Altered Expression of Disintegrin Metalloproteinases and Their Inhibitor in Human Dilated Cardiomyopathy

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Background—Disintegrin metalloproteinases (ADAMs) may contribute to structural cardiac remodeling by altering cell-surface matrix receptors (integrins) and activating potent biomolecules. We compared expression of ADAMs, their endogenous inhibitor tissue inhibitor of metalloproteinases (TIMP)-3, and integrins in human heart tissue with varied patterns of structural remodeling.

Methods and Results—Myocardium was obtained from patients with dilated cardiomyopathy (n=20), hypertrophic obstructive cardiomyopathy (n=5), and nonfailing donor hearts (n=7). Paired samples (n=10) were obtained before left ventricular assist device insertion and at transplantation. The expressions of ADAM10, ADAM12, ADAM15, and ADAM17, TIMP-3, and integrin receptors β1D and β3 were determined by quantitative immunoblotting. Integrin shedding was assessed by the ratio of integrin cleavage products to intact protein abundance. Confocal microscopy was performed. Dilated cardiomyopathy was characterized by increased ADAM10 and ADAM15 expression and reduced TIMP-3 expression. The integrin β1D cleavage ratio was elevated, indicating receptor shedding. ADAM10 and ADAM15 expressions correlated with the cleavage ratio. ADAM10 colocalized with integrin β1D by confocal microscopy. ADAM10 expression correlated with clinical indices of chamber dilatation and systolic dysfunction. Hemodynamic unloading reduced ADAM10 and ADAM12 expressions and increased integrin β1D expression. ADAM12 and integrin β1D expressions were increased in HOCM. ADAM17 was increased in both dilated cardiomyopathy and hypertrophic obstructive cardiomyopathy.

Conclusions—Disintegrin metalloproteinases are differentially expressed in human myocardium, reflecting the underlying pattern of structural remodeling. ADAM10 and ADAM15 may contribute to cardiac dilatation by reducing cell-matrix interactions via integrin shedding. Targeting disintegrin metalloproteinases, perhaps by restoring deficient TIMP-3 levels with gene or cell-based therapies, may prevent progressive chamber dilatation in human dilated cardiomyopathy.

Key Words: cardiomyopathy ■ surgery ■ transplantation ■ metalloproteinases ■ remodeling

The clinical progression of congestive heart failure is largely determined by a dynamic and seemingly relentless process of cardiac remodeling. Structural cardiac remodeling, such as ventricular dilatation with increased sphericity, involves cellular and extracellular matrix disruption with altered cell-cell and cell-matrix contacts. Matrix metalloproteinases (MMPs) are matrix-degrading proteases that are activated in the failing heart and contribute to structural cardiac remodeling. The extended metalloproteinase family includes the disintegrin metalloproteinases. These unique MMPs are also known as ADAM enzymes (A Disintegrin And Metalloproteinase), capable of activating potent biomolecules such as inflammatory cytokines and directly altering cell-surface matrix receptors (integrins) through their disintegrin domain. Excessive MMP activity can profoundly influence tissue architecture, and the multifunctional roles of ADAMs may provide insights into novel underlying mechanisms. Despite the promise of disintegrin metalloproteinases in understanding the coordinated control of structural cardiac remodeling, the pattern of ADAM expression and the role of specific ADAM enzymes in human cardiac remodeling and the progression of heart failure are unknown.
We surmised that disintegrin metalloproteinases are differentially expressed in the failing human heart in a profile that parallels the underlying pattern of structural cardiac remodeling. We hypothesized that increased activity of specific ADAMs contributes to structural cardiac remodeling by altering cell-matrix and cell-cell contact through shedding of integrin receptors. We previously documented a role for tissue inhibitor of metalloproteinases (TIMP)-3 deficiency in structural cardiac remodeling. Accordingly, we selected a profile of ADAM enzymes inhibited by TIMP-3 and those previously implicated in structural cardiac remodeling. To this end, we compared the differential myocardial remodeling.

Patient Profiles
Baseline patient characteristics are summarized in Table 1. Our study group was composed of patients with DCM (n = 20), patients with HOCM (n = 5), and patients with structurally normal and nonfailing hearts collected at the time of organ procurement for transplantation (NF group) (n = 7).

Results
Patients with DCM had significantly enlarged LVs (mean LV end-diastolic diameter [LVEDD], 7.2 ± 0.9 cm; P < 0.001) and reduced ventricular function (mean ejection fraction as percentage [%EF], 13 ± 4; P < 0.001) compared with the patients with HOCM (mean LVEDD, 4.5 ± 0.3 cm; mean %EF, 65 ± 2) or NF hearts (mean LVEDD, 4.7 ± 0.8 cm; mean %EF, 56 ± 4). DCM patient samples were obtained at the time of cardiac transplantation.

Statistical Analysis
Results are presented as mean ± SD unless otherwise specified. Comparison between groups was performed by 1-way ANOVA. When significant, pairwise tests of individual group means were compared with the Student-Newman-Keuls test. Paired samples obtained at LVAD insertion/transplantation were analyzed by paired t test. All statistical procedures were performed with the SAS software system (SAS Institute). Differences were considered significant at P < 0.05.

Methods
Human Cardiac Tissue Sample Collection
Myocardial samples of the left ventricle (LV) were collected during cardiac surgery at the time of cardiac transplantation or insertion of a mechanical assist device. All procedures involving human tissue use were approved by the institutional review boards of the Toronto General Hospital, University of Toronto, and the Cleveland Clinic Foundation. Consent was obtained from patients before tissue harvest. Transmural samples were collected whenever possible, avoiding obvious areas of scar or infarction. Samples were immediately snap-frozen in liquid nitrogen and stored at −80°C until use.

LV myocardial samples were obtained from 32 patients at the time of cardiac surgery (25 from the Cleveland Clinic Foundation and 7 from the University of Toronto General Hospital, University of Toronto). Samples were collected from patients with DCM (n = 20) at the time of cardiac transplantation. Paired serial samples were obtained in 10 of these DCM patients at the time of implantation of an LVAD and again when the heart was excised for cardiac transplantation (n = 20 samples). Additional patient samples included those with hypertrophic obstructive cardiomyopathy (HOCM) (n = 5), undergoing surgical resection of LV outflow tract obstruction, and patients with structurally normal nonfailing hearts collected at the time of organ procurement for transplantation (NF group) (n = 7).

Immunoblotting and Quantification of Protein Expression
The relative abundance of ADAM10, ADAM12, ADAM15, ADAM17, TIMP-3, and integrin β1D and β3 was examined in LV myocardial extracts with the use of standard immunoblotting procedures as described previously.

In brief, protein extracts were prepared from human heart tissue by extraction with Tris-based lysis buffer: 0.05 mol/L Tris, pH 7.6, 0.5% Triton X-100, 0.3 mol/L NaCl, 5 mM EDTA with protease inhibitors (1 mM sodium fluoride, 0.01 mg/mL phenylmethylsulfonyl fluoride). Frozen tissue was ground in liquid nitrogen and homogenized in ice with lysis buffer with the use of 20 μL of lysis buffer per 1 mg of tissue. After 30 minutes on ice, the samples were centrifuged at 14 000g for 10 minutes at 4°C. Supernatant was transferred to new tubes, and total protein content was determined by a detergent-compatible assay (DC Protein Assay, Bio-Rad). Equal amounts of total protein (60 μg) were loaded for each lane on 10% SDS-PAGE. Commercially available antibodies (Chemicon International, Temecula, Calif) used were mouse anti-human integrin β1D monoclonal antibody (specific for the cytoplasmic domain of integrin β1D subunit), mouse anti-human integrin β3 monoclonal antibody, rabbit anti-human ADAM10 polyclonal antibody, anti-ADAM12 polyclonal antibody, rabbit anti-ADAM15 polyclonal antibody, and anti–tumor necrosis factor-α (TNF-α) converting enzyme (TACE)/ADAM17 polyclonal antibody. In addition, we used TIMP-3 monoclonal antibody (Oncogene Research Products). Membranes were developed with ECL reagent (Amersham Pharmacia) and quantified by image analysis. The results were presented as percent change compared with NF controls, and their means were arbitrarily set as 100%.

Integrin Cleavage Products
With the use of the immunoblots for integrin β1D as described above, the integrin β1D cleavage ratio was calculated by measuring the relative expression of the intact mature protein (140-kDa band) to its primary cleavage product in the same lane (40-kDa band). The cleavage ratio was calculated for each sample with the 40-kDa “cleavage” band used as the numerator and the 140-kDa “intact” band used as the denominator.

Confocal Microscopy of ADAM and Integrin Expression
To localize and quantify regional protein expression, double immunofluorescent stainings were done on 15- to 20-μm-thick frozen sections from LV segments. Frozen slides were allowed to equilibrate to room temperature before they were fixed in ice-cold acetone for 2 minutes. Endogenous peroxidase activity was blocked with 0.3% hydrogen peroxide followed by blocking of nonspecific binding sites with 10% normal goat serum. Slides were then treated with various combinations of primary antibody (as performed for immunoblotting) that are raised in different species. Fluorochrome-conjugated secondaries (Alexa-Fluors, Molecular Probes) were used to enhance the signal. Nuclear counterparts were stained with Topro-3 (Molecular Probes). Sections were imaged with the use of a laser scanning confocal system (model MRC 1024, Bio-Rad). Fields were randomly selected with the exclusion of cutting or compression artifact. Four random fields were obtained from each of 2 transverse LV segments from each of 5 patient samples per group. The stained LV sections were then digitized at a final magnification of ×1200 and analyzed with an image analysis system (Scion Image, NIH Software). Image analysis was performed to quantify these parameters in blinded fashion.

Statistical Analysis
Results are presented as mean ± SD unless otherwise specified. Comparison between groups was performed by 1-way ANOVA. When significant, pairwise tests of individual group means were compared with the Student-Newman-Keuls test. Paired samples obtained at LVAD insertion/transplantation were analyzed by paired t test. All statistical procedures were performed with the SAS software system (SAS Institute). Differences were considered significant at P < 0.05.
Further, interventricular septal wall thickness (IVS) was significantly greater in HOCM patients (mean IVS, 2.3, P < 0.05) than in DCM (mean IVS, 1.0) and NF patients (mean IVS, 1.0).

**Differential ADAM Expression**

The differential profile of ADAM protein expression (ADAM10, ADAM12, ADAM15, ADAM17) was assessed in DCM, HOCM, and NF myocardium by means of immunoblotting with commercially available antibodies and quantification by computerized image analysis. Baseline expression of each ADAM studied was consistently observed in NF myocardium, suggesting constitutive expression. Notably, there was a unique pattern of ADAM expression that followed the underlying pattern of cardiac remodeling. In the dilated and dysfunctional hearts (DCM), ADAM10 and ADAM15 were uniquely increased (Figure 1). In contrast, ADAM12 was markedly increased in HOCM patients (Figure 2). ADAM17 expression was similarly increased in all remodeled hearts (DCM and HOCM) compared with NF hearts (Figure 2). In addition, we assessed ADAM expression in the serial samples obtained before and after LVAD support for DCM patients. These results are summarized in Table 2. Notably, expression of ADAM10 and ADAM12 was significantly reduced after hemodynamic unloading by LVAD support.
Expression of the Endogenous ADAM Inhibitor TIMP-3

TIMP-3 is expressed in human myocardium and serves as the primary endogenous inhibitor of ADAM10, ADAM12, and ADAM17. Accordingly, we assessed TIMP-3 expression in our patient samples by immunoblotting and quantitative computerized image analysis. These results are summarized in Figure 3. TIMP-3 expression was reduced in dilated failing hearts (DCM) compared with nondilated hearts with preserved systolic function (HOCM and NF). By confocal microscopy, TIMP-3 expression was localized to cardiomyocytes. Confirming the immunoblot data, TIMP-3 expression by confocal microscopy was also observed to be uniquely reduced in the DCM samples (Figure 3, bottom panel).

Integrin Receptor Expression and Turnover

We assessed the expression and turnover of 2 key integrin receptors, integrin β1D and integrin β3. These results are summarized in Figure 4. Notably, intact integrin β1D protein expression was increased in HOCM hearts but not in dilated failing hearts (DCM). However, integrin cleavage products were increased in DCM hearts, suggesting accelerated breakdown. ADAM10 (r=0.58, P=0.02) and ADAM15 expressions (r=0.64, P=0.01) were found to be positively correlated with the presence of integrin β1D cleavage products. By confocal microscopy, ADAM10 expression appeared to colocalize with integrin β1D at the cardiomyocyte cell surface, where shedding may occur (Figure 5).

In patients with DCM, hemodynamic unloading of the heart by LVAD support resulted in a recovery of integrin β1D

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Ten paired myocardial samples taken at the time of LVAD insertion for end-stage DCM were assessed for ADAM, integrin, and TIMP-3 protein expression and compared after LVAD removal at the time of heart transplantation. Data are expressed as percent change compared with patient’s own expression level at the time of LVAD insertion. ADAM10 and ADAM12 expression were significantly reduced after hemodynamic unloading by LVAD support with a corresponding recovery of integrin β1D expression. ADAM15 expression was similarly reduced, although the difference was not statistically significant. P value was obtained from paired t test.
expression, whereas integrin β3 expression was unchanged (Table 2). Increased integrin β1D expression was observed with a concomitant decrease in expression of ADAM10 and ADAM12. ADAM15 expression was similarly reduced, although the difference was not statistically significant.

Confocal Microscopy
Confocal microscopy was performed for ADAM10, ADAM12, ADAM17, and integrin β1D. In all images, 3 channels were used to simultaneously highlight the cell nucleus, ADAM of interest, and coexpression of integrin β1D. In heart tissue, integrin β1D is only expressed by cardiomyocytes, and, accordingly, its expression also served as a cardiomyocyte-specific marker. Computerized image analysis of multiple images for each sample with the use of a single channel allowed a quantitative analysis of individual protein expression. Representative confocal images are displayed in Figure 6. Following the
pattern of expression with immunoblotting, ADAM10 expression as assessed by confocal microscopy was significantly increased compared with NF controls (19.2 ± 15 versus 6.1 ± 3 arbitrary units; P = 0.002). In addition, ADAM10 expression was positively correlated with LVEDD (r = 0.52, P = 0.03) and LVESD (r = 0.63, P = 0.007) and negatively correlated with %EF (r = −0.67, P = 0.002).

Discussion

Structural cardiac remodeling is the reorganization of heart size and shape that underlies heart failure progression. Ventricular dilatation is a major determinant of the clinical course of congestive heart failure irrespective of its underlying cause. To define new therapeutic targets that control the progression of heart failure, novel biomolecules and mechanisms that regulate structural cardiac remodeling must be discovered. To this end, dysregulation of the interstitial myocardial matrix has emerged as a key determinant of ventricular dilatation and dysfunction. An imbalance of MMPs and their endogenous inhibitors (TIMPs) has been identified in failing hearts and is believed to promote ventricular dilatation by degrading the matrix scaffold that supports functional tissue architecture. Disintegrin metalloproteinases (ADAMs) are a unique class of MMP proteases expressed in human myocardium. ADAM enzymes may be involved in structural remodeling given their documented ability to cleave and activate growth factors and cytokines. In addition, ADAMs may regulate cell-cell or cell-matrix adhesions via proteolytic activity or by interactions between their disintegrin domains and integrin proteins resulting in structural tissue remodeling. However, ADAM enzymes have not been adequately studied in the failing human heart, and their role in the myocardium is largely unclear.

We previously demonstrated that the endogenous metalloproteinase inhibitor TIMP-3 is deficient in failing myocardium and its deficiency parallels the progression of matrix and structural cardiac remodeling. We extended these observations in mutant mice lacking the ability to express TIMP-3 by demonstrating that TIMP-3 deficiency directly results in progressive DCM. At the molecular level, TIMP-3 deficiency resulted in MMP-mediated matrix degradation and ADAM-mediated inflammatory cytokine activation. Notably, TIMP-3 is a potent endogenous inhibitor of disintegrin metalloproteinases, particularly ADAM10, ADAM12, and ADAM17. In light of the emerging relationship between loss of myocardial TIMP-3 and progressive structural remodeling, we considered these additional targets of TIMP-3 as contributors to the remodeling process. Accordingly, we surmised that a loss of TIMP-3 in human heart failure may release ADAM activity, contributing to structural remodeling. However, the profile of expressed ADAMs in human heart tissue and the relationship of these enzymes to the underlying state of cardiac remodeling had not been outlined before this study.

Unique Pattern of ADAM Expression in DCM

The present study indicates that ADAM enzymes are differentially expressed in human myocardium, and the pattern of expression follows the underlying pattern of structural remodeling. Although the specific role of each ADAM in cardiac remodeling remains undefined, there appears to be a characteristic expression of ADAM proteins in human DCM. ADAM10 and ADAM15 were exclusively elevated in human DCM. In support of a role in structural remodeling, ADAM10 expression...
in human heart failure. It is not surprising that ADAM17 was elevated in both DCM and HOCM hearts given the ubiquitous nature of proinflammatory cytokines and tissue remodeling. Similarly, given the inflammatory pathways activated by artificial mechanical hearts, LVAD support did not reduce ADAM17 expression.

Reverse Remodeling and Mechanical Unloading of the Failing Heart
Mechanical unloading of the dilated failing heart by LVAD support can promote reverse remodeling, an intriguing phenomenon that may provide novel insights toward mechanisms of myocardial recovery. We observed a recovery of ADAM expression after mechanical unloading in patients with DCM (Table 2). ADAM10 was significantly reduced after mechanical unloading, and ADAM15 was similarly reduced, although the difference was not statistically significant. Integrin β1D expression was profoundly increased with mechanical support, perhaps a result of lessened degradation from attenuated ADAM activity. Given that chamber size is sometimes reduced after mechanical unloading of the dilated failing heart, one may speculate that this is a consequence of normalized ADAM activities and preserved cell-matrix contacts. Interestingly, mechanical unloading profoundly reduced the expression of ADAM12 in DCM, suggesting that ADAM12 expression may be linked to wall stress and mechanical stretch. Given that ADAM12 triggers myocardial hypertrophy, this observation may provide some mechanistic insight into the upstream signals regulating this novel muscle growth pathway.

Deficient Endogenous ADAM Inhibitor TIMP-3 as a Therapeutic Target
In support of previous studies, TIMP-3 was reduced in DCM. Given its role in regulating the activity of the specific ADAMs studied, we speculate that the loss of this critical regulator combined with the upregulation of ADAM10 and ADAM15 resulted in excessive and maladaptive ADAM activity in the DCM heart. Notably, we did not observe a recovery of TIMP-3 expression after mechanical unloading of the dilated heart, despite the results of prior studies. Given the observations of this study, TIMP-3 may reflect an important therapeutic target in the quest to halt the progression of structural cardiac remodeling. Targeting disintegrin metalloproteinases, perhaps by restoring deficient TIMP-3 levels with gene or cell-based therapies, may provide novel insights toward mechanisms of myocardial recovery. We observed a recovery of TIMP-3 expression after mechanical unloading in patients with DCM (Table 2). ADAM10 was significantly reduced after mechanical unloading, and ADAM15 was similarly reduced, although the difference was not statistically significant. Integrin β1D expression was profoundly increased with mechanical support, perhaps a result of lessened degradation from attenuated ADAM activity. Given that chamber size is sometimes reduced after mechanical unloading of the dilated failing heart, one may speculate that this is a consequence of normalized ADAM activities and preserved cell-matrix contacts. Interestingly, mechanical unloading profoundly reduced the expression of ADAM12 in DCM, suggesting that ADAM12 expression may be linked to wall stress and mechanical stretch. Given that ADAM12 triggers myocardial hypertrophy, this observation may provide some mechanistic insight into the upstream signals regulating this novel muscle growth pathway.

Limitations
First, human tissue samples were harvested from the LV but, in some cases, from different regions within the LV (ie, HOCM tissue from the outflow tract versus DCM tissue from the anterior free wall). Regional differences in expression within the LV could result from regional differences in wall stress. Further studies will be required to determine the regional and load-dependent expression of disintegrin metalloproteinases in the human ventricle. Second, the specific β1D cleavage products that may result from ADAM interactions remain undefined. Further characterization of these cleavage products will be required to demonstrate the potential role of ADAM enzymes in the process of integrin shedding and cardiac structural remodeling.

Hypertrophic Hearts and ADAM12 Expression
ADAM12 may influence muscle growth by stimulating key growth factors. In transgenic mouse models, ADAM12 activity directly triggered cardiomyocyte hypertrophy by activating heparin-binding epidermal growth factor. In addition, ADAM12 can stimulate the insulin-like growth factor-1 pathway, a growth factor strongly implicated in human hypertrophic cardiomyopathy. In support of this mechanism, ADAM12 expression was profoundly increased in patients with HOCM. In the dilated but not thickened ventricles of patients with DCM, ADAM12 was not similarly elevated. Interestingly, HOCM patients had an increased expression of integrin β1D with a concomitant increase in the cleavage ratio. These data suggest increased integrin expression with simultaneous increased degradation. This finding is in contrast to those in DCM patients who were unable to maintain adequate levels of this key cell-matrix receptor. In noncardiac cells, ADAM12 has been observed to alter cell shape by regulating integrin β1D function. Specifically, ADAM12 binds and cleaves integrin β1D, resulting in altered cell morphology, differentiation, and survival. These data may explain the increased integrin cleavage observed in HOCM patients without concomitant increases in ADAM10 and ADAM15. Cell-matrix interactions may be important to maintain cell and chamber hypertrophy, and a dynamic turnover may be required to support an ongoing remodeling process in hypertrophic tissue.

ADAM17, TNF-α, and Inflammatory Pathways
Congestive heart failure is increasingly attributed to inflammatory processes. ADAMs shed and activate inflammatory cytokines and growth factors. Activation of TNF-α is mediated by ADAM17, also known as TACE. Structural cardiac remodeling (both cellular hypertrophy and chamber dilatation) is associated with elevated TNF-α activity. For example, overexpression of TNF-α in an animal model is associated with matrix proteolysis, cell death, and dilated cardiac failure. In addition, ADAM17 activity is strongly associated with ventricular dilatation and cardiac dysfunction was highly correlated with LV dilatation and indices of systolic contractile dysfunction. Interestingly, these specific disintegrin metalloproteinases have been similarly implicated in human atrial dilatation. Increased expression of ADAM10 and ADAM15 was associated with an abundance of integrin β1D cleavage products, suggesting a role for these enzymes in integrin β1D receptor shedding and turnover. Further supporting this mechanism, ADAM10 was colocalized to integrin β1D expression by confocal microscopy. Other studies have demonstrated a colocalization of ADAM15 with integrin β1D expression in cardiac cells. Transgenic mice engineered to lack cardiac expression of integrin β1D develop a spontaneous DCM, supporting a mechanistic role for integrin β1D loss and cardiac dilatation. In summary, the data from our study suggest that increased expression of ADAM10 and ADAM15 may play a role in human cardiac dilatation and failure by reducing cell-matrix interactions via integrin β1D shedding. Further studies will be required to confirm the validity of this proposed mechanism.
Conclusion
This study documents the novel observation that disintegrin metalloproteinases are differentially expressed in human myocardium in a pattern that reflects the underlying structural remodeling. ADAM10 and ADAM15 may contribute to progressive cardiac dilatation by reducing cell-matrix interactions via integrin shedding. ADAM12 may play an important role in myocardial hypertrophy. ADAM17 may regulate inflammation in the process of cardiac remodeling. In conclusion, disintegrin metalloproteinases may reflect an important new therapeutic target for the prevention of congestive heart failure.

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Disclosures
None.

References

CLINICAL PERSPECTIVE
Structural cardiac remodeling, particularly ventricular dilatation, is the hallmark of congestive heart failure. Hemodynamic unloading by mechanical assistance (left ventricular assist device) results in a reversal of structural remodeling in some patients. Defining the molecular mechanisms underlying structural cardiac remodeling and its reversal may result in novel therapeutic targets for the growing population of patients with heart failure. Altered interactions between cells and their interstitial (extracellular) matrix may play a key role in structural cardiac remodeling. Disintegrin metalloproteinases are a unique group of endogenous proteases capable of altering cell-surface matrix receptors (integrins). We examined human heart specimens with characteristic patterns of structural cardiac remodeling (dilated cardiomyopathy, hypertrophic cardiomyopathy, and nonfailing controls) and profiled the expression of disintegrin metalloproteinases, their endogenous inhibitor tissue inhibitor of metalloproteinases-3, and key integrin receptors. We obtained serial heart specimens from patients with dilated heart failure before and after left ventricular assist device support to explore “reverse remodeling.” We determined that disintegrin metalloproteinases are differentially expressed in human myocardium in a profile that reflects the underlying pattern of structural remodeling. Our data suggest that specific disintegrin metalloproteinases disrupt cell-matrix interactions and contribute to ventricular dilatation. Targeting disintegrin metalloproteinases, perhaps by inhibiting their activity with gene or cell-based therapies, may prevent progressive chamber dilatation and failure in human dilated cardiomyopathy.
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