Effect of Stress Relaxation on the Contraction Response of Cardiac Muscle[1] (35699)

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The fundamental relationship between muscle length and contractile response has been known since the early work of Blix (1). However, this property has been modified by the more recent observations that the tension developed during contraction in skeletal (2–5) and smooth muscles (6) will vary during periods of stretch relaxation even though overall muscle length remains fixed. Kahn (7) measured the contractile tension of the frog atrium before and after stress relaxation at various muscle lengths. His published figures show that the contractile tension remained the same or increased after stress relaxation following a considerable range of stretches. Walker (8) showed that the contraction tension of the dog papillary muscle is potentiated following sudden release after stretch. The present investigation was undertaken to study the time course of the contractile response of cardiac muscle during stress relaxation.

Materials and Methods. The left anterior papillary muscle was removed from 12 female New Zealand rabbits and placed in oxygenated Ringer–Locke solution containing, in mM/L, NaCl, 124.80; $NaHCO_3$, 20.00; dextrose, 10.00; KCl, 5.63; $CaCl_2$, 2.16; and $MgCl_2$ 2.10. The pH was maintained at 7.38 by equilibration with 95% O_2 and 5% CO_2; and the temperature was controlled at 30°. The apparatus used to measure muscle tension and apply a quick sustained stretch of a measured amount has been described elsewhere (5). Slack was removed from the muscle and its length was determined at the point that internal tension first appeared. This was designated the prestretch length (l_p). The magnitude of the quick sustained stretch were expressed as a percentage of elongation ratio, λ, by means of the following formula.

$$\lambda = \frac{l - l_p}{l_p} \times 100,$$

where l is the stretched length in mm. The new muscle length after stretch was maintained for 5 min and the muscle tension was continuously monitored by means of an oscillograph recorder. The muscle was rapidly returned to its l_p length after each experiment and allowed a 10-min recovery period before being subjected to a second stretch. Each muscle was thus stretched several times with progressively larger stretches.

The papillary muscle was assumed to be cylindrical and to have a density of 1 g (wt)/cm^3. Muscle weight was obtained at the end of the experiment, after it was blotted on filter paper. The average cross-sectional area of the muscle was calculated from the above data and the l_p length.

The papillary muscle was stimulated every 3 sec with a maximal 10 msec square wave electrical pulse applied through mass electrodes placed in the bathing solution. Stimulation was started 1 hr before the stretch procedure and continued throughout the experiment. Frequent changes of the fluid in the muscle chamber was considered adequate to prevent significant accumulation of any catecholamines which might be released by stimulation of the autonomic nerve ending within the papillary muscle (9). The tension developed in the muscle by individual con-

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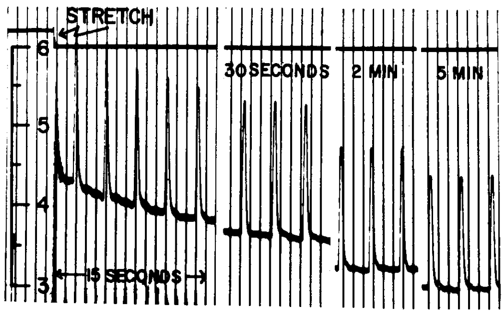

FIG. 1. Sections of a typical record showing myocardial tension produced by periodic isometric contractions during the first 15 sec after a sustained stretch and at various intervals during 5 min of stress relaxation: onset of stretch is indicated by the deviation of the top line; calibration is in grams.

tractions was measured by taking the difference between the immediate precontraction tension and the peak tension produced by the contraction.

Results and Discussion. A typical record of the myocardial tension produced by a sudden sustained stretch is shown in Fig. 1. Rest tension rose abruptly after stretch and then declined in an essentially exponential manner with time. In our studies, this loss of tension due to stress relaxation was assumed to be complete after 5 min. Isometric twitch contractions were produced at 3-sec intervals throughout the experimental period. The increase in muscle tension produced by these contractions is superimposed on the rest tension recorded from the muscle (Fig. 1). In our studies, the maximum contraction tension developed during the period of stress relaxation became larger as the precontraction muscle length was increased up to a mean λ ratio of 24.37 $\pm$ 1.05%. Lengthening of the muscle beyond this point resulted in a progressive decrease in maximum contraction tension.

It is of interest to follow the time course of the contraction tension during the period of stress relaxation at a fixed muscle length. This was done by plotting the isometric contraction tension produced at various time intervals after stretch against the muscle tension present just before each individual contraction. Typical contraction data graphed in this way for eight stretches carried out in the same muscle is shown in Fig. 2. Each arrow in Fig. 2 represents the time sequence of the data points for a single stretch. The base of the arrow shows the contraction tension produced within 3 sec after stretch and the head shows the same tension produced by the final contraction at the end of the 5-min period of stress relaxation. Intervening contraction tension values fall along the shaft of the arrow. During the interval represented by each arrow, resting muscle tension decayed in an essentially exponential fashion due to stress relaxation. As a result, each arrow points from right to left. When the arrow also points upward, it indicates that the contraction tension increased during the period of stress relaxation. When the arrow points downward it indicates the contraction tension decreased during this interval. It is helpful, in interpreting this relationship, to remember that the overall muscle length remained fixed during the time period represented by each arrow.

Current models of cardiac muscle suggest that it contains highly damped viscous units in addition to the prominent, relatively undamped elastic elements (10, 11). The change in the magnitude of the isometric contraction force that occurs during the period of stress relaxation may offer indirect evidence on the functional localization of the series viscous unit in papillary muscle. Figure

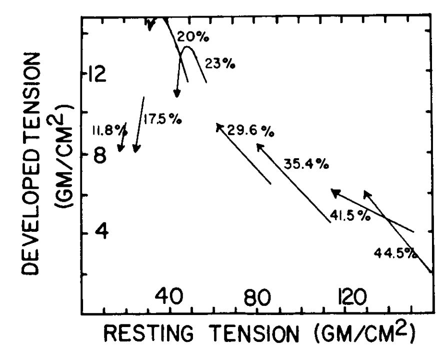

FIG. 2. Relationship between resting tension immediately before contraction and the developed tension during contraction at various intervals during stress relaxation following stretch: 8 levels of stretch of the same papillary muscle are shown; (direction of arrow) indicates the time sequence of each series; see text for discussion.

2 shows that the time course of the contraction tension differs during stress relaxation depending on whether the applied stretch is larger or smaller than the value which gives the peak tension. For example, when the muscle is subjected to a stretch that is greater than an extension ratio of 24%, the contraction tension increases during the period of stress relaxation even though the overall muscle length is fixed. With much smaller stretches, the contraction tension decreased during the period of stress relaxation.

These results can be explained simply by postulating that the viscous unit that elongates during stress relaxation is in series with both the elastic and contractile unit. In this way, movement of the viscous unit permits both elastic and contractile elements to shorten due to their elastic recoil. As a result, if the muscle was overstretched, the contractile proteins move to a more efficient binding position or, if the stretch was to less than optimal position, they interdigitate to a less efficient position. The biphasic tension response during stress relaxation following muscle stretch to near the optimal length for maximal contraction tension, such as shown in Fig. 2 for stretches of λ values of 20.8 and 23.6%, is consistent with this explanation. It can be easily visualized, that in these stretches, the contractile unit continuously shortens throughout the period of stress relaxation. The early increase in developed tension is followed by a decrease during the terminal phases of stress relaxation as the contractile unit length passes the critical value for maximal tension response.

Summary. Isolated papillary muscles from the rabbit were subjected to series of quick stretches of increasing magnitude. Each stretch was maintained for 5 min. Muscle tension was recorded during the entire period of the stretch. A maximal square wave stimulus was applied every 3 sec throughout the experimental procedure. The maximum isometric contraction tension produced during the period of stress relaxation following each stretch increased up to a mean extension ratio of 24.37%. For stretches of less than this amount, the isometric contraction tension continuously decreased during the period of stress relaxation. With stretch of greater than this value, the magnitude of the isometric contraction response increased throughout the period of stress relaxation. These data are interpreted to suggest there is a viscous muscle unit in series with both the elastic and contractile elements.

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