-operative findings, including the number of lesions and segments involved in each case, are summarized in Table 2. The aetiology of mitral regurgitation, determined by surgical inspection, was Barlow's in 27% (n = 18), fibroelastic deficiency in 33% (n = 22), ischaemic in 8% (n = 5), endocarditis in 8% (n = 5), dilated cardiomyopathy in 3% (n = 2) and rheumatic in 3% (n = 2) of patients.

Surgical procedures

All patients underwent successful mitral valve repair documented by intra-operative transoesophageal echocardiography. Group 1 (standard repairs) comprised 39% (n = 26) and Group 2 (complex repairs) comprised 61% (n = 40) of patients. No patients had systolic anterior motion of the mitral valve documented on post-bypass echocardiography. The median cardiopulmonary bypass time was 144 min (±39 min) and cross-clamp time was 129 min (±32 min) in Group 1 patients, compared with 184 min (±47 min) and 155 min (±48 min), respectively, in Group 2 patients (P = 0.001 and 0.045, respectively). Patients in the complex repair group were more likely to undergo isolated mitral repair compared with patients in the standard repair group (P = 0.01). There was no 90-day mortality.

Echocardiographic results

Successful oesophageal intubation was achieved in all patients without procedural complications. The acquisition of real-time 3D echocardiographic data was completed in approximately 10 min.

Univariate analysis revealed that the anterior and posterior mitral valve leaflet surface areas, annular circumference, anterior and posterior leaflet angles, prolapse and tenting heights and volumes (all $P < 0.05$, area under the ROC curve >0.7) were strongly predictive of repair complexity (Table 3). Using logistic regression and stepwise selection, only the height of the prolapse was entered as an independent predictor of repair complexity. The correlation of prolapsing height with the remaining nine predictors was >0.6 or <−0.6. We therefore sought to develop a model that would improve the predictability of repair complexity while utilizing more than just the prolapsing height. Using canonical discriminant analysis, we used a composite score weighted between the height of the prolapse (H_prol) and the anterior leaflet surface area (A3D_ant): 0.159*H_prol + 0.001749*A3D_ant (mm^2). This, in turn, gave a c-statistic of 0.94 and the P-value for the goodness-of-fit test was 0.98. The anterior leaflet surface area was chosen because it was one of the first variables to be statistically significant ($P < 0.05$) and not so highly correlated with the prolapsing height.

As 21 of the 22 patients with bileaflet pathology and multisegment prolapse identified echocardiographically went on to have

Table 2: Valve findings, repair techniques and results according to repair complexity

	Standard repair (n = 26, 39%)		Complex repair (n = 40, 61%)		P-value
Operative procedures					
Isolated mitral repair (n = 13)	3	12%	10	25%	0.013
Mitral + tricuspid repair (n = 48)	19	73%	29	73%	0.959
Mitral repair + AVR (n = 7)	5	19%	2	5%	0.067
Mitral repair + CABG (n = 9)	5	19%	4	10%	0.286
Mitral repair + cryomaze (n = 16)	6	23%	10	25%	0.859
Mitral repair + closure of PFO (n = 4)	2	8%	2	5%	0.654
Operative variables					
Cardiopulmonary bypass time	144.04	±39.04	184.44	±46.91	0.001
Aortic cross-clamp time	128.82	±31.81	155.70	±47.13	0.045
Number of segments repaired					
0–1	22	85%	6	15%	0.000
2–3	4	15%	26	65%	0.000
4–5	0	0%	7	18%	0.024
6	0	0%	1	3%	0.417
Bileaflet repair	0	0%	21	53%	0.000
Ring size	29.00	±2.79	33.28	±4.79	0.000
Main aetiology					
Barlow's	0	0%	18	45%	0.000
Fibroelastic deficiency	13	50%	9	23%	0.021
Ischaemic cardiomyopathy	4	15%	1	3%	0.053
Dilated cardiomyopathy	2	8%	0	0%	0.075
Endocarditis	1	4%	4	10%	0.356
Rheumatic	0	0%	2	5%	0.247
Other	6	23%	6	15%	0.406
Lesion					
Chordal rupture	12	46%	14	35%	0.365
Chordal elongation	2	8%	12	30%	0.030
Chordal tethering	8	31%	8	20%	0.319
Other	4	23%	6	15%	0.406
Carpentier classification					
I	1	4%	1	3%	0.755
II	13	50%	31	78%	0.021
IIIa	2	8%	3	8%	0.977
IIIb	10	38%	5	13%	0.014
Post-operative variables					
Ejection fraction	53.69	±10.38	51.15	±11.15	0.356
Mitral regurgitant grade					
0	9	35%	15	38%	0.812
1	17	65%	23	58%	0.522
2	0	0%	2	5%	0.247

AVR, aortic valve replacement; CABG, coronary artery bypass grafting; PFO, patent foramen ovale.

ADULT CARDIAC

Table 3: List of echocardiographic variables analysed and the mean values in each group, ranked by the c-statistic according to univariate analysis

Variable		3D or 2D	Mean (standard deviation) complex repair	Mean (standard deviation) standard repair	P-value	Area under ROC (c-statistic)
H_prol	Prolapsing height (mm)	3D	9.4 (5.4)	3.4 (3.2)	0.002	0.841
A3D_ant	Surface area of the anterior leaflet (mm^2)	3D	1094 (242)	811 (199)	0.004	0.839
V_prol	Prolapsing volume (ml)	3D	4.6 (5.1)	0.9 (1.5)	0.01	0.824
A3D	Surface area of both leaflets (mm^2)	3D	2086 (744)	1406 (365)	0.009	0.820
V_tent	Tenting volume (ml)	3D	0.61 (0.77)	1.89 (1.81)	0.01	0.769
Theta_post	Angle of posterior leaflet (°)	3D	18.9 (18.6)	32.9 (15.0)	0.06	0.744
Theta_ant	Angle of anterior leaflet (°)	3D	10.1 (8.7)	16.7 (6.3)	0.02	0.735
A3D_post	Surface area of the posterior leaflet (mm^2)	3D	948 (545)	592 (281)	0.03	0.729
A3Dmin	Area of minimal surface spanning annulus (mm^2)	3D	1580 (470)	1242 (318)	0.02	0.724
H_tent	Tenting height (mm)	3D	3.33 (2.9)	5.6 (3.1)	0.03	0.721
theta_NPA	Non-planar angle of leaflets (°)	3D	153 (29.6)	130 (17.8)	0.01	0.718
C3D	Perimeter of annulus (mm)	3D	143 (20.6)	129 (16.4)	0.03	0.713
C2D	Circumference of annulus in projection plane (mm)	3D	138 (21.1)	124 (15.4)	0.03	0.712
A2D	Area of annulus in projection plane (mm^2)	3D	1488 (428)	1211 (306)	0.03	0.706
DAP	Anterior to posterior diameter of annulus (mm)	2D	39 (5.8)	36 (5.1)	0.06	0.687
L2D_post	Direct length of P2 (mm)	2D	15.8 (5.1)	12.9 (4.1)	0.08	0.673
L3D_post	Exposed length of P2 (mm)	2D	17.9 (6.8)	14.0 (5.6)	0.07	0.668
Daipm	Anterolateral to posteromedial diameter of annulus (mm)	2D	45.0 (7.5)	41.3 (5.7)	0.08	0.645
H	Annulus height (mm)	3D	7.71 (2.3)	6.82 (2.7)	0.23	0.628
L3D_ant	Exposed length of A2 (mm)	3D	27.9 (5.5)	26.1 (4.2)	0.29	0.611
L2D_ant	Direct length of A2 (mm)	2D	25.1 (3.9)	24.6 (3.7)	0.67	0.544
E2D	Ellipsicity of annulus (%)	3D	106 (34.1)	116 (11.9)	0.34	0.531
Theta_o	Aortic orifice to mitral plane angle (°)	3D	130 (11.1)	128 (13)	0.56	0.502

repairs classed as complex, we sought to refine the model to predict repair complexity in the remaining patients. In this case, the most predictive model with a c-statistic of 0.91 included three predictors: multisegment, prolaping height and posterior leaflet angle. After bootstrap validation, the revised c-statistic was 0.88.

Pre-discharge transthoracic mitral regurgitation grade is shown in Table 2. All patients in Group 1 and 95% ($n = 38$) in Group 2 had no or trace mitral regurgitation. This was not significantly different between groups. No patients had more than mild regurgitation. There was no evidence of systolic anterior motion in any patient. The mean post-operative ejection fraction was 54% in Group 1 patients and 52% in Group 2 patients, which was not significantly different between groups ($P = 0.4$).

DISCUSSION

This study was designed to determine whether volumetric quantitative analysis of the mitral valve could reliably predict repair complexity, across a spectrum of aetiologies, lesions and leaflet dysfunctions. Repair complexity, defined after surgery by the number and type of techniques required to complete a satisfactory repair, was correlated to quantitative 3D echocardiographic variables acquired prior to the institution of cardiopulmonary bypass. 3D echocardiographic parameters derived from zoomed acquisitions of the mitral valve, particularly prolapsing height and anterior leaflet surface area, were found to be strongly predictive of surgical repair complexity, irrespective of the aetiology of mitral regurgitation. This suggests that pre-operative 3D echocardiography could offer a useful platform for screening patients for repair complexity: patients with parameters strongly predictive of complex repairs could be directed to specialist surgeons, potentially contributing to an overall improvement in mitral valve repair rates.

Mitral valve repair offers a significant event-free survival advantage over medical management and mitral valve replacement [10–12] and is the only intervention that restores normal life expectancy to patients with degenerative mitral regurgitation: it is therefore the treatment of choice in this population [1]. In degenerative disease, which is the commonest cause of mitral regurgitation in Europe and the USA, satisfactory mitral valve repair may be achieved in virtually all patients. Despite, however, the consensus in current national guidelines which strongly advocate mitral repair over replacement, over 50% of patients undergoing mitral valve surgery in Europe and the USA receive a mitral valve prosthesis [13, 14]. This is a particularly undesirable outcome in the subset of asymptomatic patients with significant mitral regurgitation who have been shown to benefit from early mitral repair and are increasingly referred for surgery. In this group of patients, current American College of Cardiology/American Heart Association and European guidelines recommend surgery only if the likelihood of mitral valve repair is high [1, 2].

Several factors influence the decision to implant a prosthetic valve in a patient with degenerative mitral valve disease, of which a mismatch between repair complexity and surgeon experience has been argued to be a principal one [4, 15]. In other words, a significant proportion of patients undergo mitral valve replacement despite having a potentially reparable valve, because the operating surgeon lacks the specific expertise to carry out a successful repair for that individual patient's set of lesions [16]. The prevalence of liberal mitral valve replacement likely results in both decreased life expectancy and event-free survival in many patients, some of whom could have otherwise achieved a normal life expectancy. Additionally, data from large series suggest that a sizeable minority of patients who do undergo repair either leave the operating room with significant residual mitral regurgitation [17, 18] or suffer early recurrent regurgitation [19]. Experienced cardiac surgeons should be able to carry out a standard mitral valve repair, whereas complex repairs necessitating bileaflet repair techniques, requiring multiple leaflet resections or patch augmentation, which comprised almost two-thirds of the repairs in this series, are likely to be successfully attempted only by mitral valve specialist surgeons. This is supported by the 100% repair rate in this series in the complex group, which reflects the outcomes in a previous series [20], and which compares with mitral valve repair rates of ∼60–70% nationally [14].

Consequently, one strategy to improve both repair rates and quality would be for the referring clinician to identify complex repairs at an early stage and refer these patients to reference centres with mitral valve specialist surgeons. This approach would help optimize repair rates, without the need to restructure service provision. The challenge, however, lies in accurately predicting repair complexity. Standard 2D echocardiography provides detailed information on morphology and haemodynamics allowing highly experienced clinicians to accurately determine valve complexity, but this level of interpretation is subjective.

In our study, we demonstrated that the 3D echocardiographic paramaters of prolapsing height, multisegment involvement, bileaflet prolapse and anterior leaflet surface area are strong predictors of repair complexity. Volumetric quantification of the mitral valve may offer a relatively simple, reproducible and reliable method of identifying patients who would benefit from referral to reference mitral surgeons. These parameters are likely surrogate markers for Barlow's disease (underlined by the larger ring sizes used in the complex group), but in the absence of universally agreed definitions of valve aetiology, these quantitative parameters provide a useful framework on which to base pre-referral decision-making, particularly in light of data suggesting that asymptomatic patients with severe mitral regurgitation due to Barlow's disease are more likely to benefit from a strategy of watchful waiting, than asymptomatic patients with severe mitral regurgitation due to fibroleastic deficiency [21, 22]. Although the number of patients in this study precludes more detailed subgroup analysis, the fact that more than half of the patients in the complex repair group had aetiology other than Barlow's disease suggests that these quantitative measures are predictive of repair complexity across a range of disease aetiologies.

Strengths and limitations

This study provides a unique analysis of objective pre-operative echocardiographic determinants of mitral repair complexity. The principal strengths of this study include the prospective documentation of valve analysis and repair techniques, uniform application of surgical approach and the classification of repair complexity based on an objective measure of the number and type of reconstructive techniques employed. The classification method is supported by the finding of significantly longer bypass and ischaemic times in the complex group, despite fewer concomitant procedures in this group. The limitations of this model stem from the difficulty of defining repair complexity, particularly when decision-making rather than technical difficulty dictates outcome, such as in repair of ischaemic Carpentier type IIIb mitral regurgitation. 3D echocardiography with complete volumetric analysis was performed only recently, and in only a minority of patients during the study period, and so the numbers in this report are relatively small, with no long-term follow-up.

Clinical significance

3D echocardiography quantitative parameters such as prolapsing height and anterior leaflet surface area can be reliably used to predict the complexity of mitral valve repair. These simple, reproducible parameters, which are independent of haemodynamic status, constitute a platform to guide pre-referral decision-making with a view to advancing mitral valve repair rates closer to the standards proposed by national consensus guidelines.

Conflicts of interest: D.H.A. is a consultant and inventor for Edwards LifeSciences. R.M.L. receives equipment grants from Philips Medical Imaging. G.W.F. is a consultant for Philips.

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