Changes in myocardial repolarization in patients undergoing balloon valvuloplasty for congenital pulmonary stenosis: evidence for contraction–excitation feedback in humans

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ABSTRACT Alterations in ventricular loading conditions lead to changes in action potential duration and arrhythmias via contraction-excitation feedback; a decrease in load leads to prolongation of repolarization. To determine whether changes in right ventricular load alter ventricular repolarization in man, the corrected QT interval, a measure of overall ventricular repolarization, was measured in 32 patients before and after valvuloplasty for pulmonary stenosis. Right ventricular systolic pressure decreased (82.5 ± 30.7 to 40.5 ± 9.5 mm Hg, p<.001) and the QTc increased concurrently (409.1 ± 24.3 to 440.7 ± 28.0 msec, p<.001) after successful valvuloplasty. The increase in QTc was most marked for those patients with a greater than 30 mm Hg decrease in right ventricular pressure (40.0 ± 22.3 vs 16.3 ± 21.3 msec, p=.006). In a subset of seven patients in whom monophasic action potentials were recorded, monophasic action potential duration, a measure of local repolarization, was prolonged (230.0 ± 24.3 vs 216.9 ± 21.9, p<.001) after successful valvuloplasty, confirming that the QTc prolongation reflected changes in local ventricular repolarization. In addition, during nine acute right ventricular outflow tract occlusions in a subset of six patients, monophasic action potential duration shortened (206.6 ± 17.6 vs 221.7 ± 20.9 msec, p<.01) and early afterdepolarizations developed consistent with contraction-excitation feedback. These data suggest that, in humans, changes in mechanical load are associated with changes in ventricular repolarization consistent with contraction-excitation feedback.


BALLOON VALVULOPLASTY has evolved as a therapeutic alternative for patients with stenotic pulmonary valves. The present study focuses on the electrocardiographic and electrophysiologic changes that develop in patients undergoing balloon valvuloplasty for congenital pulmonary stenosis. The purpose of this study was to demonstrate that changes in ventricular repolarization consistent with contraction-excitation feedback mechanisms occur in man.

In patients undergoing balloon dilatation of stenotic valves, three mechanical states are present: (1) before valvuloplasty, at which time pulmonary stenosis associated with increased right ventricular afterload is present, (2) after valvuloplasty of the stenotic valve, associated with decreased afterload and right ventricular pressure generation, and (3) during balloon occlusion of the right ventricular outflow tract and pulmonary valve, at which time maximal afterload and right ventricular pressure generation are noted and tensions approach those seen under isovolumetric conditions. Contraction-excitation feedback theory predicts that the time course of ventricular repolarization will be influenced by the mechanical loading conditions. Studies in isolated preparations and experimental animals have demonstrated that alterations in mechanical load lead to changes in conduction and refractoriness of ventricular myocardium. In addition, changes in monophasic action potentials (MAPs) have been recorded in experimental preparations undergoing acute occlusion of the aorta. Specifically, increases in mechanical stress have led to shortened action potential durations and shortened effective refractory periods.
and afterdepolarizations. Thus, in patients undergoing balloon valvuloplasty, contraction-excitation feedback theory predicts that the time course of ventricular repolarization will be shortest during balloon occlusion of the pulmonary valve, will be longest after successful valvuloplasty, and will be intermediate before valvuloplasty, at which time hemodynamically significant pulmonary stenosis is present. In these patients, the QT interval, a measure of overall ventricular repolarization, was measured to evaluate mechanically induced changes in repolarization. Right ventricular MAPs were measured in a subset of patients to document that changes in QT intervals were due to changes in local ventricular repolarization.

**Methods**

Thirty-two patients with congenital pulmonary valve stenosis were referred to the Johns Hopkins Hospital for transluminal balloon valvuloplasty. All patients were referred because of clinical evidence of significant pulmonary stenosis and all had had diagnostic cardiac catheterization to confirm the diagnosis. All patients gave informed consent for the procedures that are described below.

**Technique of valvuloplasty.** The method of valvuloplasty has been described in detail previously. Briefly, after sterile preparation and draping of both groins, a No. 7F sheath was introduced percutaneously into the right femoral vein, a No. 5F or 6F sheath was introduced into the left femoral vein, and a Teflon arterial cannula was inserted into the left femoral artery of each patient. In those patients in whom MAPs were recorded, a second No. 5F sheath was inserted into the left femoral vein. After the administration of intravenous heparin (100 units/kg), right heart catheterization was performed with a No. 7F balloon-tipped, central-lumen, fluid-filled catheter. Femoral arterial, right ventricular, and pulmonary arterial pressures were recorded. A standard electrocardiographic lead (lead II) was also recorded in each patient (25 to 100 mm/sec).

An 0.035 inch diameter (200 cm) angioplasty J guidewire was introduced through the central lumen of the fluid-filled catheter and the wire was positioned such that the J was well into the left lower limb of the pulmonary artery. The catheter was removed over the guidewire and the right femoral vein was dilated with a No. 9F dilator. The balloon-tipped catheter used for dilation was advanced over the 0.035 inch guidewire and was positioned across the pulmonary valve under fluoroscopic guidance.

A No. 5F catheter was passed into the right ventricle to monitor pressure before, during, and after balloon inflation and valvuloplasty. In those patients in whom MAPs were recorded, a No. 5F or 6F catheter was passed into the right ventricle such that MAPs of stable amplitude and configuration were recorded (see below).

The balloon (20 ml) was inflated by hand pressure and was filled with diluted (30%) contrast material. The balloon was inflated until the visible indentation of the balloon caused by the stenotic valve suddenly disappeared, indicating successful release of the stenotic valve. Three to five dilations were performed until no further evidence of stenotic physiology was apparent.

After balloon valvuloplasty, the dilating catheter was removed and a repeat right heart catheterization was performed. Femoral arterial, right ventricular, and pulmonary arterial pres-

sures as well as an electrocardiographic lead II rhythm were recorded.

QT intervals were measured from the first deviation of the QRS complex from the isoelectric PQ segment to the initial part of the isoelectric TP segment. The QT interval was corrected for heart rate by the method of Bazzett (QTc = QT/VRR). Since ventricular repolarization is affected by both the rate and duration of the preceding train of beats, it was only possible to measure QT and QTc intervals before and after valvuloplasty, during which steady-state heart rate conditions prevailed. It should be noted that the Bazzett formula provides only approximate for QT interval correction. Unfortunately, there is no other correction that is uniformly accepted and shown to be significantly better than the Bazzett correction, nor is there a validation for this or other corrections in patients with pulmonary stenosis. As such, we used the method of Bazzett with the reservations cited to yield an approximation of the QTc.

**MAP.** The QT interval is a measure of overall left and right ventricular repolarization. Although in these patients with hemodynamically significant pulmonary valve stenosis and marked right ventricular hypertrophy, changes in right ventricular repolarization likely dominate in the surface QT interval, prolongation of the QT interval may be due to prolongation of the right or left ventricular repolarization. In addition, the end of the T wave is asymptotic and may represent residual repolarization gradients. Therefore, it was desirable to evaluate changes in local right ventricular repolarization in a subset of our patients. MAPs were therefore recorded from the right ventricular endocardial surfaces by use of a silver–silver chloride tipped catheter (Mansfield) in seven patients. Differential amplification relative to a second silver–silver chloride reference electrode 5 mm away and not in contact with the myocardium minimized the effects of remote electrical activity on the MAPs. The amplified signals were displayed on an oscilloscope and recorded on an ink-jet paper recorder (50 to 250 mm/sec). MAP duration was measured at 90% repolarization. By these techniques, MAPs of stable amplitude, smooth contour, and isopotential diastolic baseline could be recorded for greater than 30 min. Thus, MAPs from a single site could be recorded throughout the relatively brief protocol of outflow tract obstruction and release. Stable MAPs were successfully recorded during nine acute occlusions of the right ventricular outflow tract in six patients in whom atrial pacing was needed because of symptomatic bradycardia. In addition, MAPs were recorded before and after successful balloon valvuloplasty in seven patients. Because of the confounding effects of heart rate on MAP duration, comparisons were only analyzed for data collected during a constant atrial pacing rate.

**Justification of the MAP.** MAPs can be recorded by suction or contact electrode techniques. The MAP recording is an injury potential; the myocardium beneath the electrode is depolarized secondary to suction or pressure. This creates a voltage gradient between surrounding normal myocardium and the tissue beneath the electrode catheter. Activation of surrounding myocardium leads to a change in this voltage gradient, which is recorded by the electrode catheter as an MAP. Using a suction electrode to record monophasic action potentials, Hoffman et al. demonstrated that the time course of repolarization of the MAP parallels that of simultaneously recorded intracellular action potentials recorded by standard microelectrode techniques. Unfortunately, the suction electrode technique is associated with a progressive and relatively rapid decrement in the MAP signal. More recently, a contact electrode technique using pressure rather than suction to injure underlying myocardium was described as an alternative method. We have studied this technique in vitro and validated its use under certain circumstances. We have demonstrated that the MAP...
signal results from activation of cells in an area approximately 1.2 cm long, 0.6 cm wide, and 0.3 cm deep. The MAP results almost entirely from activation of normal surrounding cells. We have shown that the MAP technique is a sensitive means of detecting membrane phenomena such as afterdepolarizations as well as electrotonic phenomena. Finally, we have demonstrated that the time course of repolarization of the MAP recorded with the contact electrode technique accurately reflects that of local repolarization as indexed by action potential duration determined by standard microelectrode techniques. Thus, the characteristics of repolarization of the MAP recorded with a contact electrode appear to reflect the characteristics of repolarization of local intracellular action potentials. This technique may be applied in vivo to detect changes in action potential duration as well as record the development of afterdepolarizations or electrotonic phenomena.

Statistical methods. Comparisons of means were performed by the use of a paired t test or an analysis of variance. A Wilcoxon nonpaired rank-sum test was used to evaluate differences between groups without a normal distribution. For all determinations statistical significance was considered at the \( p<.05 \) level.

Results

Changes in QT and QTc intervals after successful balloon valvuloplasty. The QT and QTc intervals, measures of overall ventricular repolarization, were determined under steady-state conditions before and after successful balloon valvuloplasty in 32 patients with pulmonary stenosis. These data are presented in table 1. Shown are the right ventricular systolic pressure, QT intervals, native sinus cycle length, and QTc interval before and after successful balloon valvuloplasty in each patient. A significant elevation in right ventricular systolic pressure was present in each patient during the baseline

| TABLE 1 |
|-----------------|-----------------|-----------------|
| RV systolic pressure | QT interval (msec) | Cycle length (msec) |
| No. | Pre (mm Hg) | Post | Pre | Post | Pre | Post | Pre | Post |
| 1 | 60 | 28 | 260 | 240 | 420 | 340 | 401 | 412 |
| 2 | 78 | 35 | 285 | 260 | 420 | 330 | 440 | 453 |
| 3 | 55 | 40 | 355 | 350 | 700 | 740 | 424 | 407 |
| 4 | 80 | 28 | 320 | 330 | 530 | 480 | 440 | 476 |
| 5 | 133 | 45 | 290 | 330 | 560 | 520 | 388 | 458 |
| 6 | 180 | 38 | 300 | 360 | 490 | 500 | 429 | 509 |
| 7 | 86 | 32 | 320 | 310 | 720 | 530 | 377 | 426 |
| 8 | 66 | 52 | 310 | 270 | 490 | 400 | 443 | 427 |
| 9 | 112 | 60 | 250 | 310 | 400 | 460 | 395 | 457 |
| 10 | 44 | 30 | 335 | 350 | 600 | 600 | 432 | 452 |
| 11 | 60 | 34 | 350 | 360 | 830 | 890 | 384 | 382 |
| 12 | 72 | 37 | 340 | 330 | 660 | 460 | 419 | 486 |
| 13 | 142 | 40 | 240 | 290 | 420 | 500 | 370 | 410 |
| 14 | 96 | 54 | 285 | 300 | 470 | 410 | 416 | 469 |
| 15 | 55 | 50 | 280 | 270 | 490 | 410 | 400 | 421 |
| 16 | 110 | 34 | 240 | 320 | 360 | 520 | 400 | 449 |
| 17 | 60 | 25 | 290 | 340 | 540 | 610 | 390 | 438 |
| 18 | 57 | 30 | 300 | 290 | 550 | 420 | 405 | 453 |
| 19 | 58 | 36 | 360 | 320 | 960 | 640 | 370 | 401 |
| 20 | 84 | 50 | 300 | 360 | 640 | 680 | 380 | 436 |
| 21 | 108 | 40 | 320 | 300 | 590 | 520 | 414 | 416 |
| 22 | 80 | 42 | 320 | 320 | 510 | 450 | 447 | 468 |
| 23 | 55 | 45 | 310 | 320 | 510 | 530 | 434 | 440 |
| 24 | 72 | 44 | 360 | 390 | 760 | 760 | 413 | 448 |
| 25 | 58 | 28 | 330 | 410 | 680 | 840 | 400 | 447 |
| 26 | 104 | 48 | 345 | 375 | 785 | 750 | 389 | 433 |
| 27 | 70 | 43 | 290 | 270 | 500 | 430 | 410 | 412 |
| 28 | 50 | 34 | 290 | 310 | 600 | 570 | 374 | 410 |
| 29 | 94 | 45 | 260 | 245 | 430 | 350 | 396 | 414 |
| 30 | 72 | 54 | 310 | 310 | 530 | 450 | 426 | 462 |
| 31 | 70 | 34 | 270 | 290 | 400 | 400 | 425 | 458 |
| 32 | 120 | 60 | 400 | 405 | 630 | 630 | 459 | 474 |

Mean: 82.5 ± 40.5
SD: ± 30.7

p value: <.001

Pre = before balloon valvuloplasty; Post = after balloon valvuloplasty.
PATHOPHYSIOLOGY AND NATURAL HISTORY—VENTRICULAR PERFORMANCE

FIGURE 1. QTc prolongation for patients with less than and greater than a 30 mm Hg change in right ventricular systolic pressure (before-after balloon dilation of stenotic pulmonary valves). The degree of QTc prolongation was significantly greater in those patients with larger changes in right ventricular pressure after successful balloon valvuloplasty.

measurements. After balloon valvuloplasty, right ventricular systolic pressure decreased in each patient. Mean right ventricular systolic pressure decreased from 82.5 ± 30.7 to 40.5 ± 9.5 mm Hg (p<.001). There was a concomitant increase in the absolute QT interval. The mean QT interval increased from 306.8 ± 37.7 to 319.9 ± 43.1 msec (p<.05). This increase was noted even though the overall steady-state sinus cycle length decreased from 567.9 ± 139.9 to 535.0 ± 144.6 msec (p = .07). The corrected QT interval increased in most patients and the mean QT interval corrected for heart rate increased from 409.1 ± 24.3 to 440.7 ± 28.0 msec (p<.001). Thus, ventricular repolarization, as indexed by the QT interval, was prolonged after successful balloon dilation of stenotic pulmonary valves in these patients.

The degree of prolongation of the QT interval was related to change in ventricular pressure induced by successful valvuloplasty. The degree of QTc prolongation in those patients with a pressure change (before vs after valvuloplasty) of less than 30 mm Hg was compared with the QTc prolongation in those patients with a pressure change greater than 30 mm Hg (i.e., mild vs moderate-to-marked change in the mechanical state). These data are presented in figure 1. The mean increase in the QTc interval was 16.3 ± 21.3 and 40.0 ± 22.3 msec for these two groups, respectively (p = .006). In addition, a weak but statistically significant linear correlation was present between the change in right ventricular pressure and the change in QTc interval (R = .52, p<.01). Thus, the prolongation of the QTc interval was most marked with at least a moderate change in right ventricular pressure after successful valvuloplasty.

Direct demonstration of altered ventricular repolarization in man. Although we have demonstrated that there is prolongation of the QT and QTc intervals in patients associated with alleviation of pulmonary valve stenosis, a decrease in right ventricular afterload, and a decrease in right ventricular pressure generation, we have not proven that the changes are a reflection of prolongation of local right ventricular repolarization. Right ventricular MAPs were recorded in seven patients to evaluate changes in local ventricular repolarization. Analog recordings from one patient are presented in figure 2. Shown are the electrocardiogram and MAP recordings before, during, and after the occlusion of the pulmonary outflow tract in a patient undergoing balloon valvuloplasty. A constant ventricular rate of 100 beats/min was accomplished by atrial pacing at a cycle length of 600 msec. Before balloon valvuloplasty, the QT interval was 345 msec and MAP duration at 90% repolarization was 248 msec. During complete occlusion of the occlusion outflow tract and

FIGURE 2. Electrocardiographic tracings (ECG) and MAP recordings from a patient before, during, and after balloon dilation of a stenotic pulmonary valve. A constant cycle length (600 msec) was maintained with atrial pacing. The QT interval and MAP duration shortened during balloon occlusion. In addition, after balloon dilation of the stenotic valve, associated with decreased right ventricular afterload and generated pressure, prolongation of the QT interval and MAP duration were noted.
Stable MAP recordings were obtained during nine occlusions in six patients and the MAP duration decreased during each occlusion (associated with an increase in right ventricular afterload) (figure 3, A). In nine occlusions in these six patients, the mean MAP duration decreased from 221.7 ± 20.9 msec on baseline recordings to 206.6 ± 17.6 msec during the occlusion (p<.001). In addition, prolongation of right ventricular MAP duration was noted in all patients after successful balloon valvuloplasty associated with a decrease in right ventricular pressure (figure 3, B). The mean MAP duration increased from 216.9 ± 21.9 to 230.0 ± 24.3 msec (p<.01). Of note is that changes in MAP duration during the occlusions were seen within 2 to 5 beats of the balloon occlusion, suggesting that the changes were due to contraction-excitation feedback, rather than to reflex neurogenic changes. Thus, the changes in the QT interval are paralleled by similar changes in right ventricular MAP duration, suggesting that the changes in the QT interval reflect changes in local ventricular repolarization in these patients.

Other alterations in the MAPs were also noted during acute occlusion of the pulmonary outflow tract. Specifically, there were depolarizations during phase 3 of the MAP that were morphologically similar to early afterdepolarizations developed during seven balloon occlusions in four patients. Figure 4 illustrates an example of one such trace. Panel A shows MAPs recorded during the baseline period just before balloon occlusion. Note that a smooth repolarization phase was present. Panel B shows recordings during the balloon occlusion. Early afterdepolarizations were present that were associated with the development of spontaneous ectopic beats. Note also that afterdepolarizations were not present in the ectopic beats arising at short coupling intervals, consistent with the properties of early afterdepolarizations in vitro.

**Discussion**

The major finding of this study is that contraction-excitation feedback mechanisms are operative during right ventricular outflow tract occlusions in humans. In patients undergoing balloon valvuloplasty for stenotic pulmonary valves, changes in right ventricular afterload and generated right ventricular pressure are associated with altered ventricular repolarization, as indexed by QT intervals and MAP duration.

Contraction-excitation feedback-induced changes in action potential duration have been demonstrated in vitro and in vivo. Several groups of investigators have demonstrated that action potential duration is depen-
dent, in part, on mechanical loading conditions; that is, changes in mechanical loading conditions lead to changes in action potential duration and configuration. Specifically, an increase in stretch on a papillary muscle or in ventricular wall tension associated with an acute change in afterload or preload is associated with shortening of action potential duration. Conversely, a reduction in mechanical load is associated with prolongation of action potential duration. In addition, afterdepolarizations have been noted in intracellular and monophasic action potentials during acute increases in mechanical stress.5'7 The ventricular arrhythmias that develop under these circumstances have been attributed to the afterdepolarizations.5'7

We have demonstrated in this study that these mechanisms are operative in certain clinical situations as well. Valvuloplasty of stenotic pulmonary valves is an effective means of correcting these lesions.1'2 The procedure, however, has been associated with ventricular premature beats and ventricular tachycardia. Three distinct mechanical states are present in patients undergoing balloon valvuloplasty for pulmonary stenosis: (1) during valvuloplasty, at which time there is near-total balloon occlusion of the right ventricular outflow tract and marked increases in developed right ventricular pressure, (2) before valvuloplasty, at which time there is a moderate (relative to total occlusion) increase in right ventricular afterload due to the stenotic valve, and (3) after successful valvuloplasty afterload, at which time right ventricular afterload and generated pressure are decreased due to successful dilation of the stenotic valve. Contraction-excitation theory predicts that action potential duration is inversely related to mechanical stress on the myocardium. Therefore, one would predict that the time course of repolarization would be shortest during balloon occlusion of the right ventricular outflow tract, would be intermediate before balloon valvuloplasty, and would be maximal after successful dilation of the stenotic pulmonary valve. This is what was seen in our patients. Alterations in ventricular repolarization, as indexed by the QT interval, occurred in our patients consistent with contraction-excitation feedback (table 1; figure 1). The changes in the QT and QTc interval were related to the altered hemodynamics that were present. Successful balloon valvuloplasty was associated with a significant reduction in steady-state right ventricular pressure that was accompanied by a concomitant prolongation of the QT and QTc intervals. That a close relationship between these variables is present is suggested by the fact that more pronounced pressure changes were accompanied by a greater prolongation of the QT and QTc intervals (figure 1). In addition, a weak but significant linear relationship was present between the change in QTc and right ventricular pressure, perhaps explaining why the changes in QTc were quite variable with little or no change in some patients.

Prolongation of QT and QTc intervals was likely a reflection of alterations in local ventricular repolarization. MAPs, recorded in seven patients, changed in a fashion analogous to the changes QT and QTc intervals; that is, decreases in right ventricular afterload and pressure generation were associated with prolongation of MAP duration (figure 2). Conversely, balloon occlusion of the pulmonary valve was associated with shortened MAP duration, afterdepolarizations, and ventricular ectopic activity (figures 2 to 4).

Afterdepolarizations were noted during seven balloon occlusions in four patients (figure 4). These afterdepolarizations were morphologically similar to early afterdepolarizations identified in vitro.24'25 In indi-

![Figure 4](https://example.com/assets/figure4.png)

**FIGURE 4.** A. MAPs recorded just before occlusion; B, MAPs recorded continuously from the same patient during balloon occlusion of the right ventricular outflow tract. During balloon occlusion, typical early afterdepolarizations developed (small arrow) that were associated with spontaneous ectopic beats (large arrow).
individual cases, these afterdepolarizations appeared to be associated with the development of ectopic beats (figure 4). We have previously demonstrated that the MAP technique is a sensitive method for recording afterdepolarizations in vitro and in vivo, and have demonstrated a close association of ventricular ectopic activity and early afterdepolarizations in animals intoxicated with cesium chloride.18 The complete characterization of these afterdepolarizations or a full evaluation of the relationship between them and the ventricular ectopic activity that developed was not possible in this study. This was due to two factors. First, only a relatively small number of patients was studied. Second, it was not possible to subject these patients in a controlled setting to the interventions required to fully characterize the afterdepolarizations and the ventricular ectopy that developed. The causes of the afterdepolarizations are unclear. Although they might be due to ionic current flow via a membrane channel, they may also represent an electrotonic phenomenon due to dispersion of repolarization between closely juxtaposed cells. This latter mechanism for recordings that resemble early afterdepolarizations has been described, and the mechanism for arrhythmogenesis in this setting has been termed reflected reentry.26 The recordings in patients and the ventricular ectopic activity that developed are consistent with this mechanism. It should further be noted that the presence of MAP early afterdepolarizations on intracardiac traces is not inconsistent with the finding of shortened overall QTc intervals at high loads. The surface T wave results from the vector sum of myocardial repolarization, and hence is the result of electrical activity from a large mass of muscle. The local MAP recording, on the other hand, results from local activity of cells in a relatively small area, approximately 1.2 cm × 0.6 cm × 0.3 cm.19 Thus, the electrical potential of nonuniformly distributed MAP afterdepolarizations may be detectable in local MAP recordings but may not be of sufficient magnitude to be expressed on standard surface electrocardiographic tracings.

We cannot exclude the possibility that motion artifact may have played a role in the abnormalities of repolarization and afterdepolarizations recorded. We believe, however, that this is unlikely. In control experiments, increased contractility and ventricular wall motion induced by catecholamines were not associated with the development of afterdepolarizations.18 In addition, motion artifacts associated with MAP recordings are often random and associated with changes in the morphology, amplitude, and resting potential of the MAP. In contrast, in our experiments, the afterdepolarizations had a constant relationship to the MAP (phase 3) and were present in the presence of stable MAP amplitude, morphology, and resting potential. Finally, our findings in the intact ventricle are consistent with previous observations of contraction-excitation feedback in isolated ventricular preparations and experimental animals.

The changes in the QT interval and in monophasic duration may have been due to alterations in the autonomic tone of our patients. We believe, however, that this is unlikely. First, the changes in MAP duration during the acute right ventricular outflow tract occlusions occurred in every case within the first several beats; the time course of reflex autonomic changes, on the other hand, would be expected to be somewhat longer. Second, the change in the QT interval and action potential duration were opposite to those predicted if the heart rate changes reflected alterations autonomic tone; that is, MAP duration shortened in spite of bradycardia (increase vagotonia and/or decreased sympathetic tone) during the occlusions and QTc intervals prolonged in spite of relative tachycardia (decreased vagotonia and/or increased sympathetic tone) after successful valvuloplasty (table 1).

These findings are clinically relevant. Balloon valvuloplasty has evolved as a therapeutic alternative for patients with stenotic valves.1, 2 The procedure, however, has been associated with the development of ventricular ectopic activity. Our data suggest a possible mechanism for this ectopy. If, in fact, action potential changes develop leading to dispersion of the time course of repolarization, or to the development of early afterdepolarizations and triggered activity, then certain interventions may be salutary in these patients. For example, overdrive atrial pacing is one such intervention that is associated with suppression of arrhythmias caused by these mechanisms. Unfortunately, the role of the action potential changes in arrhythmogenesis could not be fully examined. Further studies are needed to better characterize the mechanisms of the ectopic activity that develops so that a strategy for management of the ventricular arrhythmias associated with balloon valvuloplasty can be found.

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References
15. Khatib S, Lab MJ: Differences in electrical activity in the apex and base of left ventricle produced by changes in mechanical conditions of contraction. J Physiol (Lond) 324: 25, 1982
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