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ENERGY BALANCE-SHEET IN ISOMETRIC TETANI AT 0°C

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INTRODUCTION

During an isometric tetanus, tension and rate of heat production show a characteristic dependence on muscle length: they both show a maximum at a length about the mean muscle length *in situ*, l_o.

The rate of heat production can be analyzed as a sum of two terms, one which decreases exponentially with time, called 'labile heat', and the other, time—independent, called 'stable heat' (Aubert, 1956). The stable heat is strongly correlated to tension, and therefore to muscle length: the relationship is however different at different muscle lengths: at lengths larger than l_0, the stable heat rate is proportional to tension, falling to zero at zero tension. At lengths smaller than l_o, heat rate does not point to zero at zero tension, but to about a half of its maximum value. Moreover, at lengths about l_0, tension and heat rate appear dissociated: the length for maximum heat rate is about 0.9 l_o (sarcomere length 1.9 μm), whereas the length for maximum tension is about 1.05 l_o (sarcomere length 2.25 μm). As a result, identical tensions can be obtained at two different lengths about l_0, with very different stable heat rates (Gilbert & Aubert, 1980).

The aim of this study was to explore the expenditure of chemical energy (essentially phosphorylcreatine hydrolysis) at lengths about l_o particularly in relation to tension production: is there also a dissociation between tension and chemical energy expenditure in that range of length?

METHOD

The following experiment was designed: frog sartorius muscle] stimulated at 0°C at either one of two lengths: 0.85 l_o, (sarcomere 1.8 μm), or 1.15 l_o (sarcomere length 2.42 μm). At these two lengths, the muscles were expected to produce roughly the same tension, but the heat rate at 1.15 l_o was expected to be about two thirds of its value at 0.85l_o. One muscle of each muscle pair was set at 0.85 l_o and the other at 1.15 l_o, both of them being stimulated simultaneously. The muscles were frozen either 6s or 12s after the first stimulus, and the muscles were analyzed for phosphorylcreatine and total creatine by the diacetyl method.

Heat production was measured using a Hill—Downing type thermopile in separate muscles. Each muscle pair was split, and measurements were obtained from single muscles; as in the case of chemical measurements, muscle of each pair was set at 0.85l_o and the other one at 1.1l_o. Great care was taken to control the muscle length, the uncertainty be one percent of the muscle length. After the tetanus, the muscle used for the heat measurements were frozen and analyzed for total creatine for the purpose of normalizing the data.

RESULTS

The results are given in Table 1, in the form of an energy balance-sheet. Q_{exp} refers to the amount of energy which could be expected from the observed hydrolysis of phosphorylcreatine, and obtained as follows. The amount of phosphorylcreatine hydrolyzed is multiplied by -34 kJ.mo1^{-1}which is the accepted value of the enthalpy change of the reaction (Curtin & Woledge, 1978). The result is the energy accounted for by the only significant energy-yielding chemical reaction. Other reactions involving nucleotides, glycolysis or oxidative phosphorylations have been shown to contribute insignificantly to the overall energy expenditure (see Curtin & Woledge, 1978 for a review). This explained enthalpy is compared to the heat measured with the thermopile, reported in the Table as Q_{obs} It can be seen (column Q_{obs}) that for both time intervals considered more heat was produced at the shorter length. A corresponding difference is found in column Q_{exp} In other words, phosphorylcreatine remains correlated to heat production at both lengths.

On the other hand, column $Q_{obs} - Q_{exp}$ shows insignificant fluctuations about zero, which means that in these experiments, all the heat liberated by the muscles could be accounted for by phosphorylcreatine hydrolysis.

CONCLUSION

It seems that at the lengths explored, tension is dissociated not only from physical energy output (essentially heat in isometric tetani) but also from chemical energy expenditure.

Table 1. Energy balance-sheet at either 0.85 l_o, or 1.15 l_o, during the interval 0 to 6 s or 6 to 12 s after the first stimulus of a tetanus at 0°C. .PC/CT: decrease in phosphorylcreatine content, a. fraction of total creatine, CT. Qexp heat accounted for by phosphorylcreatine hydrolysis, using a molar enthalpy change of-34 kJ/mol. Qobs: heat liberated by the muscles (measured by the thermopile). Heat is given in kJ/molCT.

time	length	ΔPC/CT	Q_{exp}	Q_{obs}	$Q_{obs} - Q_{exp}$
sec	l/l_o	mol/mol	kJ/molCT	kJ/molCT	kJ/molCT
0 to 6	0.85	0.138	4.7	4.9	0.2
	1.15	0.124	4.2	3.9	-0.3
6 to 12	0.85	0.085	2.9	3.5	0.6
	1.15	0.079	2.7	2.6	-0.1

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