Computationally Efficient Formal Optimization of Regional Myocardial Contractility

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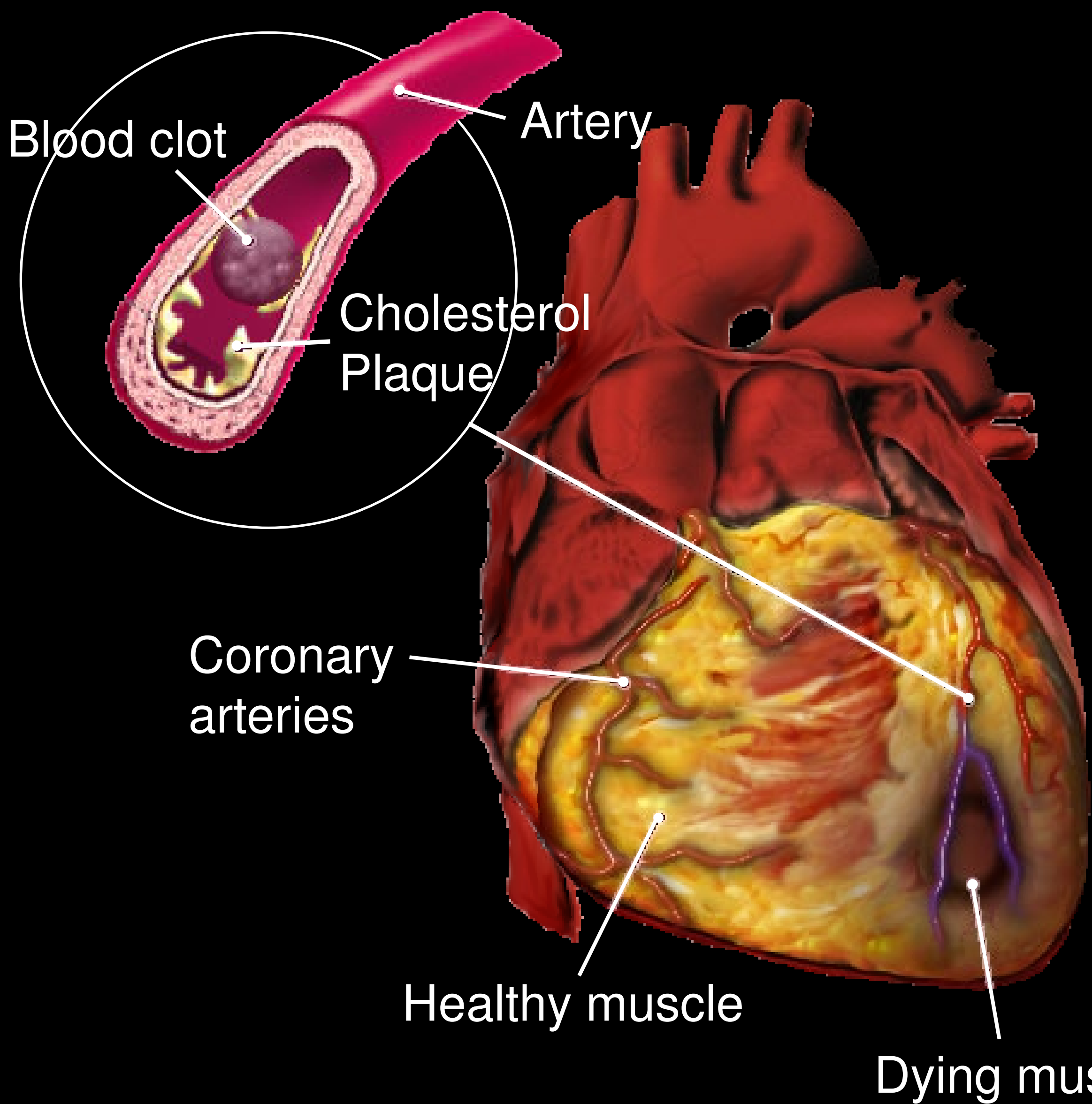
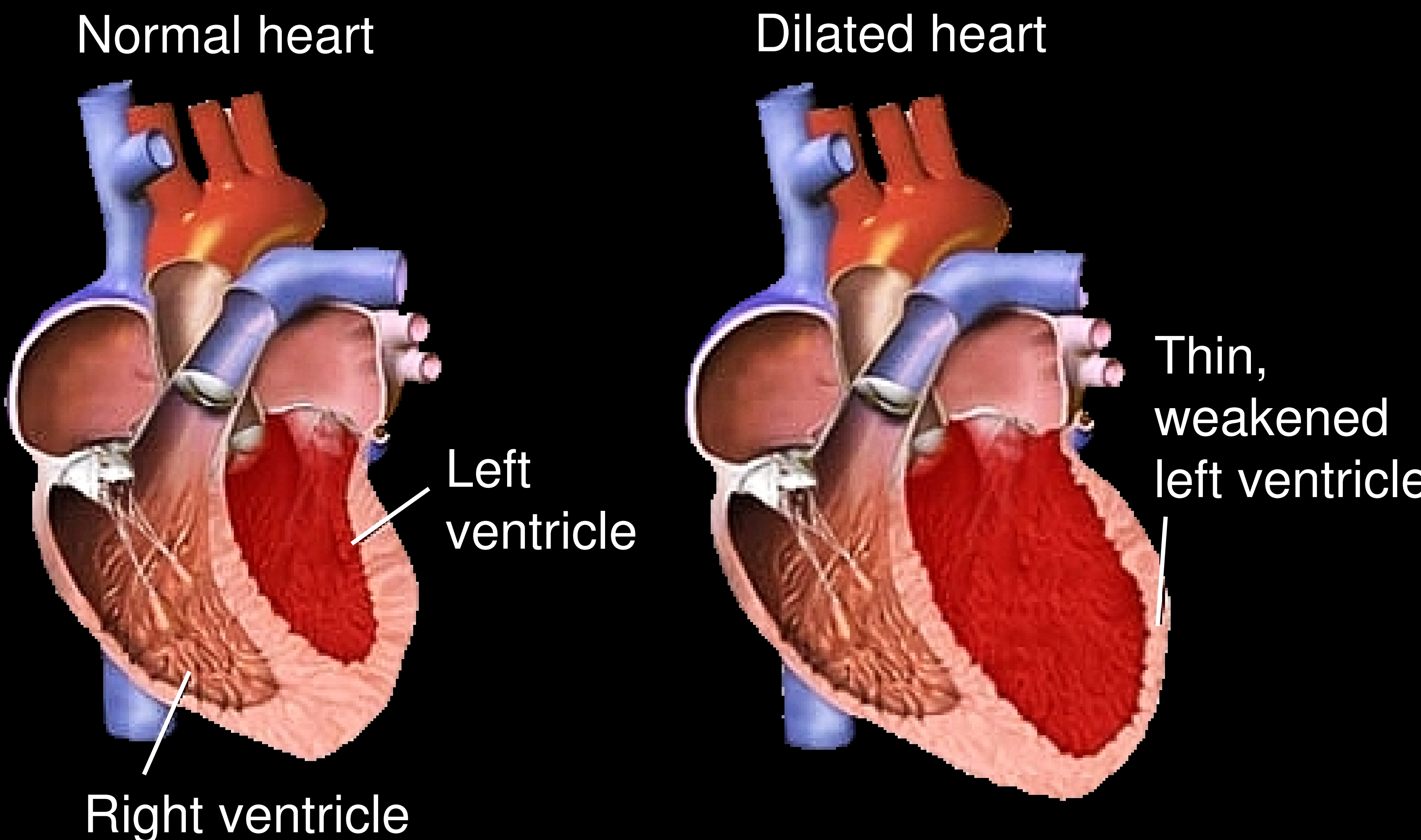
Myocardial Infarction



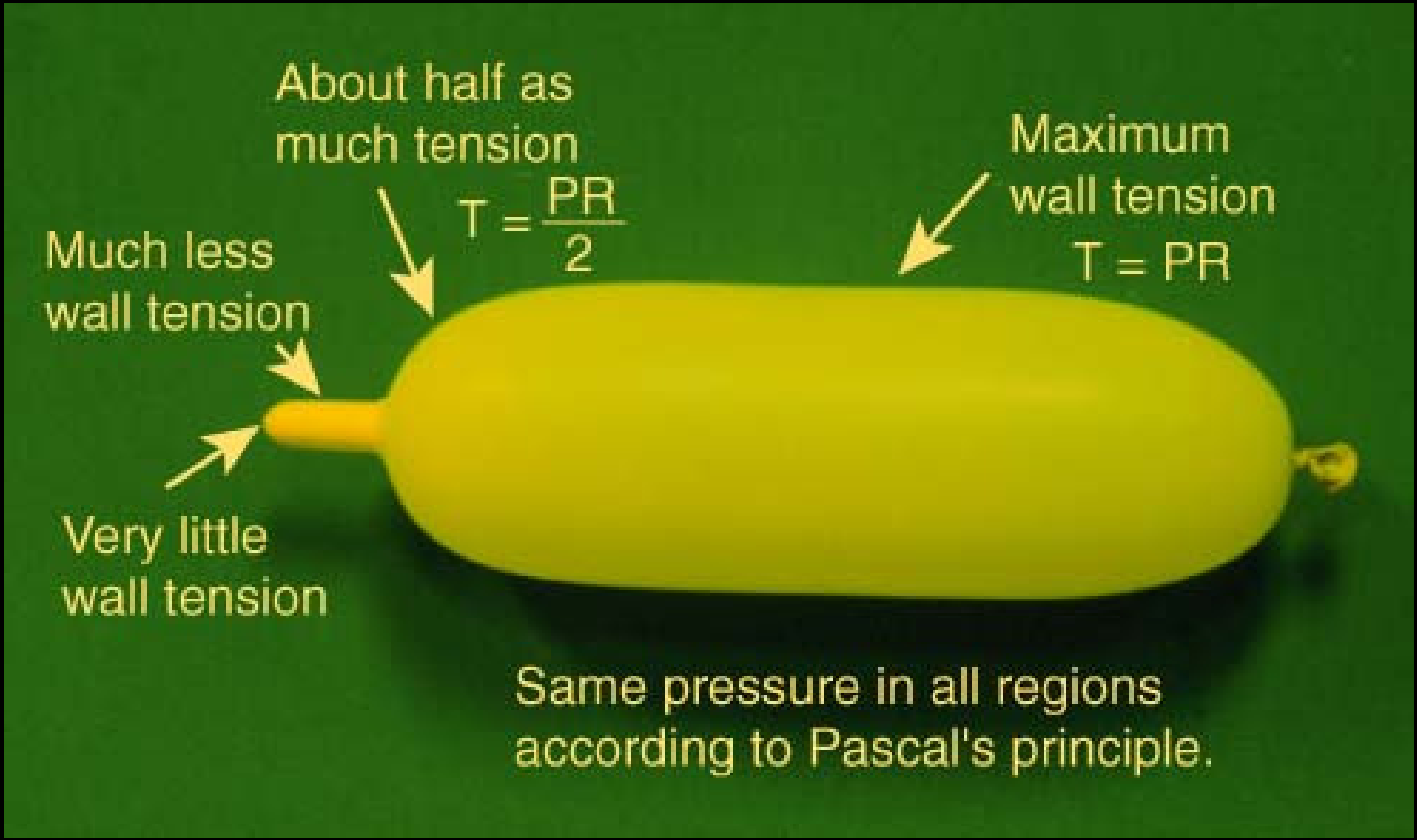
http://www.medicinenet.com

Congestive Heart Failure



http://www.medmarketplace.com

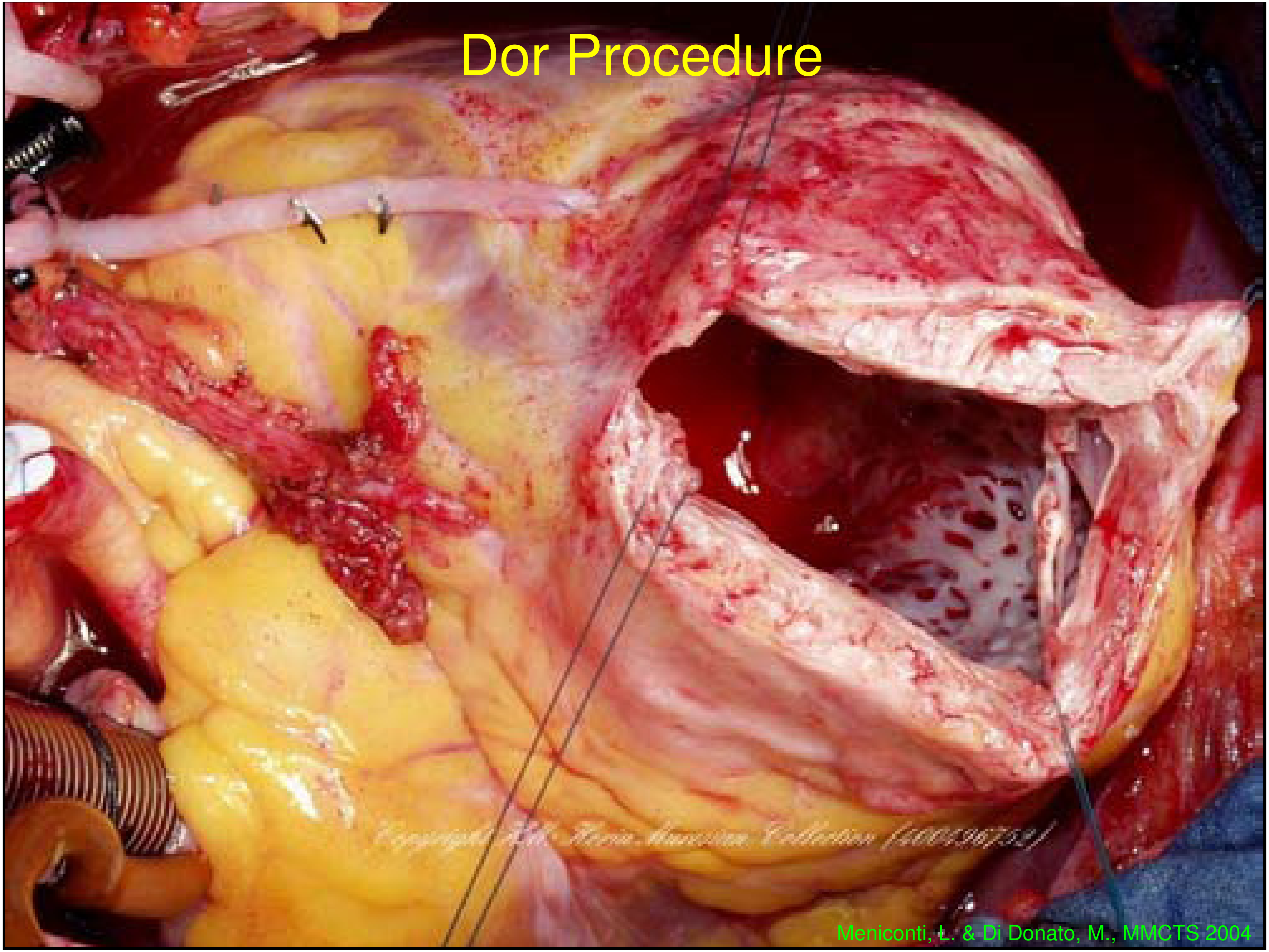
LaPlace's Law



http://hyperphysics.phy-astr.gsu.edu

Ventricular remodeling surgery reduces the size of the failing, enlarged heart so that blood is more efficiently pumped out of the heart to rest of the body

Dor Procedure

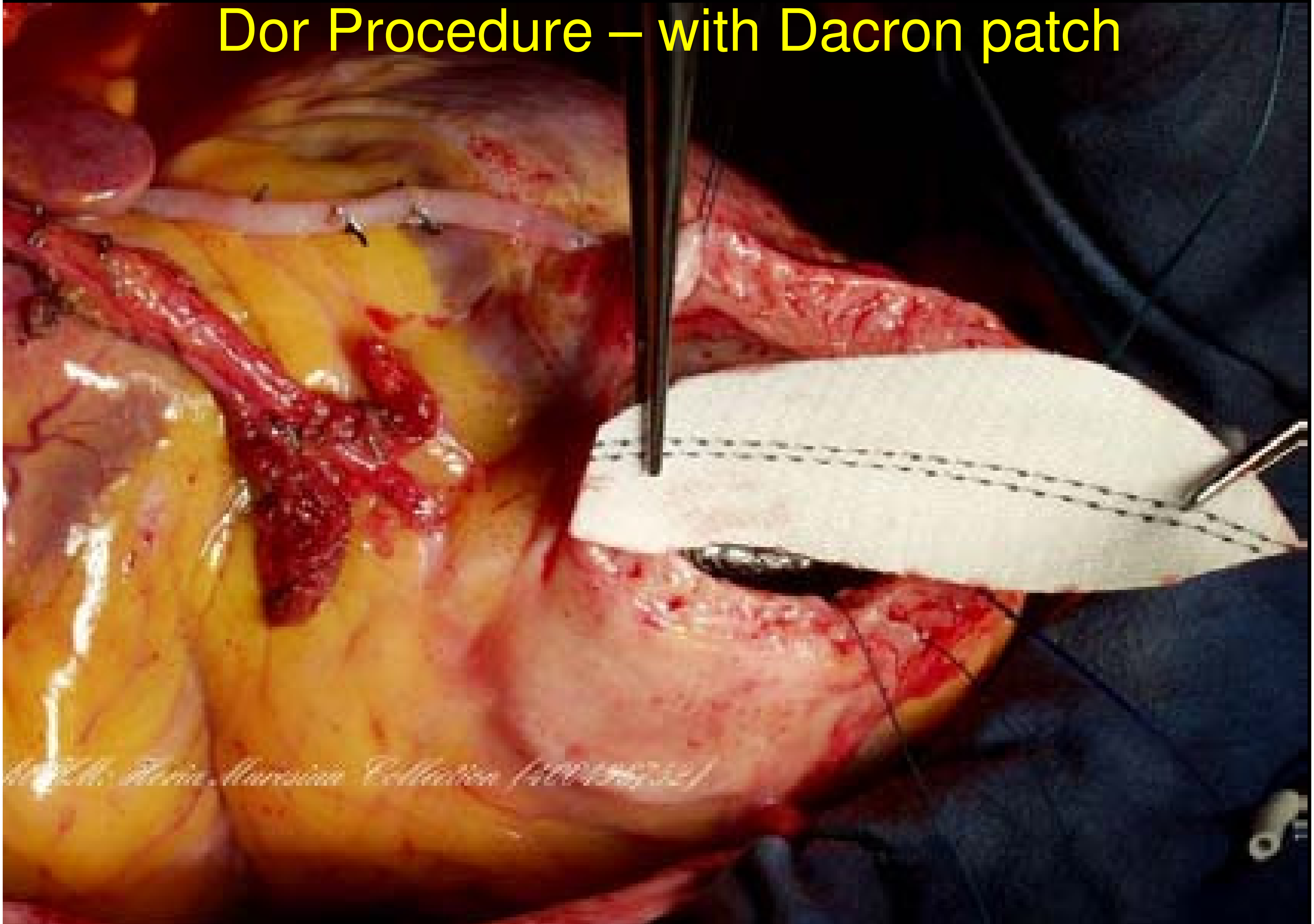


Meniconti, L. & Di Donato, M., MMCTS 2004

Dor Procedure – no patch

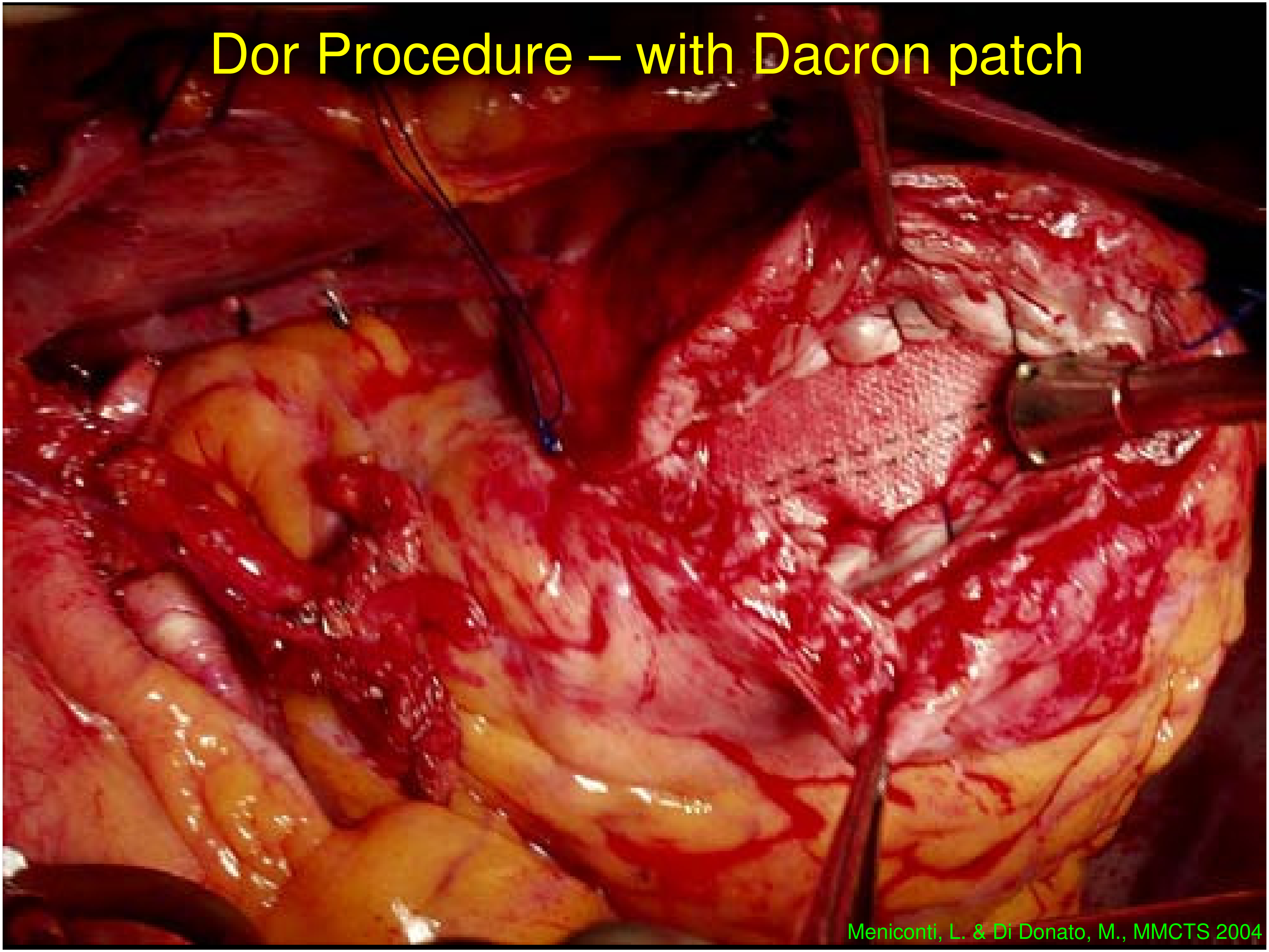
http://www.clevelandclinic.org

Dor Procedure – with Dacron patch



Meniconti, L. & Di Donato, M., MMCTS 2004

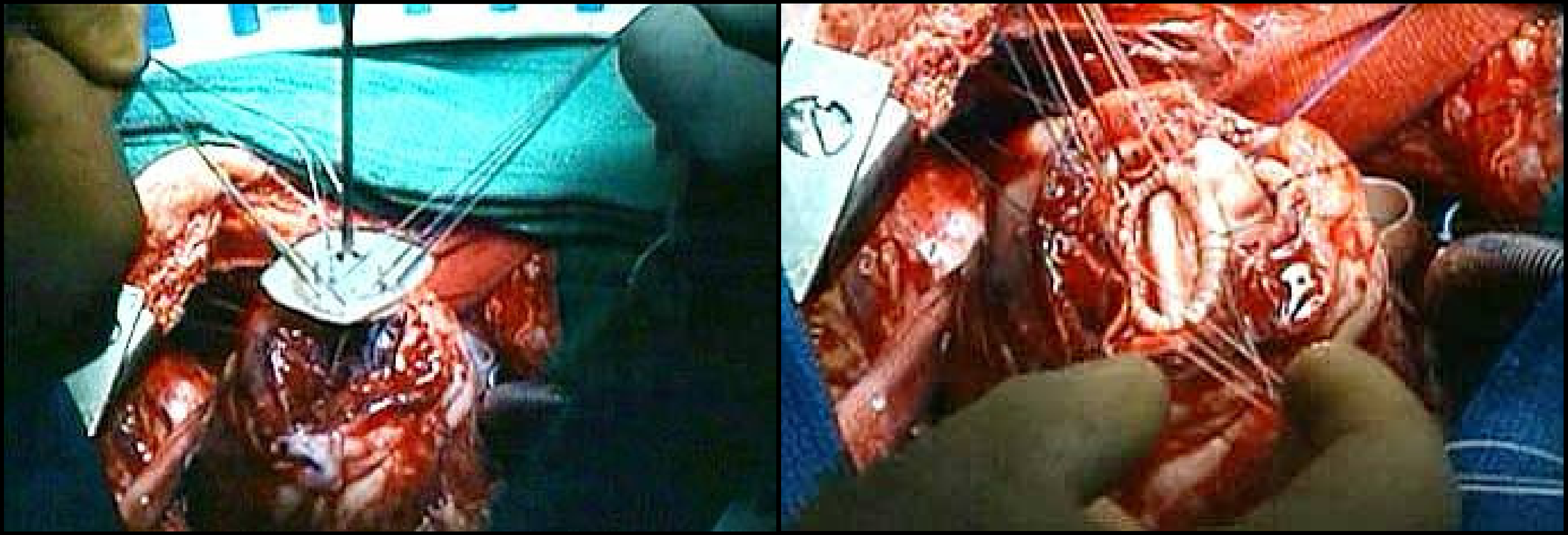
Dor Procedure – with Dacron patch



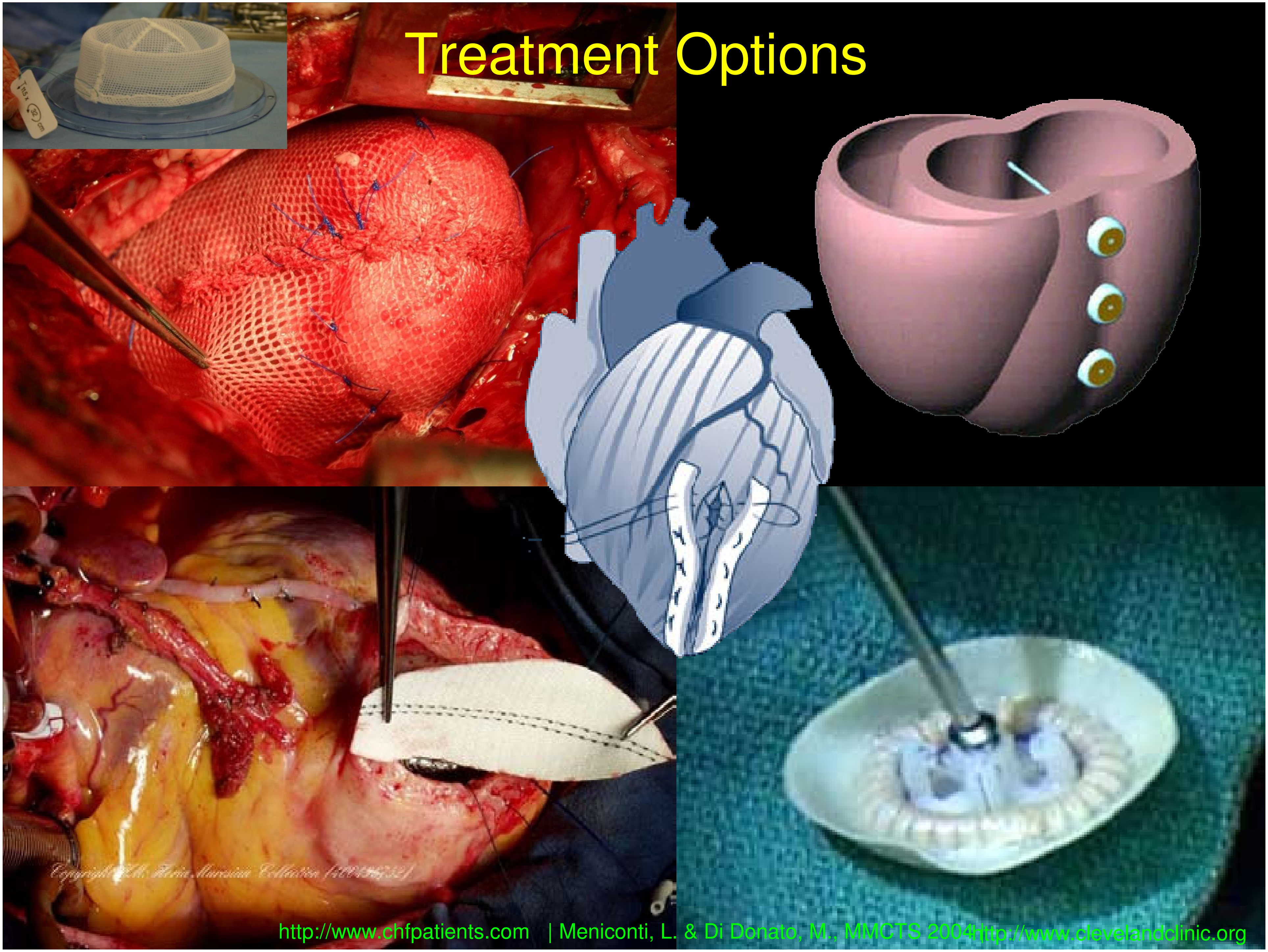
Meniconti, L. & Di Donato, M., MMCTS 2004

Dor Procedure – with CorRestore Patch

Dor Procedure – with CorRestore Patch



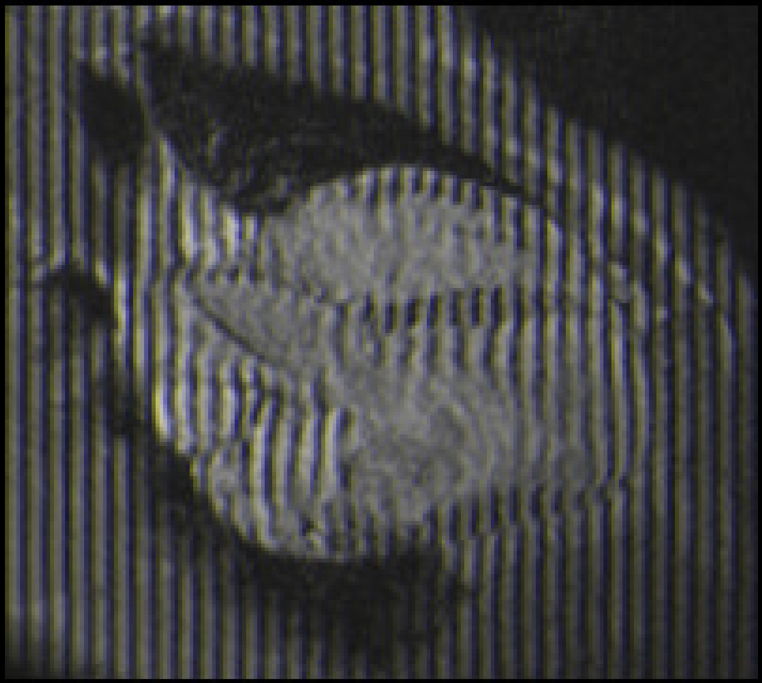
Treatment Options



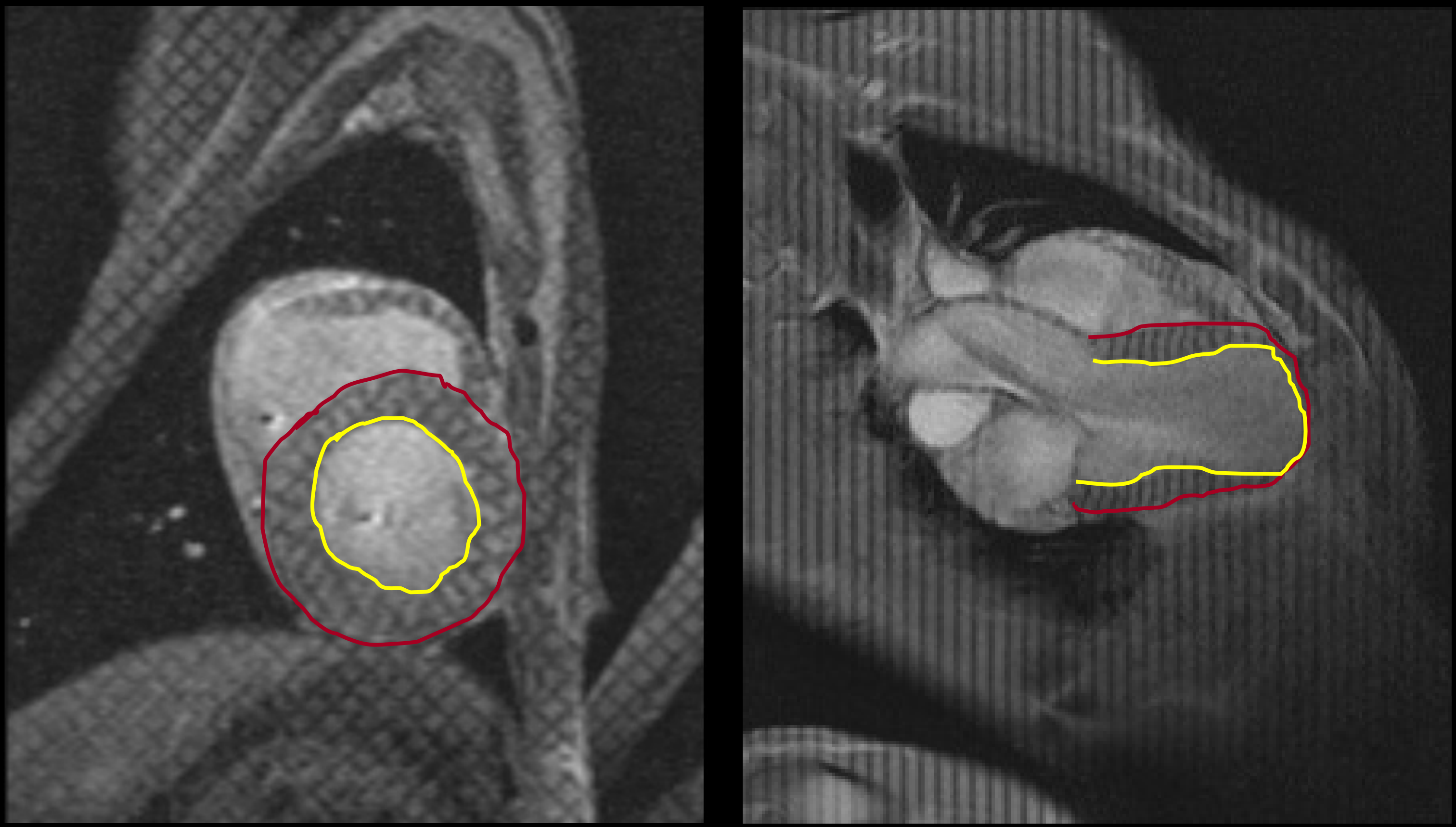
http://www.chfpatients.com | Meniconti, L. & Di Donato, M., MMCTS 2004http://www.clevelandclinic.org

Creation of patient - specific virtual tools to evaluate ventricular remodeling procedures for surgical planning

Geometry from MRI

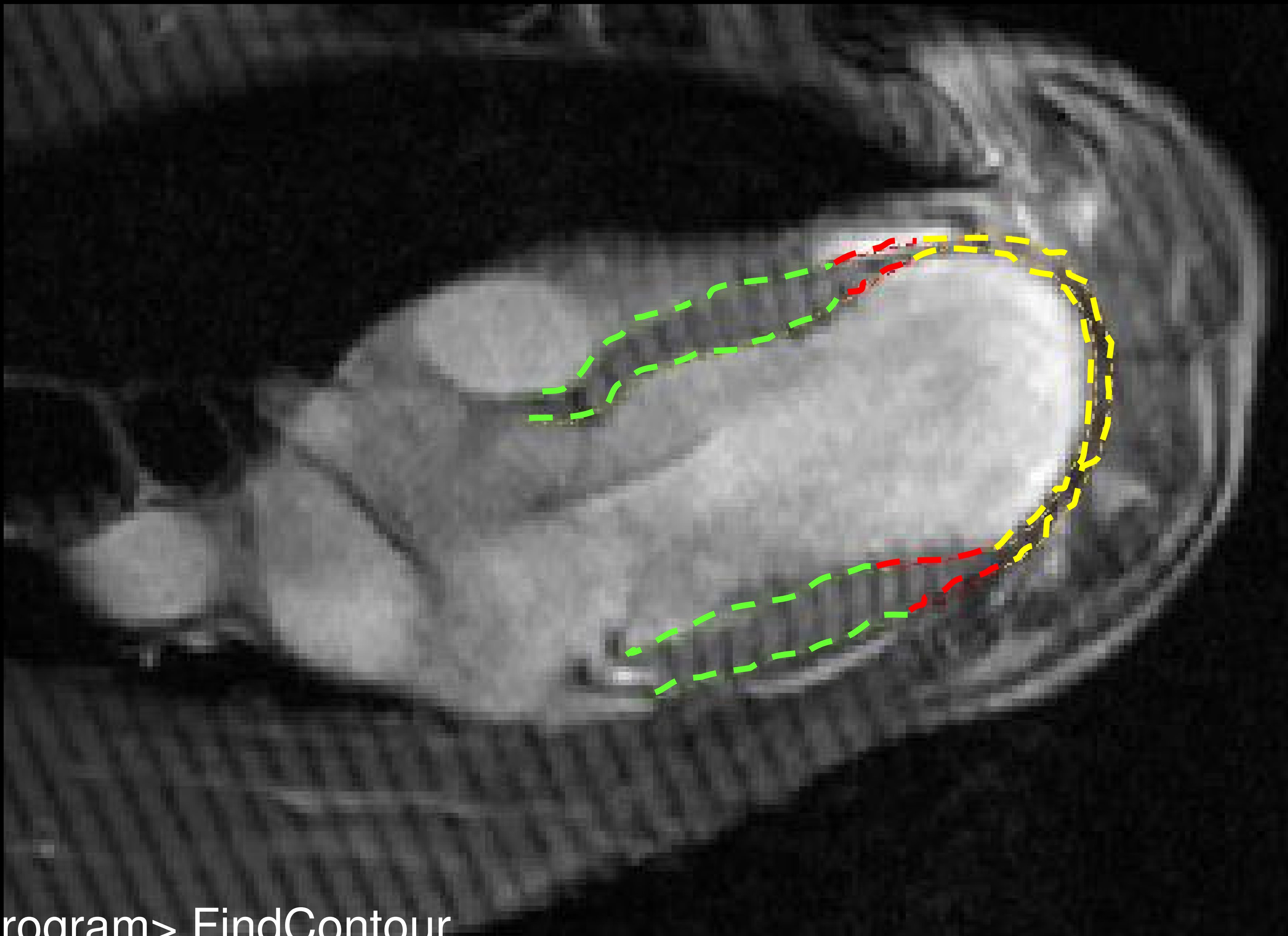


Geometry from MRI



Program> FindTags

Definition of Infarct Area



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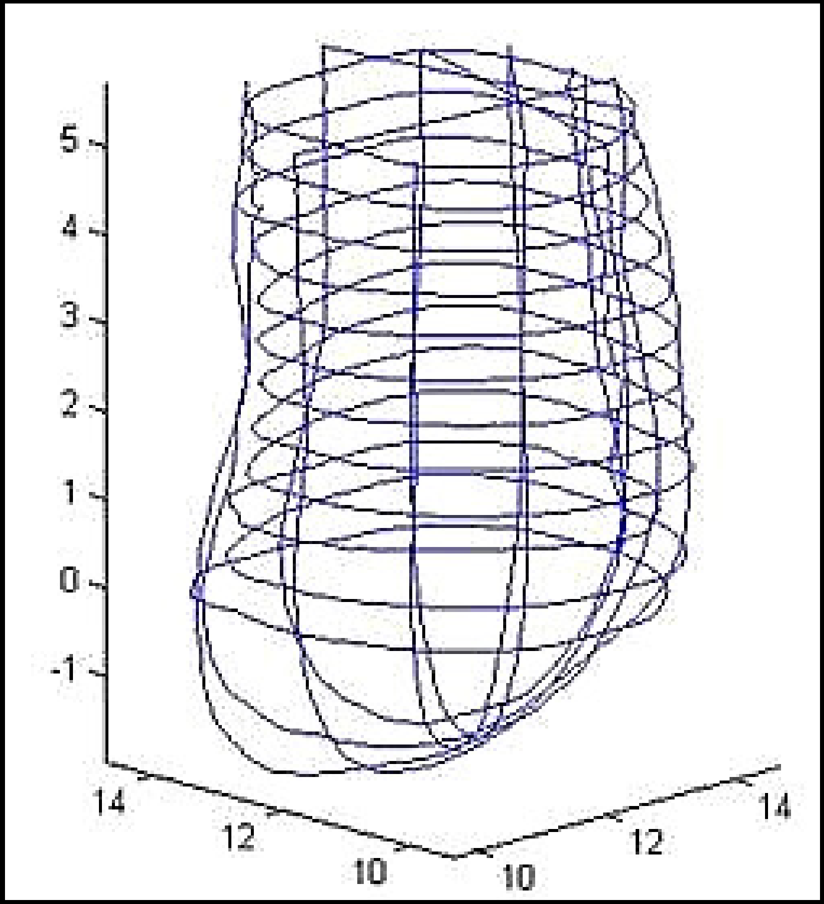
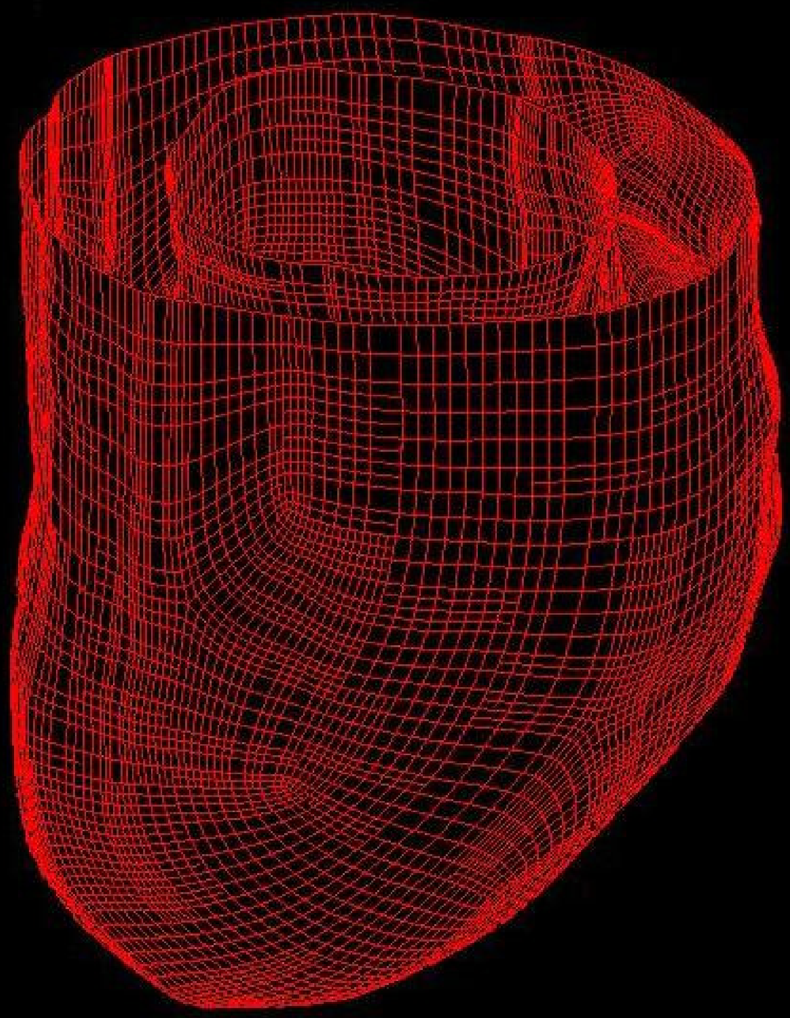
Wireframe

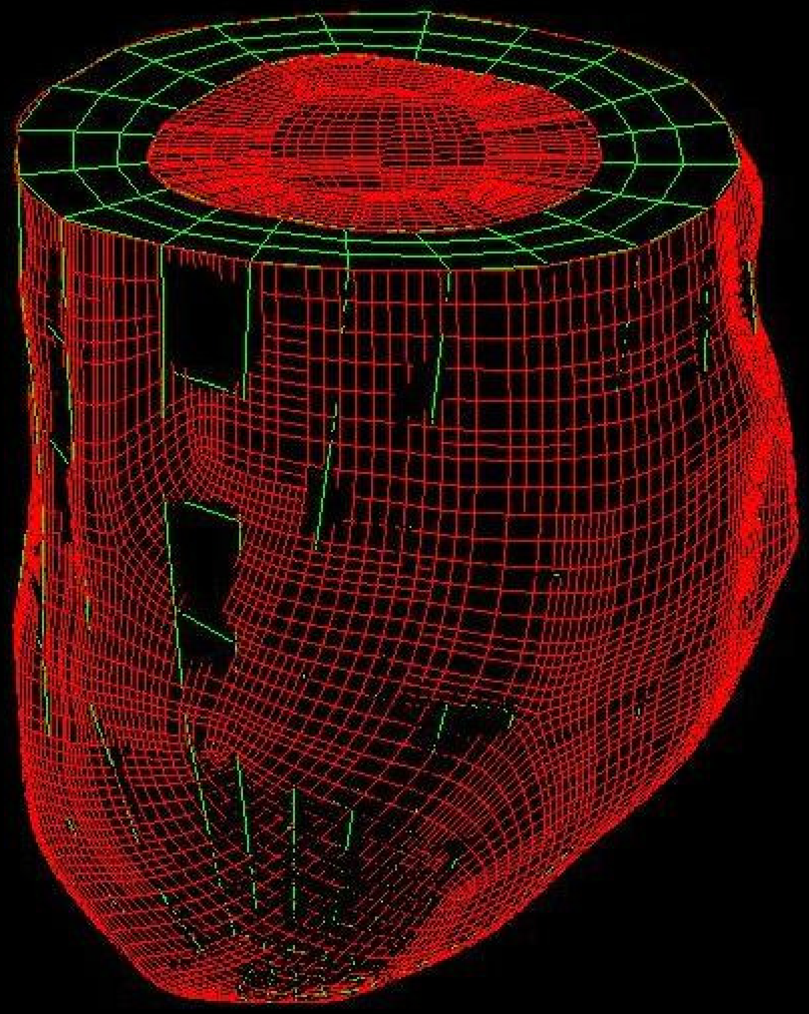


Surface Mesh



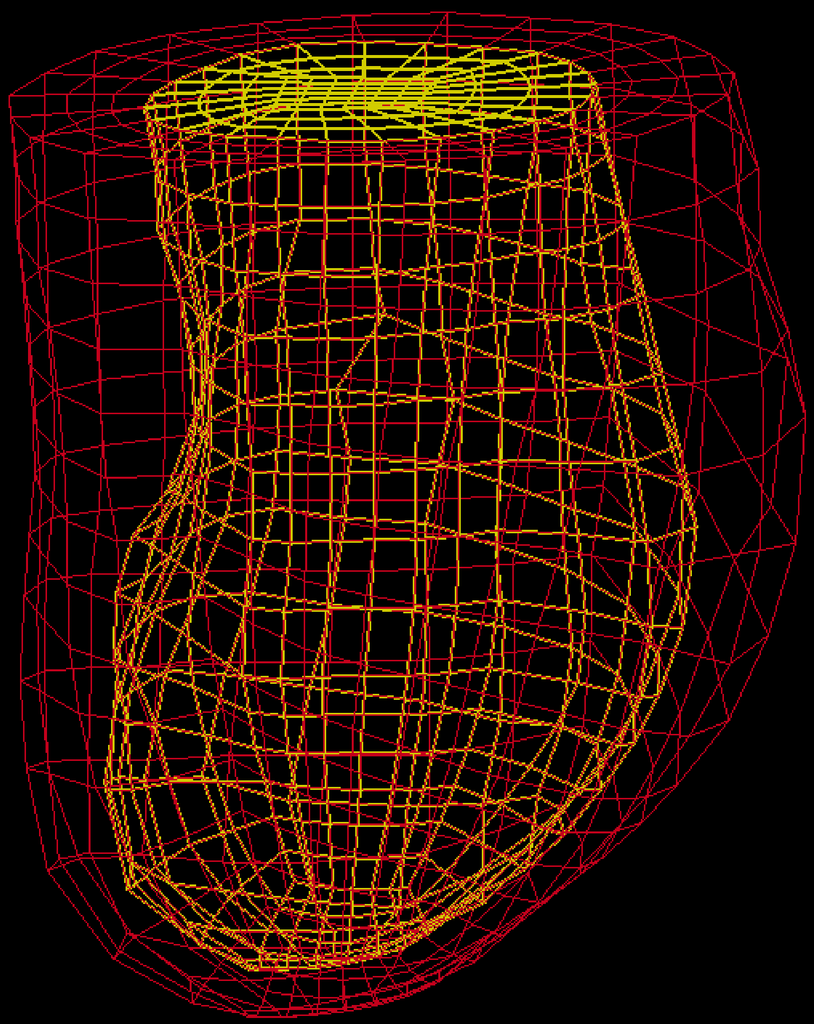
Program> Rapidform

Volume Mesh & Surface Mesh



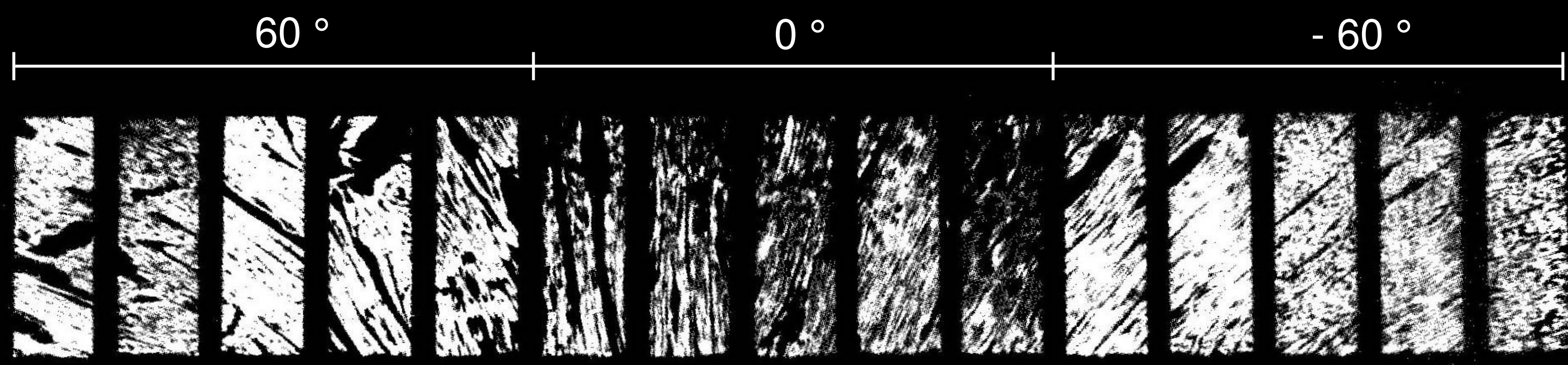
Program> Truegrid

Volume Mesh



Program> Truegrid

Muscle Fiber Direction



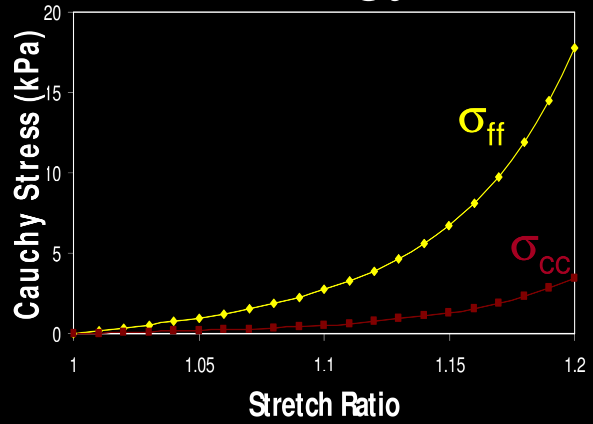
Streeter Jr., D. & Hanna, W. , Circ. Res. 1973

Cardiac Mechanics

Deformation gradient, F from LSDYNA

Green's strain: $$E = \frac{1}{2}\left(F^T F - I\right)$$

Strain energy function: $$W = \frac{1}{2} c \left(e^Q - 1\right)$$



$$Q = b_f E_{ff}^2 + b_t\left(E_{cc}^2 + E_{rr}^2 + E_{cr}^2 + E_{rc}^2\right) + b_{fs}\left(E_{fc}^2 + E_{cf}^2 + E_{fr}^2 + E_{rf}^2\right)$$

2nd Piola Kirchoff stress: $$S_{diastole} = \frac{\partial W}{\partial E}$$

Program> LSDYNA

Walker, J., et al., Am J Physiol heart Circ Physiol 2005

Active contraction

Yes:

$$S_{systole} = S_{systole}\left(T_{\max}, E_{ff}\right)$$

No:

$$S_{systole} = 0$$

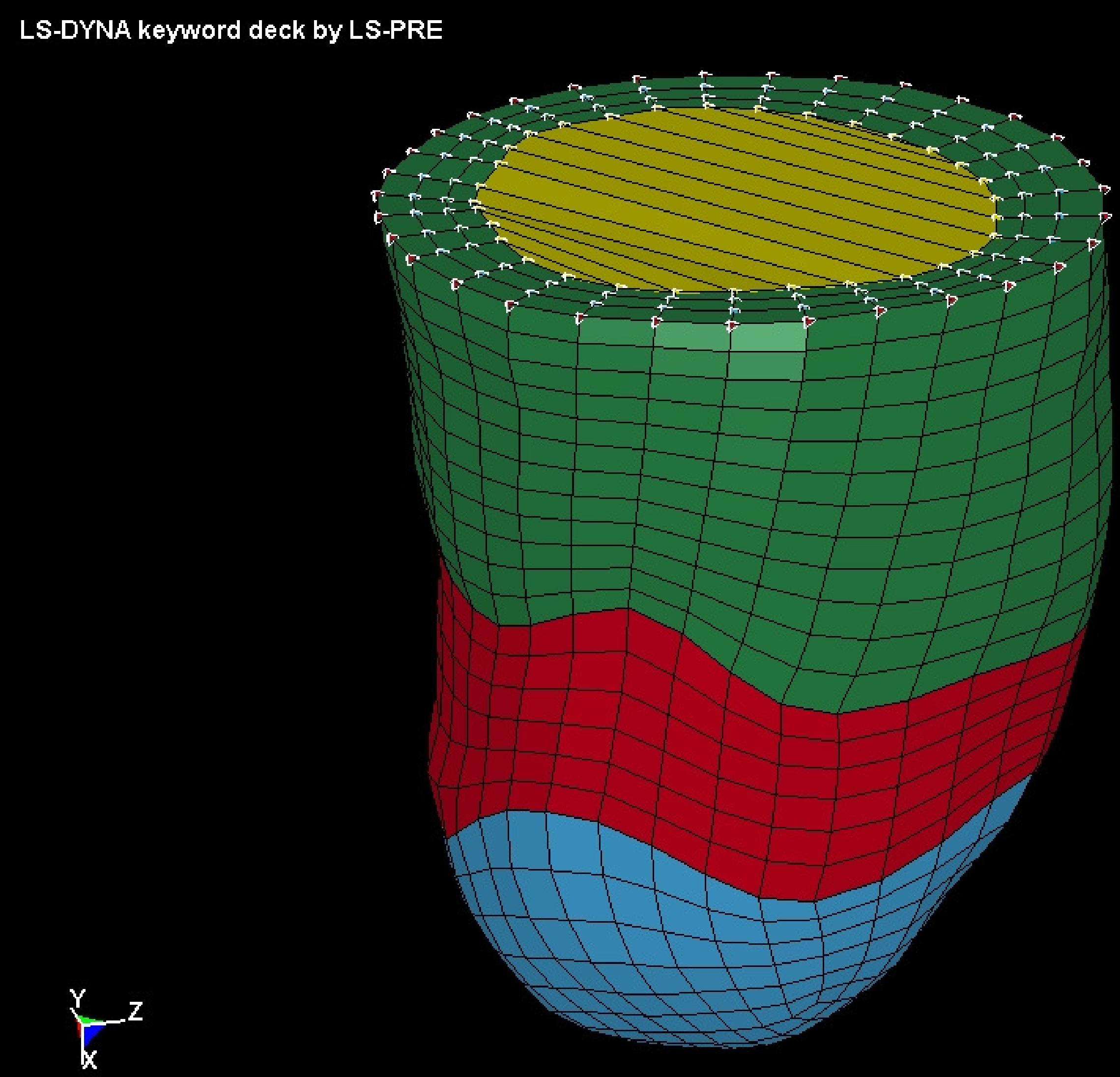
2nd Piola Kirchoff stress: $S_{total} = S_{diastole} + S_{systole}$

Cauchy stress: $\sigma = \frac{1}{J} F^{T} S_{total} F$

Program> LSDYNA

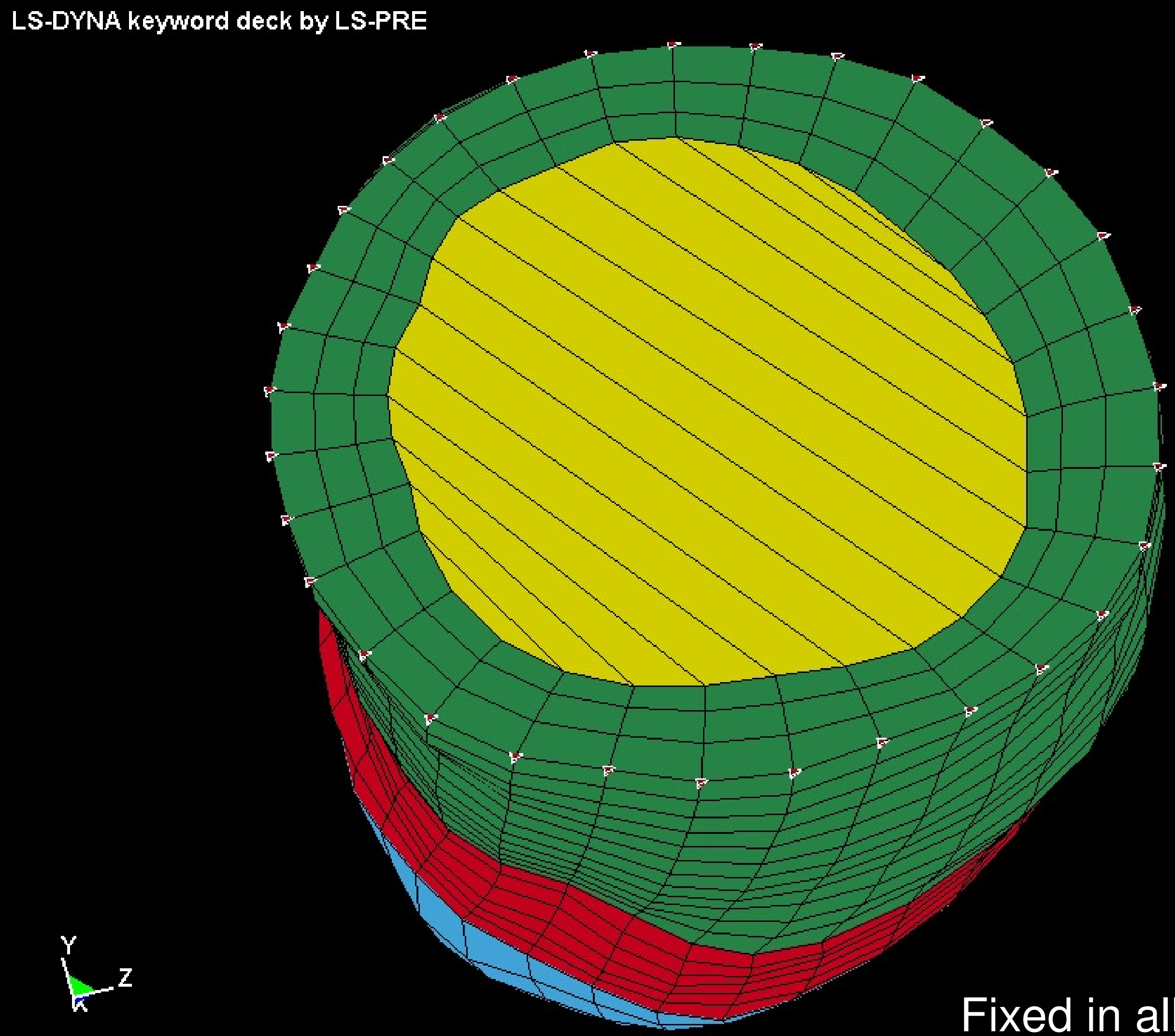
Walker, J., et al., Am J Physiol Heart Circ Physiol 2005

Boundary Conditions



Program> LSDYNA

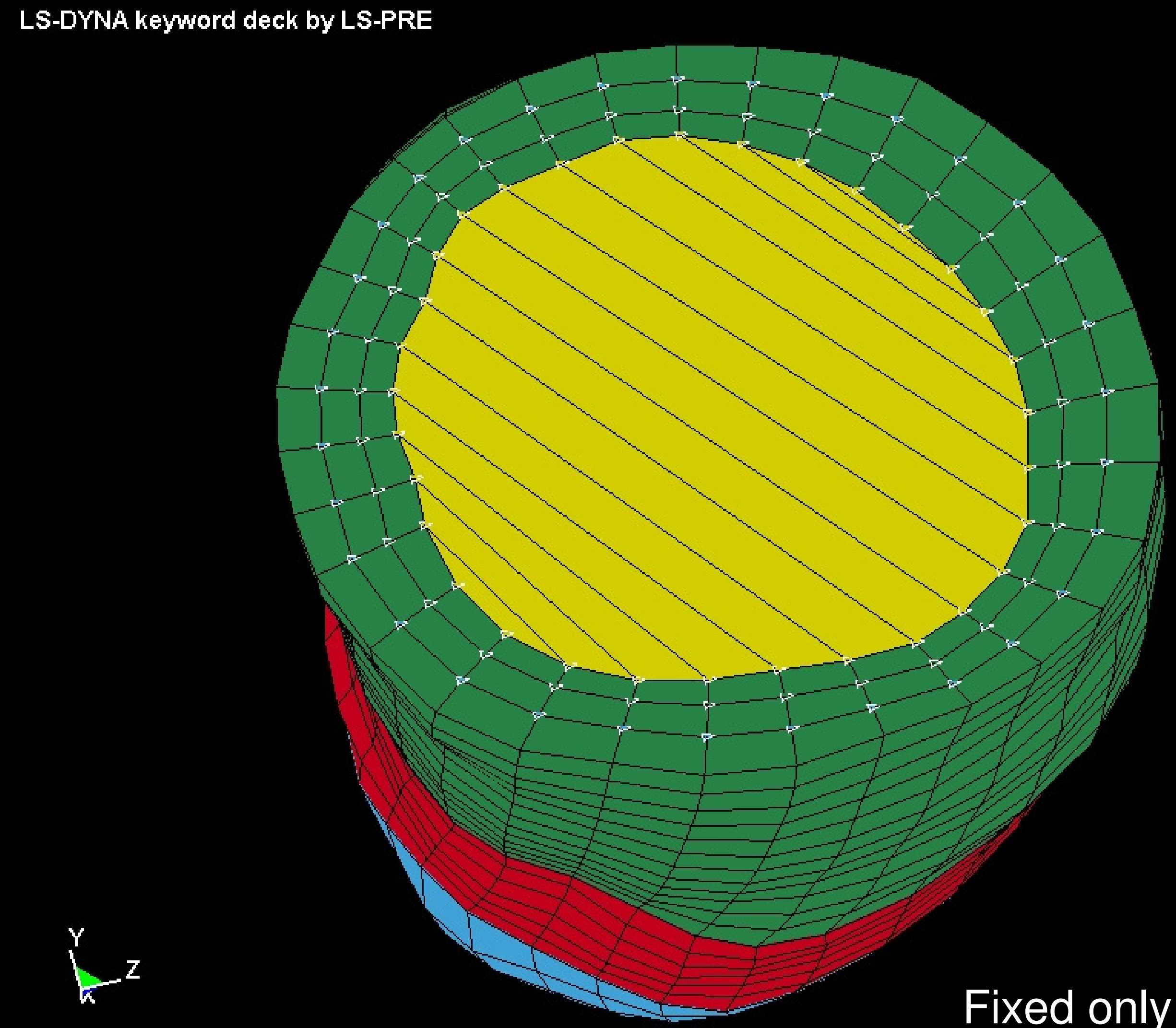
Boundary Conditions



Fixed in all directions

Program> LSDYNA

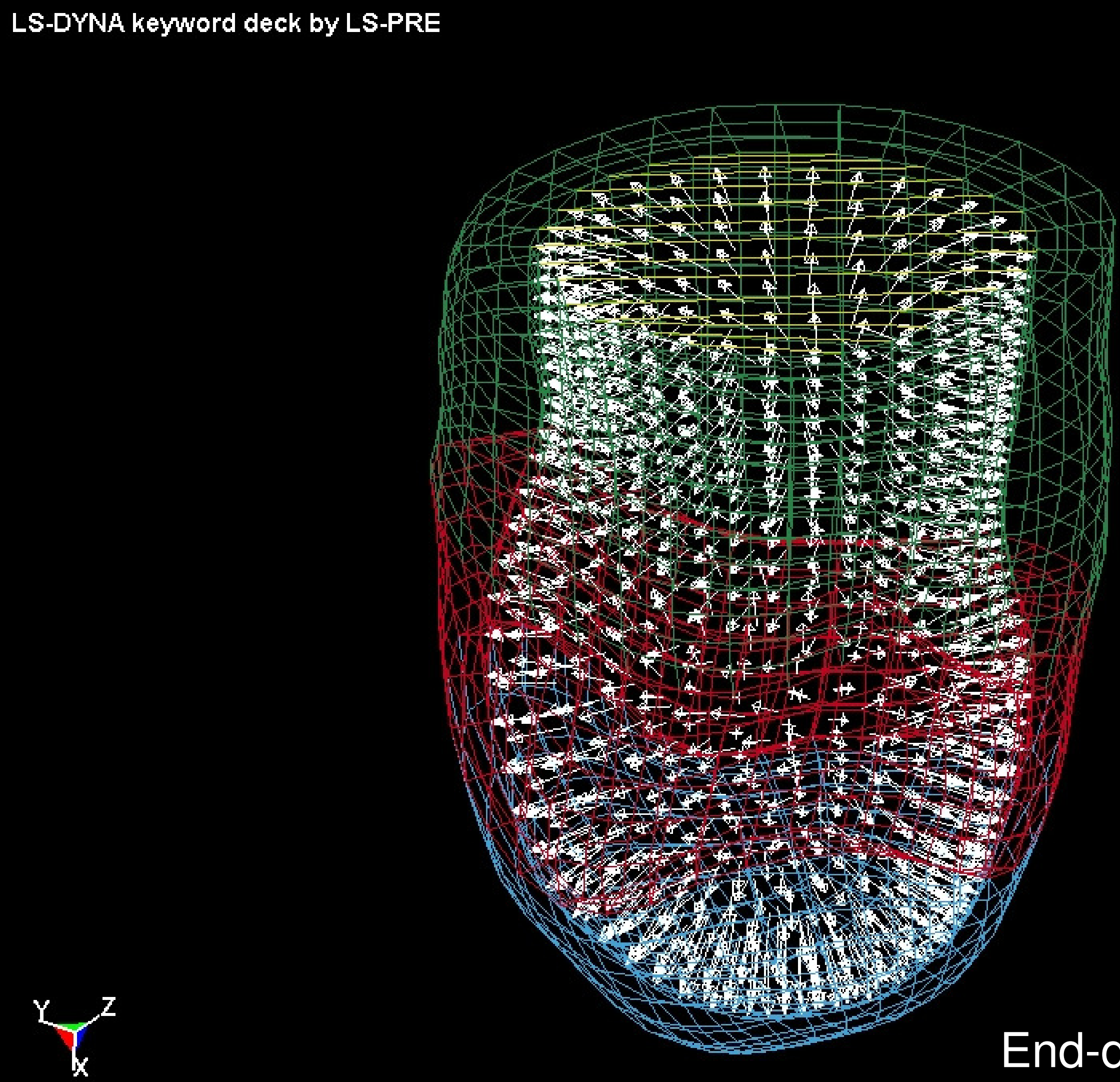
Boundary Conditions



Fixed only in longitudinal direction

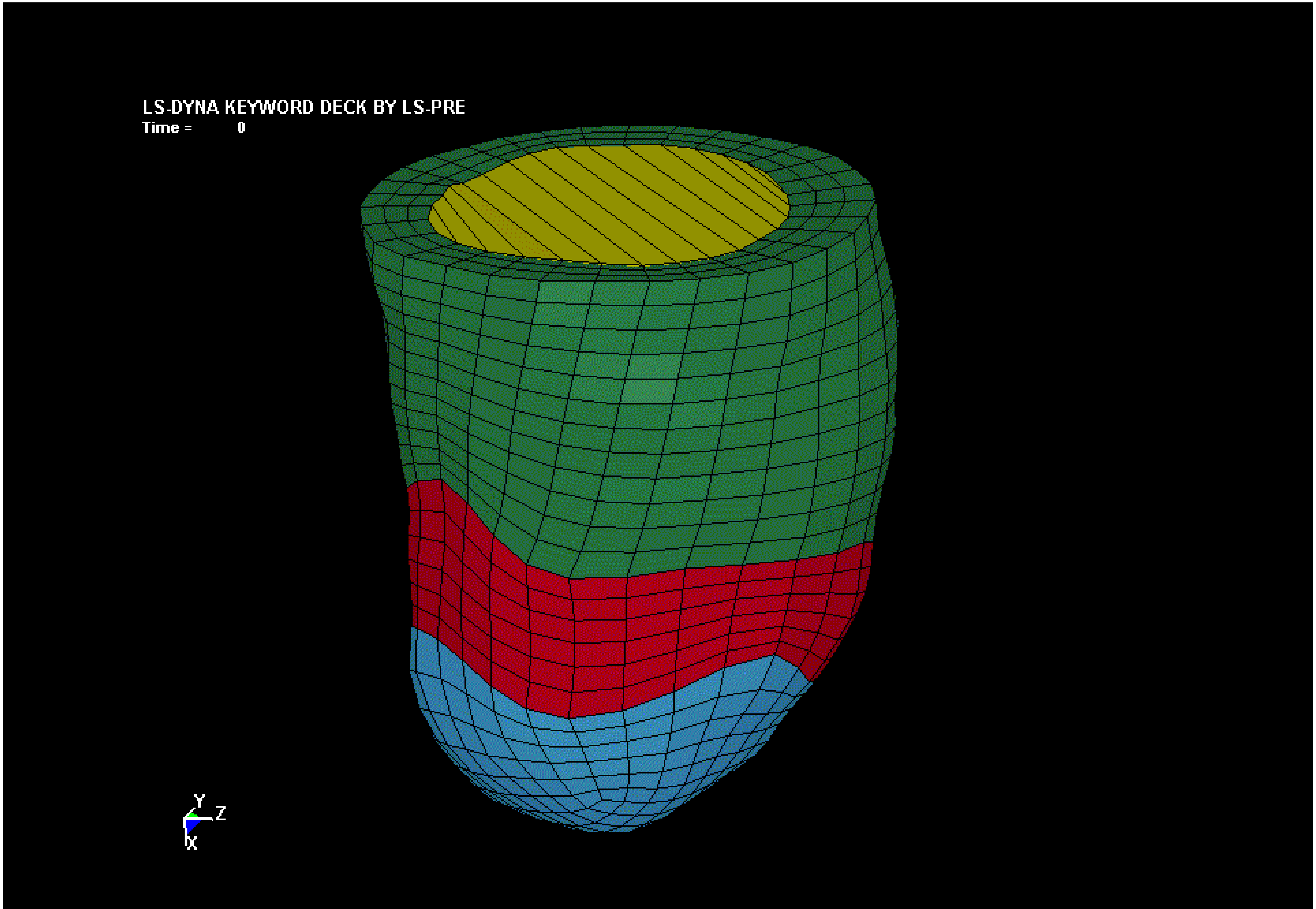
Program> LSDYNA

Loading Conditions



End-diastolic (filling) pressure
End-systolic (ejection) pressure

Program> LSDYNA



Program> LSDYNA

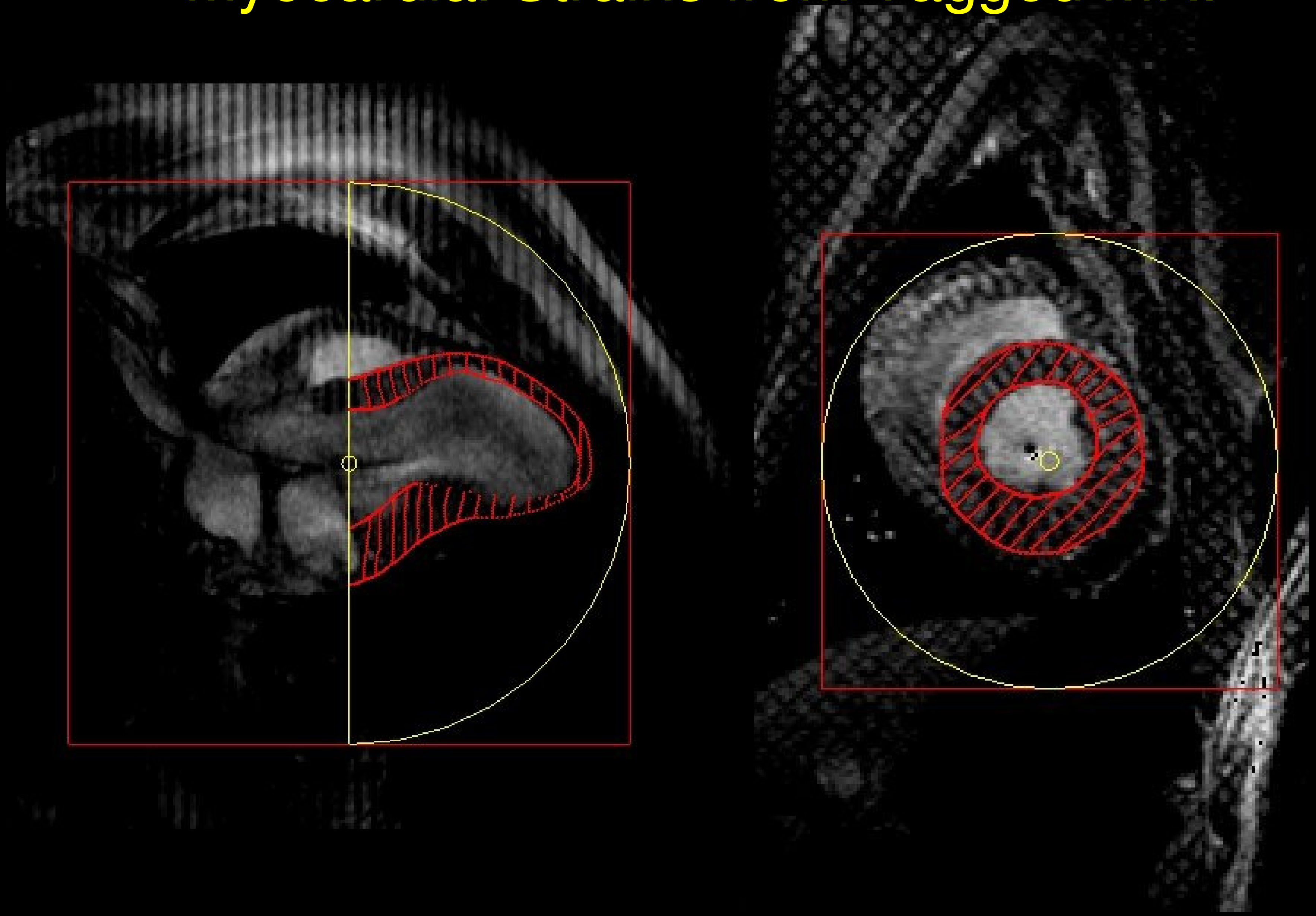
Geometry

Mechanics

Material Parameters
(c, b_f, b_t, b_{fs}, T_{max})

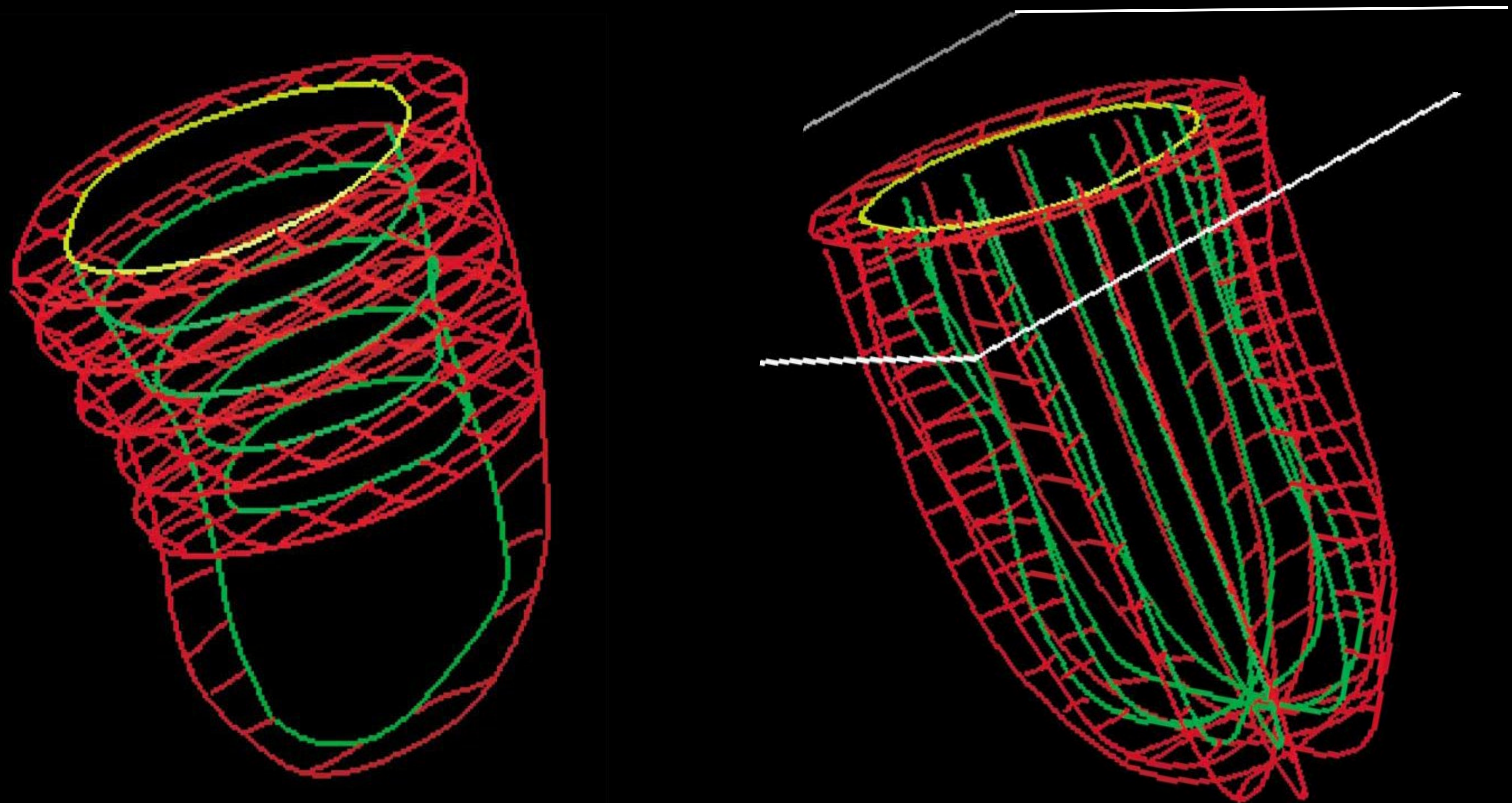
Ventricular motion
(strains,
end-diastolic volume,
end-systolic volume)

Myocardial Strains from Tagged MRI



Program> FindTags

Myocardial Strains from Tagged MRI



Program> FindTags

Guccione, J., et al., J. Thorac Cardiovas Surg 2006

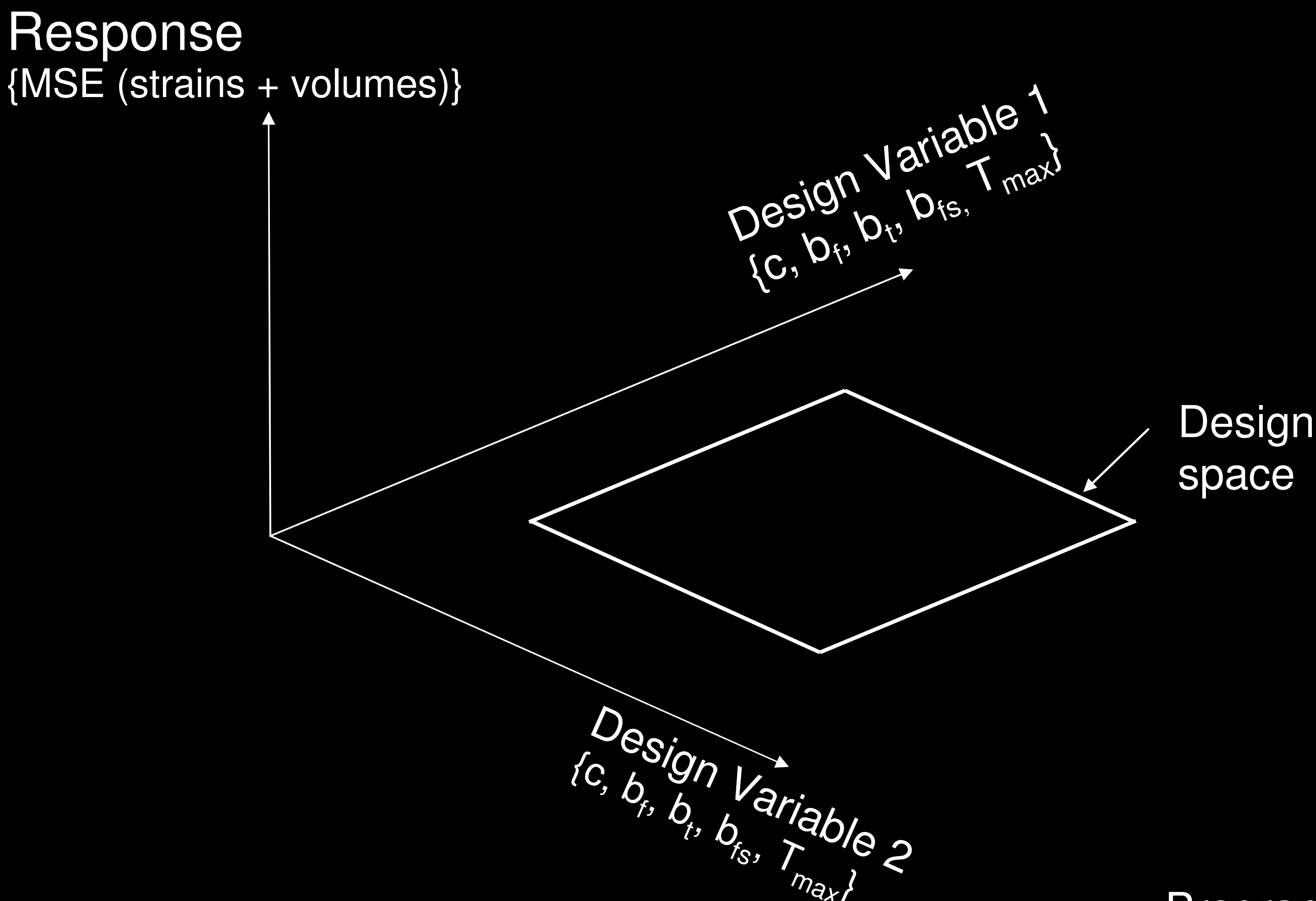
Geometry

Mechanics

Material Parameters
$(c, b_f, b_t, b_{fs}, T_{max})$

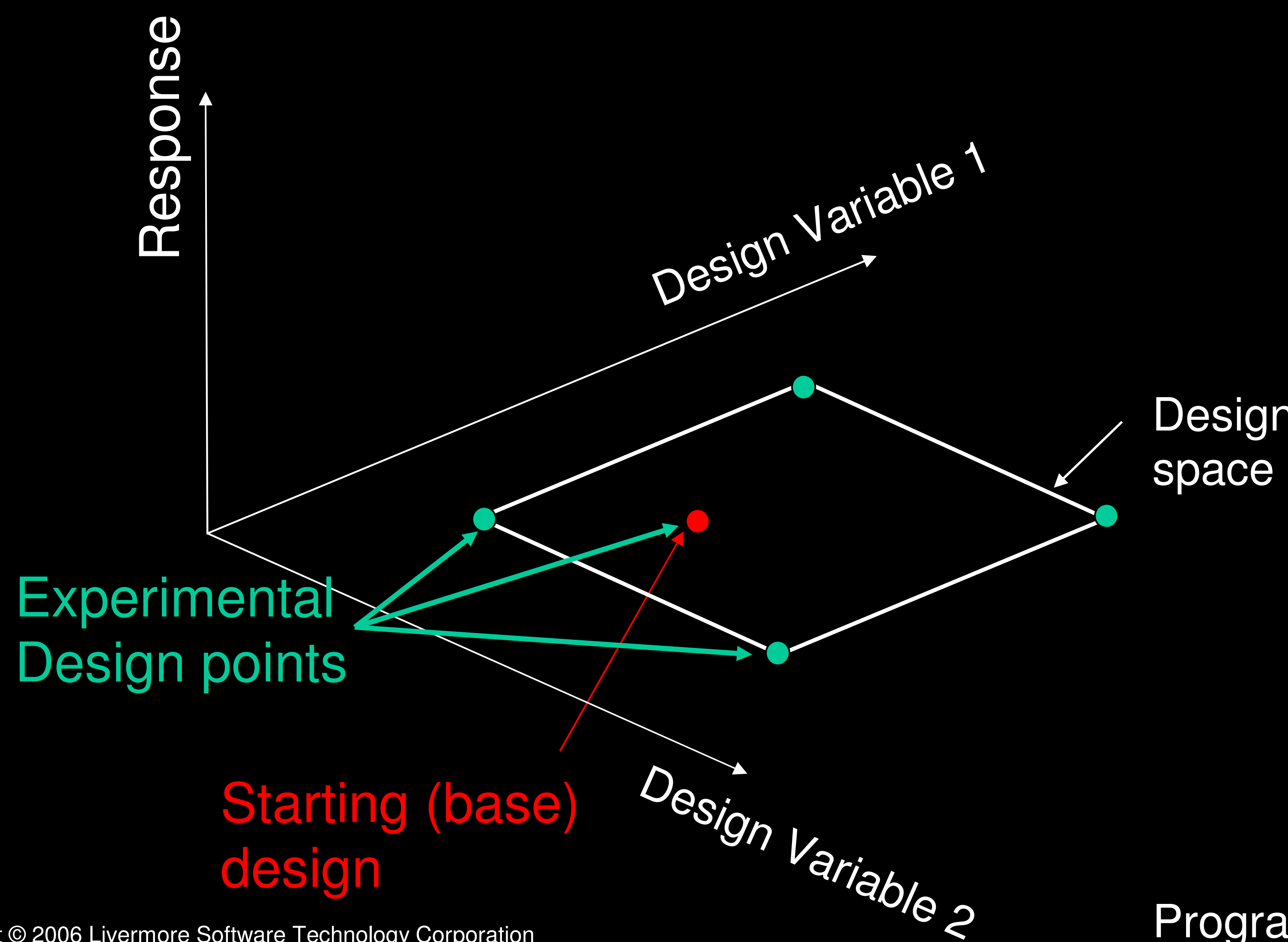
Cardiac motion
(strains,
end-diastolic volume,
end-systolic volume)

Response Surface Method



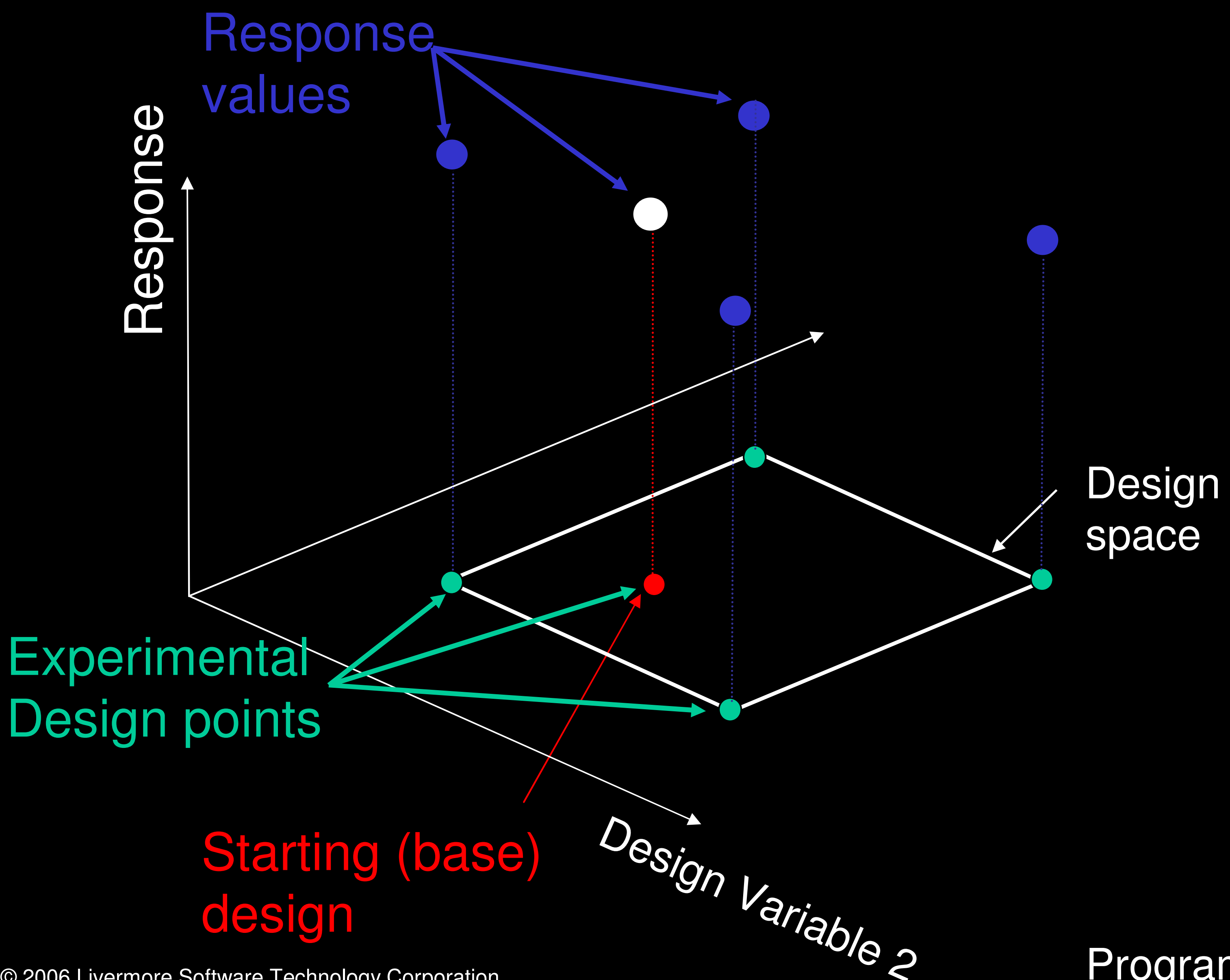
Program> LSOPT

Response Surface Method



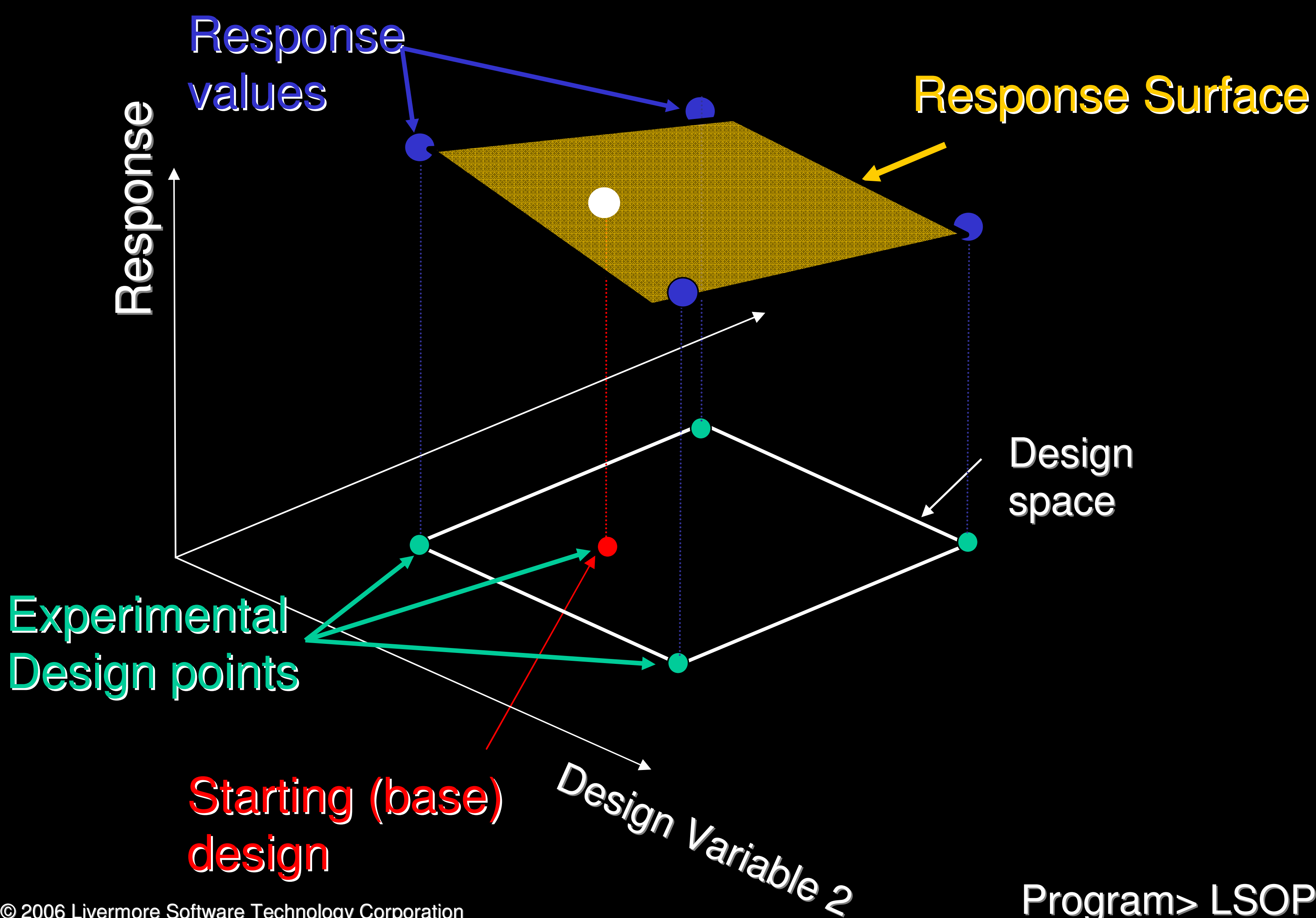
Program> LSOPT

Response Surface Method



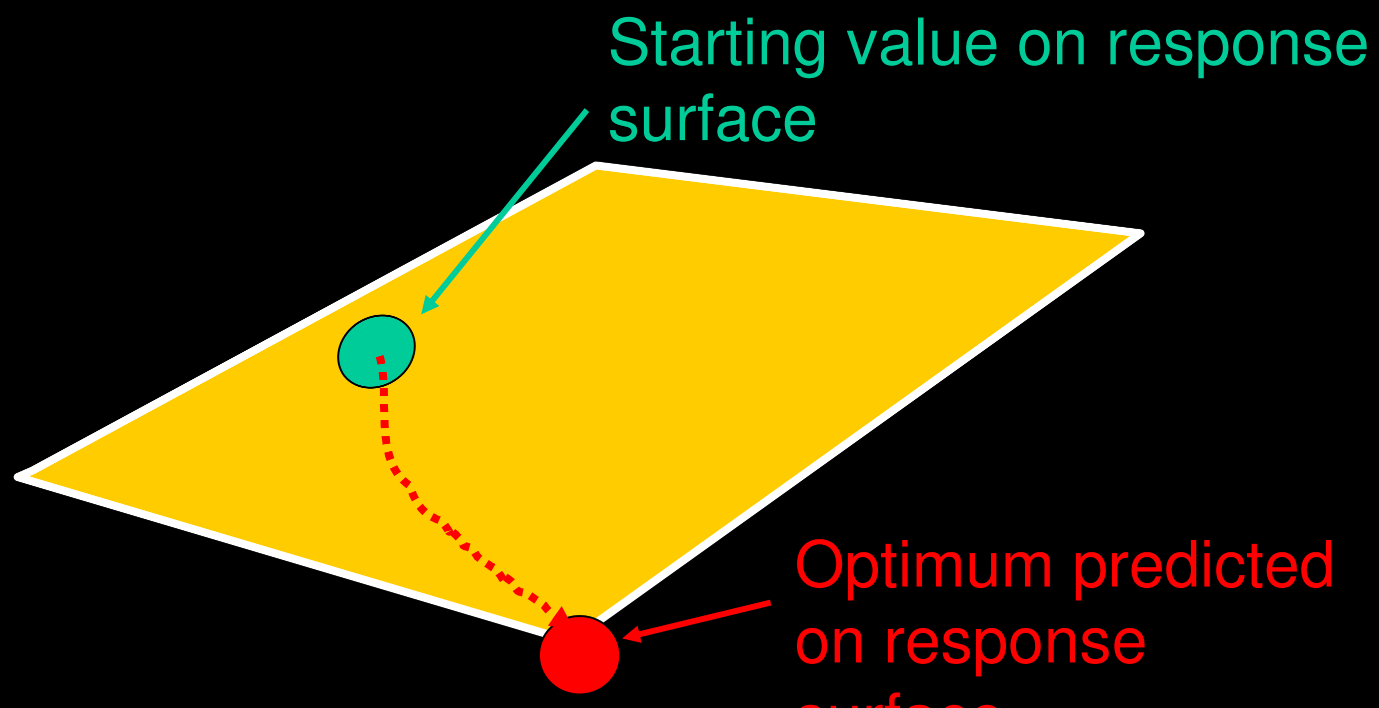
Program> LSOPT

Response Surface Method



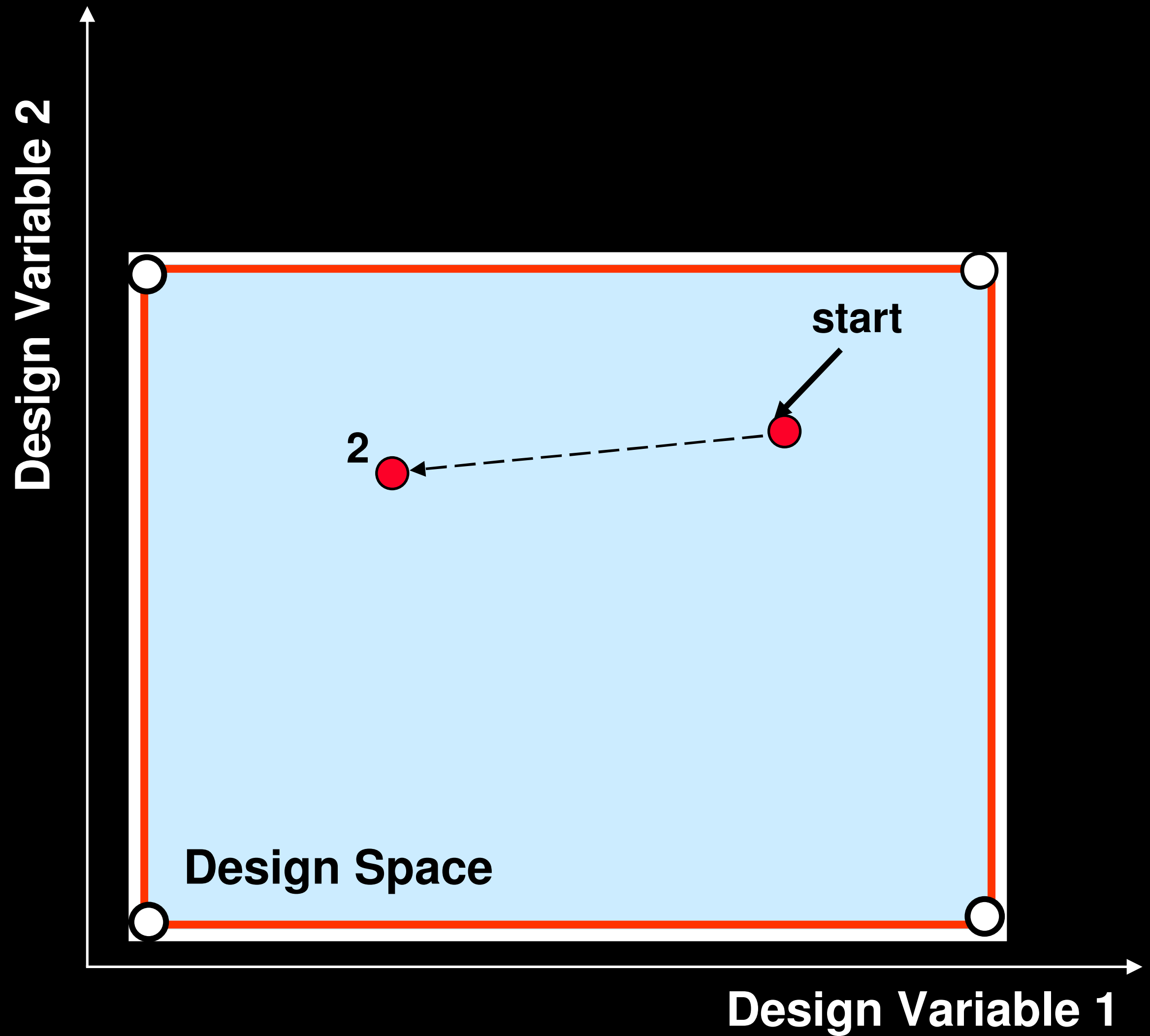
Program> LSOPT

Optimization



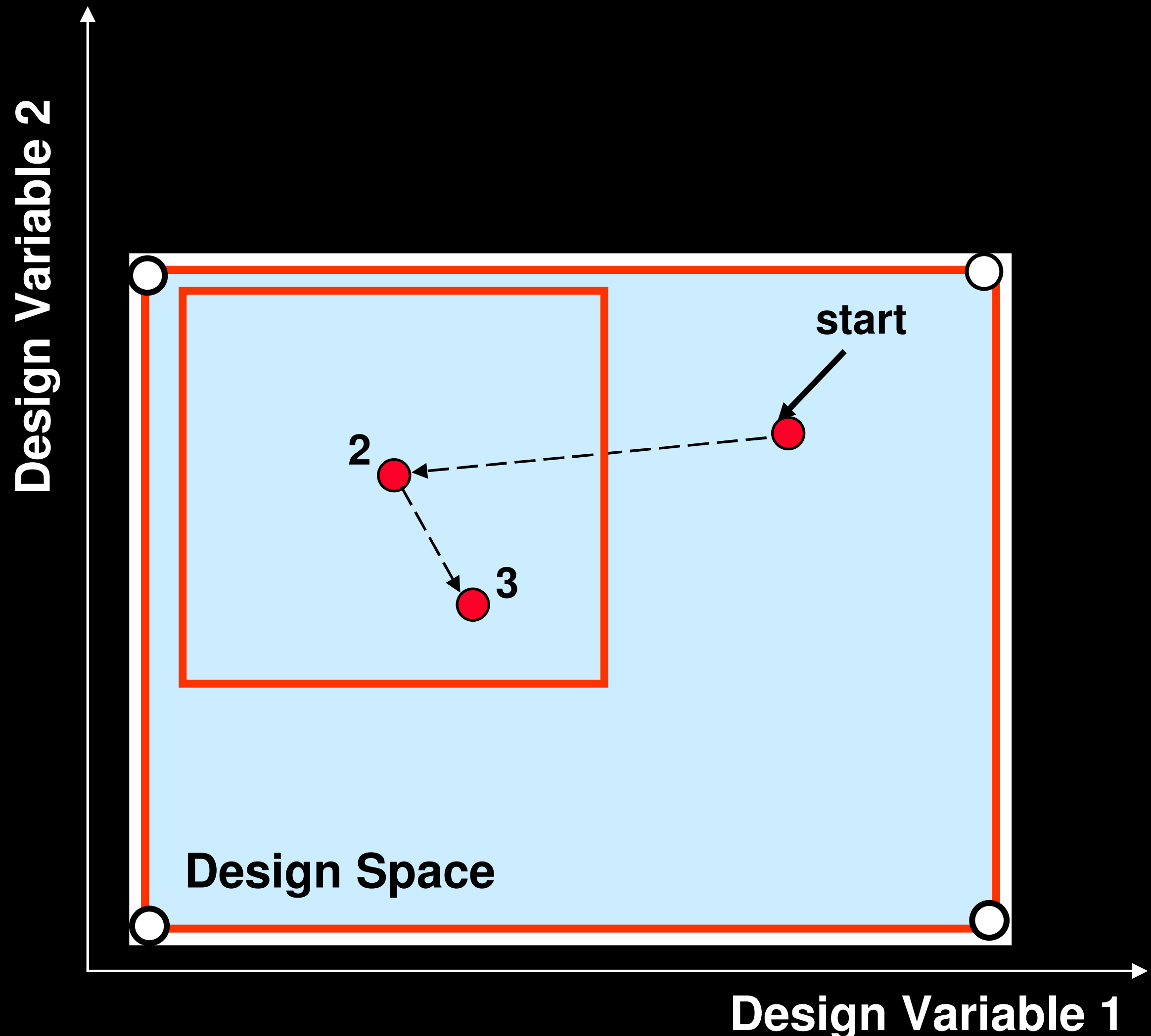
Program> LSOPT

Successive Response Surface Method



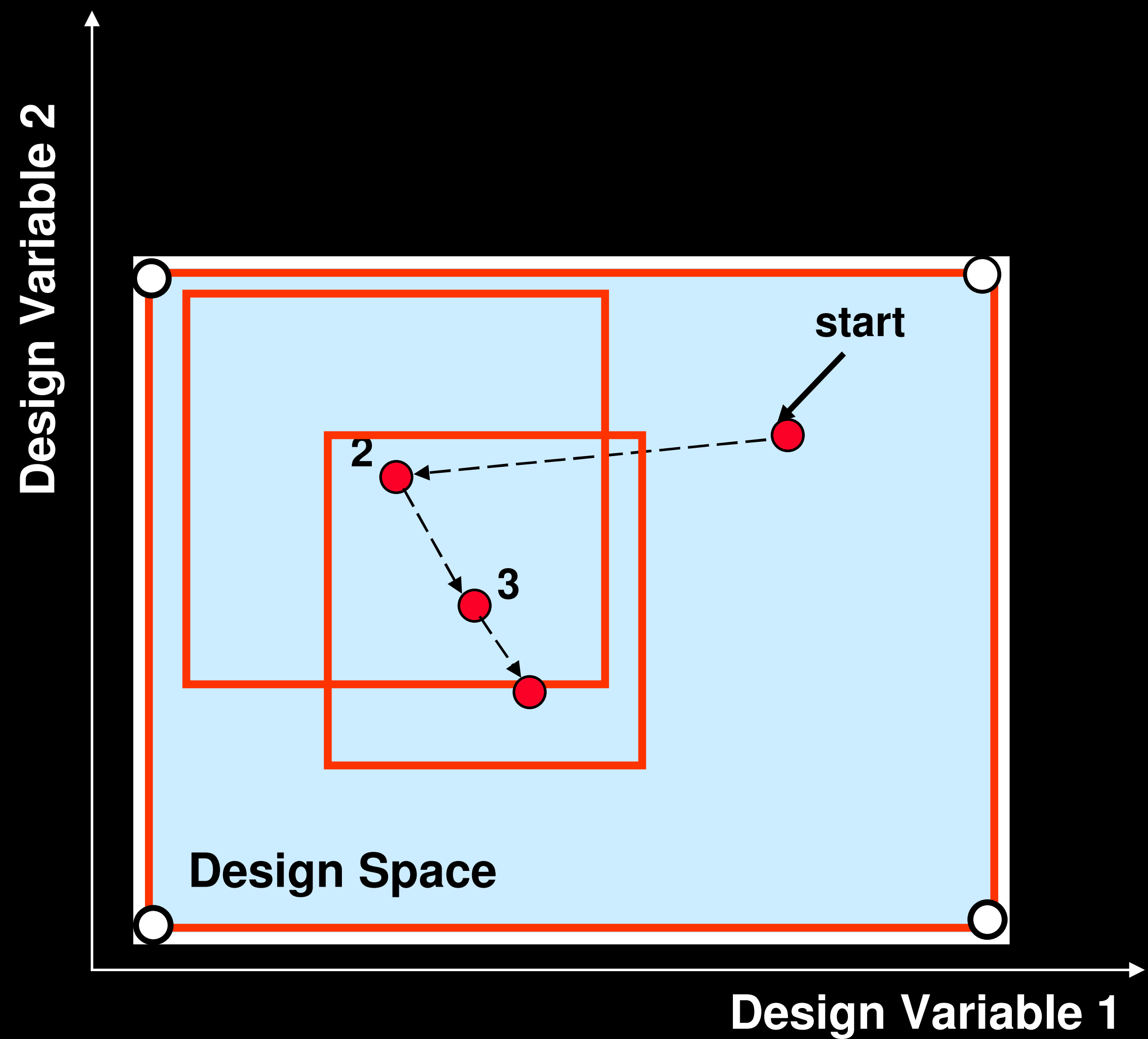
Program> LSOPT

Successive Response Surface Method



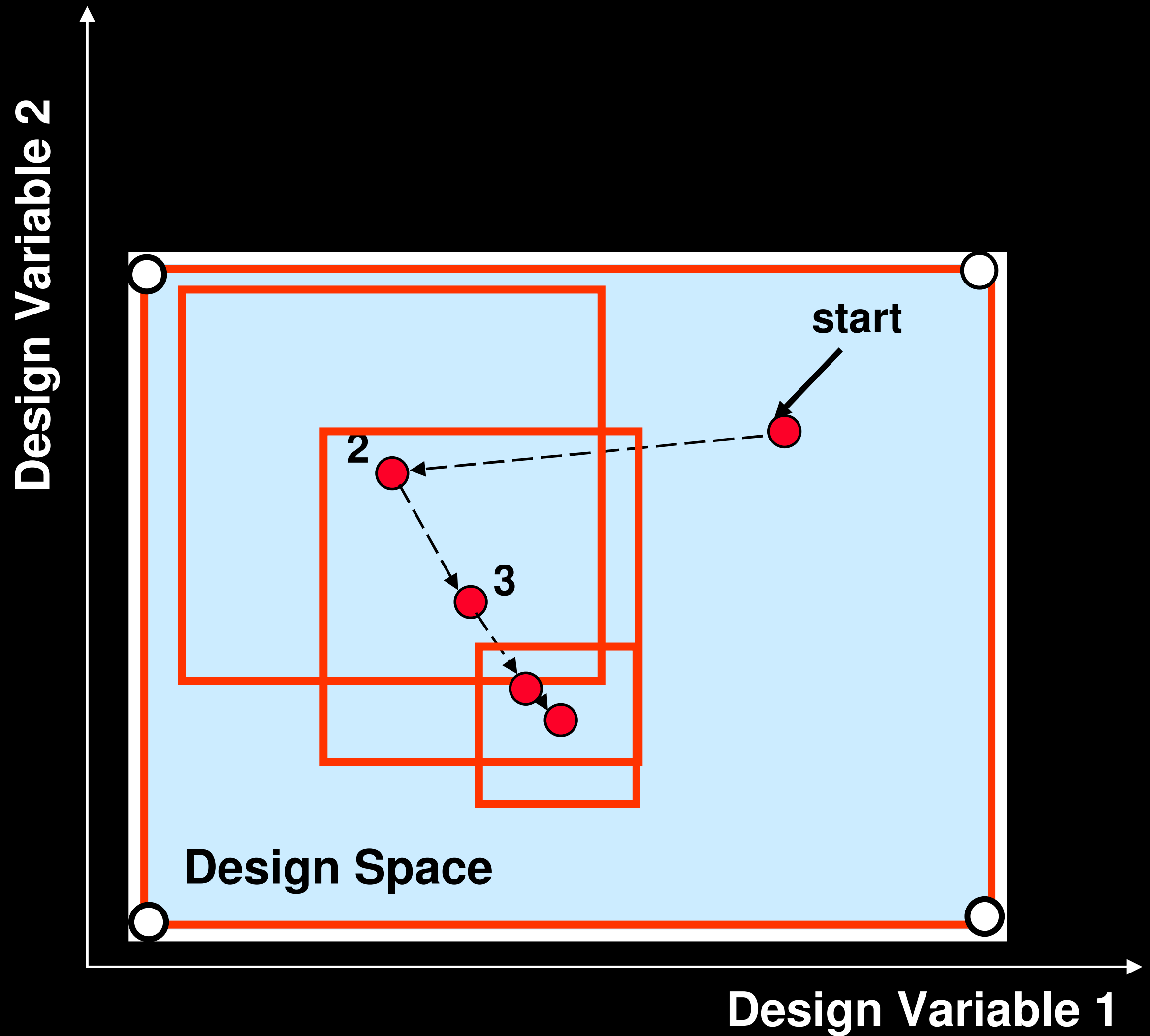
Program> LSOPT

Successive Response Surface Method



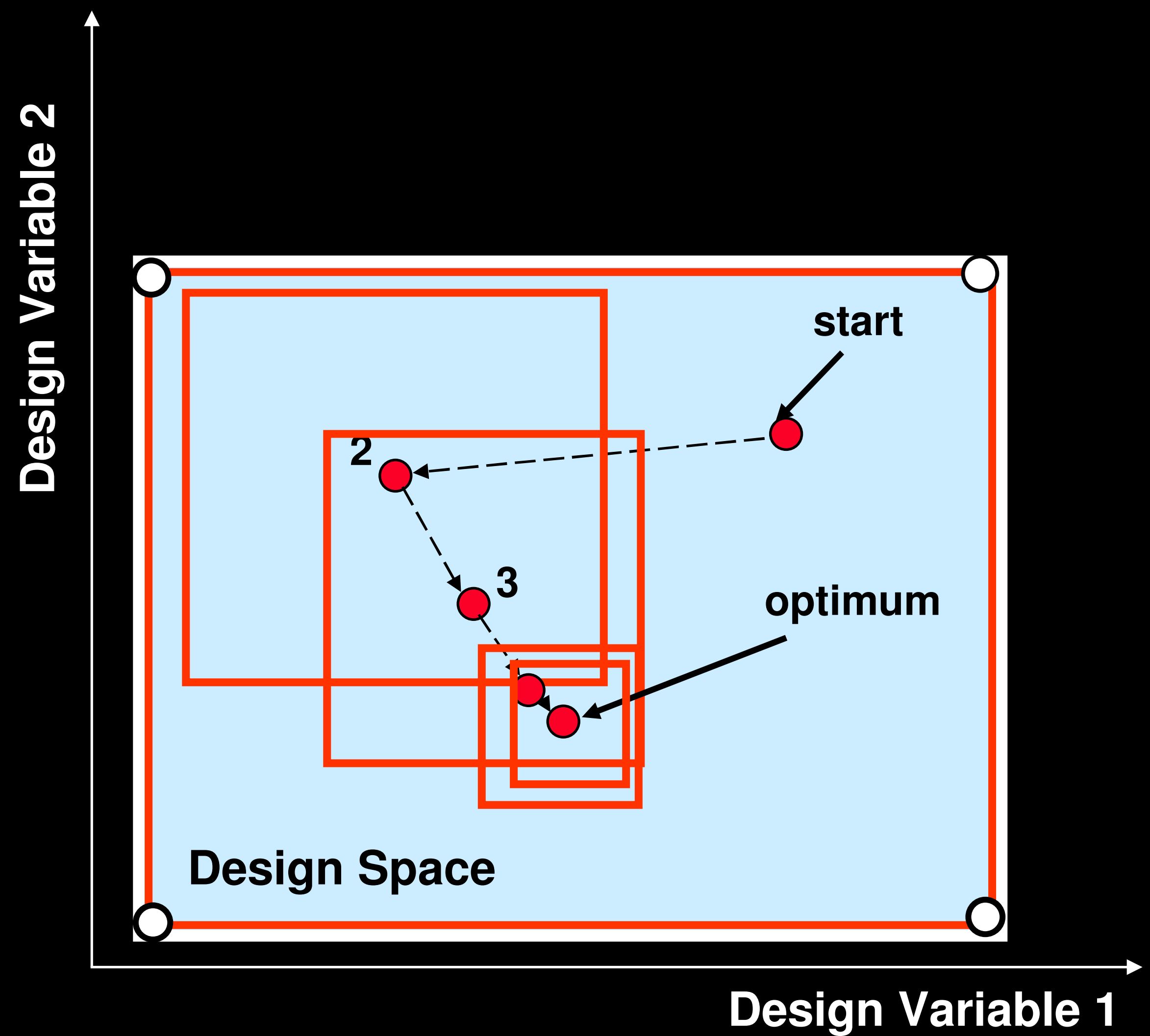
Program> LSOPT

Successive Response Surface Method



Program> LSOPT

Successive Response Surface Method



Program> LSOPT

Material Parameters

$$S_{total} = S_{diastole} + S_{systole}$$

$$\left\{c, b_f, b_t, b_{fs}\right\} \quad \left\{T_{\max}\right\}$$

diastolic
strains
(filling)

Material Parameters

$$S_{total} = S_{diastole} + S_{systole}$$

$$\{c, b_f, b_t, b_{fs}\} \qquad \{T_{\max}\}$$

systolic strains
(ejection)

Material Parameters

$$S_{systole} >> S_{diastole}$$

$$S_{total} = S_{diastole} + S_{systole} \approx S_{systole}$$

$$\downarrow$$

$$\left\{ \left(c, b_f, b_t, b_{fs} \right), T_{\max} \right\}$$

$$\downarrow$$

systolic strains
(ejection)

Results thus far

Using systolic strains and
constants for $b_f = 49.25$, $b_t = 19.25$, $b_{fs} = 17.44$*

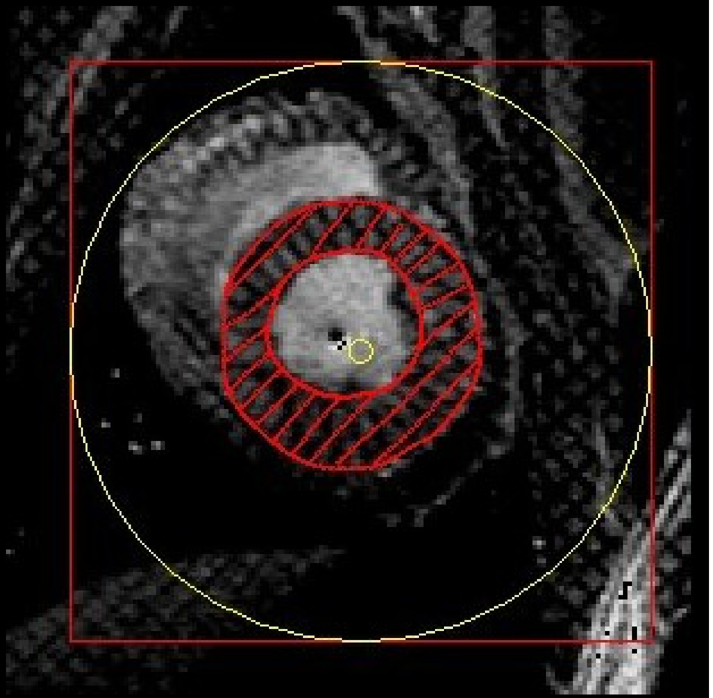
After 5 iteration,
$c = 0.135$ kPa (+ / - 0.003)
90% confidence interval = 0.134 to 0.137 kPa

$T_{max} = 574.1$ kPa (+ / - 11.5)
90% confidence interval = 568.4 to 579.9 kPa

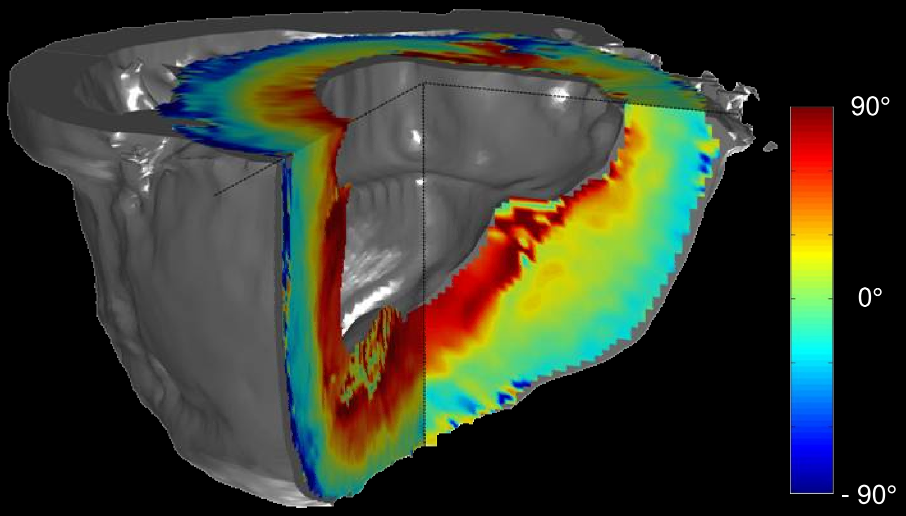
*Walker, J., et al., Am J Physiol Heart Circ Physiol 2005

Coming Soon

Diastolic (filling) strains and systolic (ejection) strains



Realistic fiber angles from MR-DTI



Acknowledgements

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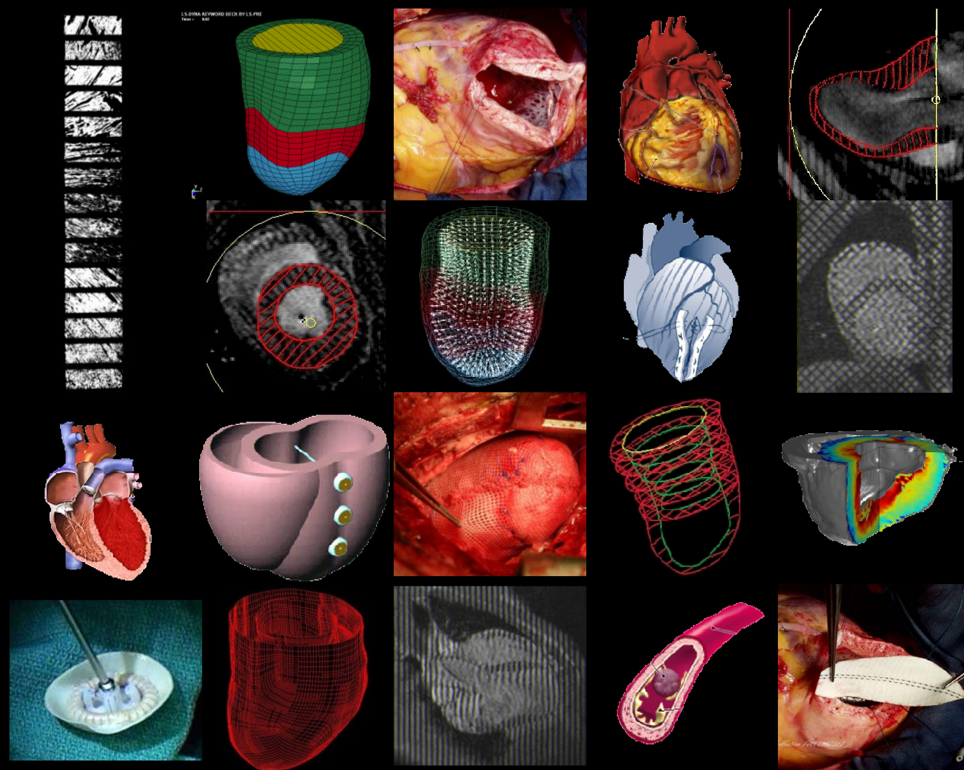
Arthur Wallace, MD, PhD

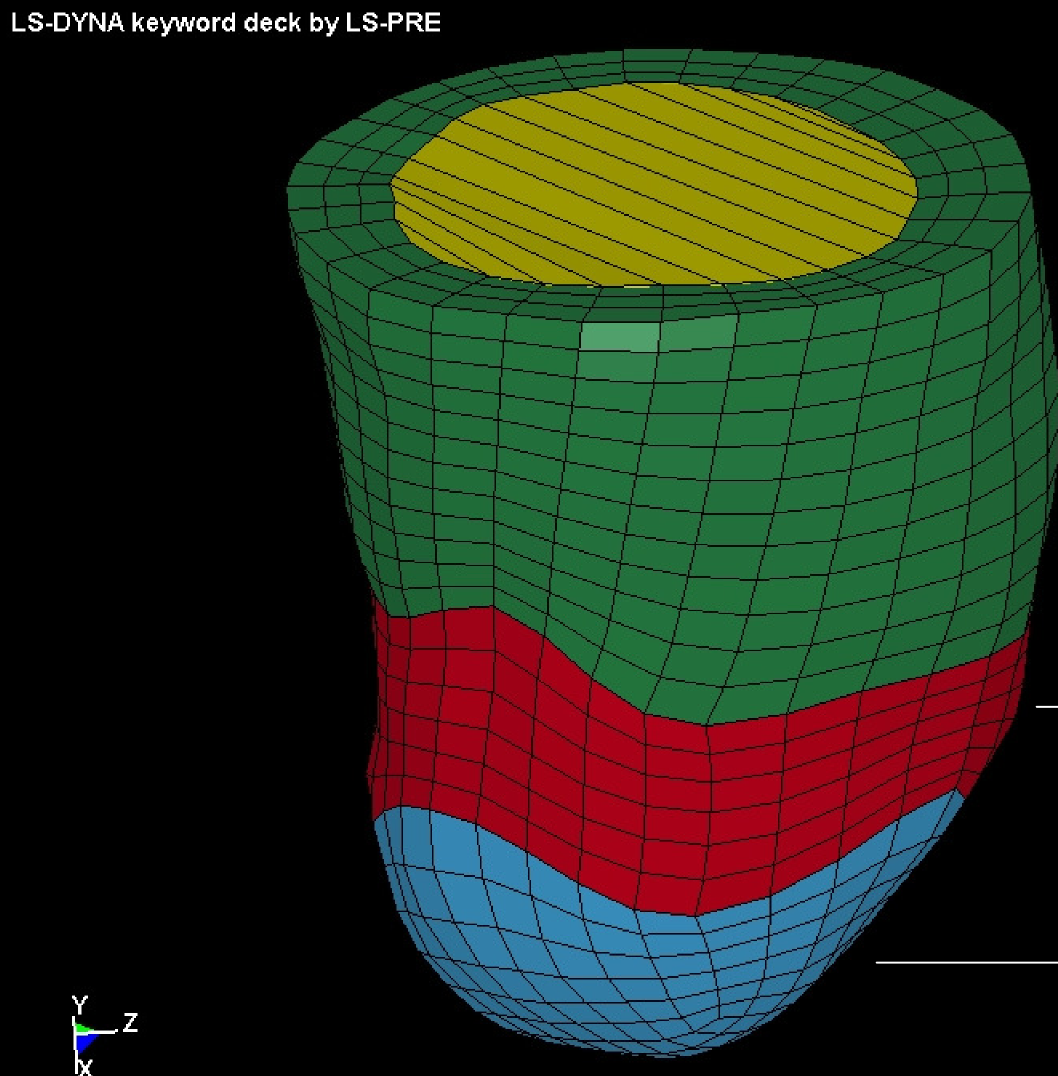
MR Imaging

Gabriel Avcevedo - Bolton , PhD



[redacted]

Material Parameters



$c, b_f, b_t, b_{fs}, T_{max}$

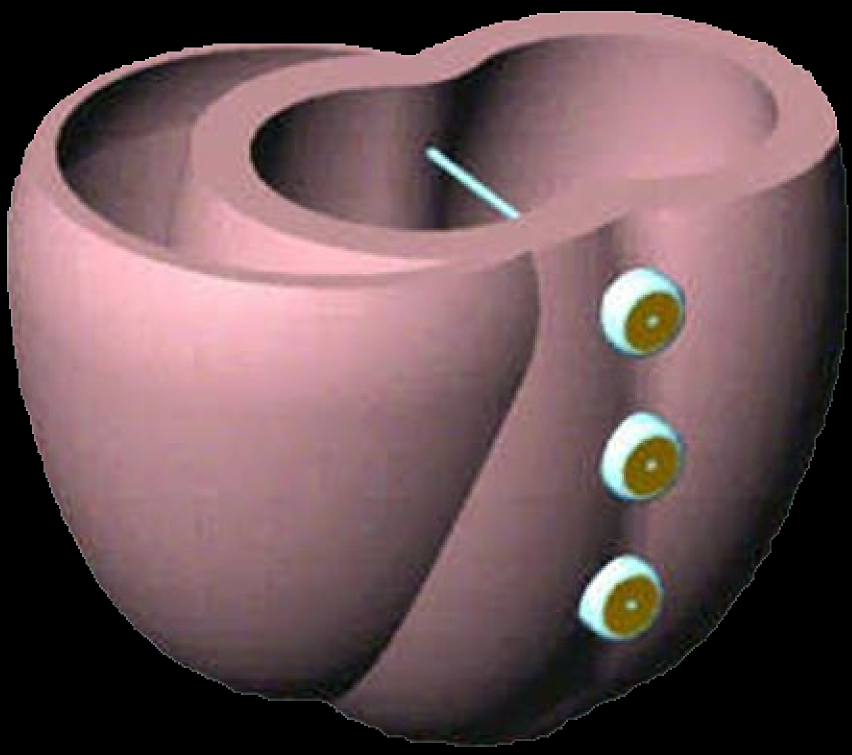
Remote:
C_R
T_{max_R}

Borderzone:
C_R
$T_{max\_B} = ½ * T_{max\_R}$

Infarct:
$C_I = 10 * C_R$
$T_{max\_I} = 0$

Dang, A., et al., Am J Physiol Heart Circ Physiol 2005 | Guccione, J., et al., Ann Thorac Surg 2001

Myosplint Device



http://www.clevelandclinic.org

Acorn Cardiac Support Device