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# **Assessment of Left Ventricular Diastolic Function with Three Dimensional Cardiac Magnetic Resonance Imaging**

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A thesis submitted in partial fulfilment of the requirements for the degree of  
Doctor of Philosophy at the University of Auckland



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I stand on the brink, on the edge of myself  
and wonder at All that is beyond me  
I am jealous of the Ocean and the Sky  
that do not seem to end;  
of the Universe itself  
that holds so much Immensity.

I seek to comprehend all knowledge,  
and I can't even know of all that has been written  
I am a finite creature  
but I ever struggle to hold within my grasp  
the mystery of being  
I want the power of knowing All,  
of seeing All,  
of having All

And I cannot even possess myself;  
I have thoughts and fears and hopes  
that I cannot often understand,  
nor more frequently admit  
I am not a comfortable creature  
Even my most cherished dreams I cannot make come true  
My heart cries out to me to be God!  
and my life shouts out that I am not!  
and my faith is based on the hope that  
Someone else is!

I am left with the experience  
that I exist beyond myself  
but cannot contain my source  
I am a grain of sand wanting to possess the ocean  
and the miracle of Love is that I can  
He has made me so small so that He can stretch me  
to Immensity  
He has made me so poor so He can fill me pressed down, and overflowing  
with his Richness  
He has made me so limited so that He can make me  
Boundless  
He has made me a creature  
so he can make me God.  
He has entered my heart and he has called me,  
'Home'

~ Edward J Farrell

# Abstract

Measurement of diastolic left ventricular (LV) function is vitally important in the assessment of cardiac disease. However, only limited information on tissue function can be obtained with current clinical techniques. This Thesis developed and investigated novel parameters of both global and regional myocardial function, using cardiac magnetic resonance imaging (MRI) with three-dimensional tissue tagging.

Multidirectional peak myocardial shortening strains and strain rates, as well as the peak systolic displacement and velocity of the mitral valve annulus plane (MVP), were considered as parameters of LV systolic function. The corresponding peak diastolic strain relaxation rates and peak diastolic MVP velocity were used to assess diastolic function. The effects of normal ageing were studied in people with no evidence of cardiac disease, and compared with the effects of disease in patients with type 2 diabetes mellitus (DM).

In normal healthy subjects, systolic strain parameters were preserved, while diastolic parameters were impaired, with age. DM patients showed impaired diastolic function on correction for age, and systolic functional parameters were also impaired, even though LV ejection fraction was normal. MVP systolic and diastolic motion were reduced both with age and in DM patients. Systolic LV torsion was increased with age and in DM, with no corresponding increase in torsional relaxation. Both systolic and diastolic function parameters were regionally heterogeneous. With normal ageing, diastolic function was impaired in a regionally non-uniform manner.

Thus, a complete assessment of LV function requires measurement of LV tissue mechanics as well as chamber haemodynamics. MRI provides valuable information regarding myocardial tissue behaviour, contributing to systolic and/or diastolic dysfunction, which cannot be obtained otherwise. Systolic tissue dysfunction may develop concomitantly in patients with diastolic dysfunction, even when global ejection fraction is preserved. Regional analyses provide important information on how local changes contribute to global function. The influence of age must be taken into account in studies of disease.

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## List of Publications

The following publications have arisen from work done as part of this Thesis:

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Fonseca CG, Oxenham HC, Cowan BR, Occleshaw CJ, Young AA. Ageing Alters Patterns of Regional Non-Uniformity in LV Strain Relaxation: A 3D MR Tissue Tagging Study. *American Journal of Physiology – Heart and Circulatory Physiology*. 2003, 285(2):H621-H630. (Chapter 3).



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## List of Abbreviations

%SC	percent circumferential shortening strain
%SL	percent longitudinal shortening strain
$\alpha_{CL}$	torsion angle (also ' $\alpha$ ')
3D	three dimensional; in three dimensions
A	late diastolic transmitral flow velocity (due to atrial contraction) measured by Doppler echocardiography
A'	late diastolic mitral annular velocity measured by tissue Doppler imaging
AFP	echocardiographic abnormal filling pattern
ANCOVA	analysis of covariance (statistical)
ANOVA	analysis of variance (statistical)
ATP	adenosine triphosphate
B <sub>0</sub>	magnetic field
BMI	body mass index
BP	blood pressure
BSA	body surface area
DBP	diastolic blood pressure
DENSE	displacement encoding with stimulated echoes (in cardiac magnetic resonance imaging)
DM	diabetes mellitus
E	early diastolic transmitral flow velocity measured by Doppler echocardiography
<i>E</i>	Lagrangian strain tensor
E'	early diastolic mitral annular velocity measured by tissue Doppler imaging
E:A	ratio of early to late transmitral flow velocity measured by Doppler echocardiography
ECG	electrocardiogram
ED	end-diastole
EDV	end-diastolic volume
EF	ejection fraction
e.g.	<i>exempli gratia (Latin)</i> : for example
ES	end-systole
ESV	end-systolic volume
FEM	finite element model
FID	free induction decay
FLASH	fast low angle shot

---

HARP	harmonic phase
HbA1c	haemoglobin A1c;
HR	heart rate
i.e.	<i>id est (Latin)</i> : that is
LV	left ventricle; left ventricular
MANOVA	multivariate analysis of variance (statistical)
mm Hg	millimetres of mercury
MR	magnetic resonance
MRI	magnetic resonance imaging
MVP	mitral valve (annulus) plane
$n$	sample size (statistical)
NC	normal control
NMR	nuclear magnetic resonance
NS	non-significant (statistical)
$P$	P-value; probability (statistical)
$P^B$	Bonferroni corrected P-value (statistical)
PFP	echocardiographic pseudonormal filling pattern
PWD	echocardiographic pulsed wave Doppler recording
$r$	correlation coefficient (statistical)
RAAS	renin-angiotensin-aldosterone system
$R_C$	peak rate of relaxation of circumferential shortening strain
RF	radiofrequency
$R_L$	peak rate of relaxation of longitudinal shortening strain
ROC	receiver operator curve analysis (statistical)
$R_P$	peak rate of relaxation of principal shortening strain
$R_T$	peak rate of relaxation of torsional shear strain
SBP	systolic blood pressure
$S_C$	peak value of circumferential shortening strain
$S_L$	peak value of longitudinal shortening strain
$S_m$	systolic mitral annular velocity measured by echocardiography
$S_P$	peak value of principal shortening strain
SPAMM	spatial modulation of magnetization
SR	strain rate
SRI	strain rate imaging
$SSR_C$	peak systolic circumferential strain rate
$SSR_L$	peak systolic longitudinal strain rate
$SSR_P$	peak systolic principal strain rate
$SSR_T$	peak systolic torsional shear strain rate
$S_T$	peak value of torsion
SV	stroke volume
T	tesla
$T_1$	$T_1$ Relaxation time
$T_2$	$T_2$ Relaxation time
TDI	tissue Doppler imaging

---

TE	echo time
TR	repetition time
tR <sub>C</sub>	time from end-diastole to peak rate of relaxation of circumferential shortening strain
tR <sub>L</sub>	time from end-diastole to peak rate of relaxation of longitudinal shortening strain
tR <sub>T</sub>	time from end-diastole to peak rate of recovery of torsion
tS <sub>C</sub>	time from end-diastole to peak circumferential shortening strain
tS <sub>L</sub>	time from end-diastole to peak longitudinal shortening strain
tS <sub>T</sub>	time from end-diastole to peak torsion
viz	videlicet; that is to say; namely
vs.	versus; as opposed to