Work Loop Parameters and Their Units

Definitions and descriptions of work loop parameters as well as associated units and formulas.

Introduction

A Work Loop refers to the Left Ventricular Pressure vs Volume relationship that arises during the cardiac cycle. Instead of Pressure and Volume, we use Force and Muscle Length.

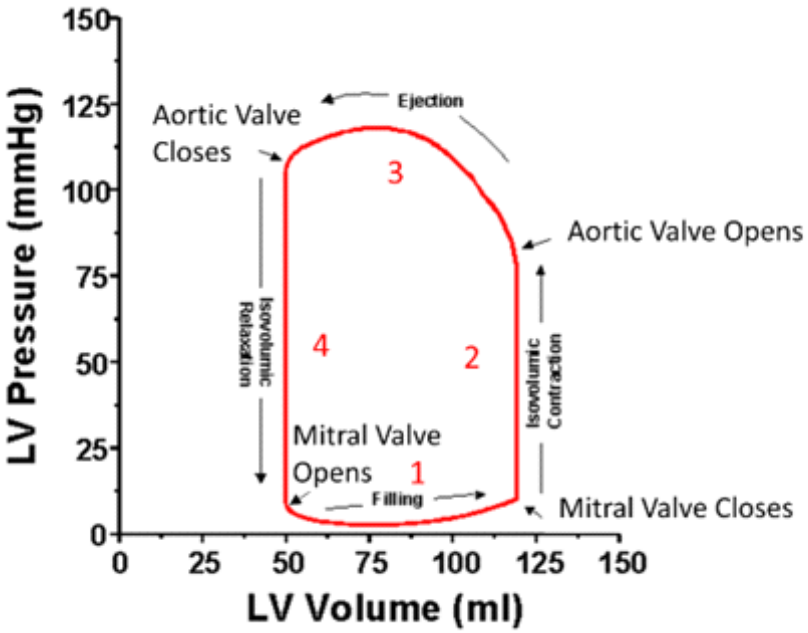

Figure 1: Pressure-Volume Loop. In isolated cells and tissue, force is analogous to pressure while length is analogous to volume.

During data collection in IonWizard, the work loop states 1, 2, 3, and 4 are recorded during generation of the work loop. The record of these states allows for the calculation of important work loop parameters explained below.

The work loop parameters listed below rely upon the following units used during recording:

Table 1: Recorded measures used to determine work loop parameters.

Measure or Parameter	Cardiac Slices	Cardiac Myocytes
Force	**mN**	**uN**
Length	**mm**	**um**
Width	**mm**	**um**
Thickness	**mm**	**um**
Cross-sectional area	mm^2	um^2
Strain	fraction of initial length	fraction of initial length
Stress	$mN.mm^{-2}$ or kPa	$uN.um^{-2}$ or MPa
Velocity	$mm.s^{-1}$	$um.s^{-1}$
Work	mN.mm or uJ	uN.um or pJ
Normalized Work	$mN.mm^{-2}$ or $uJ.mm^{-3}$	$uN.um^{-2}$ or $pJ.um^{-3}$

Work Loop Parameters

State Parameters: Units are seconds

Time Start (s) Time of stimulation relative to start of data collection.
Time AVo (s) Time when aortic valve opened (transition from 2 to 3) relative to Time Start.
Time AVc (s) Time when aortic valve closed (transition from 3 to 4).
Time MVo (s) Time when mitral valve opened (transition from 4 to 1).
Time MVc (s) Time when aortic valve closed (transition from 1 to 2).

IVC duration (s) Duration of the isovolumic contraction period.
Ejection duration (s) Duration of the ejection period.
IVR duration (s) Duration of the isovolumic relaxation period.
Filling duration (s) Duration of the filling period.

Length Parameters: Units are either mm (for slices) or um (for myocytes)

Muscle Length ED The muscle length at end diastole, i.e., at Time Start.
Muscle Length ES The muscle length at end systole, i.e., at Time AVc.
Stroke Length Calculated as Muscle Length ED - Muscle Length ES.

Strain Parameters: Units are fraction of Initial Muscle Length

Strain ED (fraction) The Strain at end diastole, i.e., at Time Start.
Strain ES (fraction) The Strain at end systole, i.e., at Time AVc.
Stroke Strain (Fraction) Calculated as Strain ED - Strain ES.

NOTE: ***Strain = (Muscle Length – Initial Muscle Length) / Initial Muscle Length***

Initial Muscle Length is the muscle length at motor position = 0.0 as provided by the user.

Work Loop Parameters (cont.)

Force Parameters: Units are normally mN (for slices) or uN (for myocytes)

Force MVc	Force at Time MVc.
Force AVo	Force at Time AVo.
Force AVc	Force at Time AVc.
Force MVo	Force at Time MVo.

Stress Parameters: Units are mN.mm-2 or kPa (for slices), uN.um-2 or MPa (for myocytes)

Stress MVc	Stress at Time MVc.
Stress AVo	Stress at Time AVo.
Stress AVc	Stress at Time AVc.
Stress MVo	Stress at Time MVo.
Stress min (Fmin/CSA)	The minimum stress.
Stress max (Fmax/CSA)	The maximum stress.
Stress Developed	Calculated as Stress max – Stress min

NOTE: ***Stress = Force / Cross-sectional Area***

Cross-sectional area (CSA) = Muscle Width × Muscle Thickness as provided by the user.

Work Parameters: Units are mN.mm or uJ (for slices), uN.um or pJ (for myocytes)

Work Ejection	Work during ejection.
Work Filling	Work during filling.
Work Total	Total work calculated as Work Ejection + Work Filling.

Using F = force, ML = muscle length, T = time, V = velocity = dML / dT

Work is often defined as

$$Work\ of\ Ejection = \int_{ML\ at\ AVo}^{ML\ at\ AVc} F\ dML$$

$$Work\ of\ Filling = \int_{ML\ at\ MVo}^{ML\ at\ MVc} F\ dML$$

We use the equivalent expressions:

$$Work\ of\ Ejection = \int_{T\ at\ AVo}^{T\ at\ AVc} F\ V\ dT$$

$$Work\ of\ Filling = \int_{T\ at\ MVo}^{T\ at\ MVc} F\ V\ dT$$

Work Loop Parameters (cont.)

Because ML at AVc is shorter than ML at AVo, the Work of Ejection is negative valued!

Conversely, Work of Filling is positive valued. Total work is also negative valued, because the work of ejection is always greater than the work of filling.

Normalized Work: Units are uJ.mm-3 (for slices) and pJ.um-3 (for myocytes)

Norm Work Ejection	Normalized work during ejection.
Norm Work Filling	Normalized Work during filling.
Norm Work Total	calculated as Normalized Work Ejection + Normalized Work Filling.

NOTE: ***Normalized Work = Work / (Muscle Length Cross-sectional area)***

or

Work / Muscle Volume

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