1: Vet Clin North Am Equine Pract. 1985 Dec;1(3):513-31. Links

Cardiovascular adaptations to exercise and training.

- **Evans DL**.

The cardiovascular system provides the link between pulmonary ventilation and oxygen usage at the cellular level. During exercise, efficient delivery of oxygen to working skeletal and cardiac muscles is vital for maintenance of ATP production by aerobic mechanisms. The equine cardiovascular response to increased demand for oxygen delivery during exercise contributes largely to the over 35-fold increases in oxygen uptake that occur during submaximal exercise. Cardiac output during exercise increases greatly owing to the relatively high heart rates that are achieved during exercise. Heart rate increases proportionately with workload until heart rates close to maximal are attained. It is remarkable that exercise heart rates six to seven times resting values are not associated with a fall in stroke volume, which is maintained by splenic contraction, increased venous return, and increased myocardial contractibility. Despite the great changes in cardiac output, increases in blood pressure during exercise are maintained within relatively smaller limits, as both pulmonary and systemic vascular resistance to blood flow is reduced. Redistribution of blood flow to the working muscles during exercise also contributes greatly to the efficient delivery of oxygen to sites of greatest need. Higher work rates and oxygen uptake at submaximal heart rates after training imply an adaptation due to training that enables more efficient oxygen delivery to working muscle. Such an adaptation could be in either blood flow or arteriovenous oxygen content difference. Cardiac output during submaximal exercise does not increase after training, but studies using high-speed treadmills and measurement of cardiac output at maximal heart rates may reveal improvements in maximal oxygen uptake due to increased stroke volumes, as occurs in humans. Improvements in hemoglobin concentrations in blood during exercise after training are recognized, but at maximal exercise, hypoxemia may reduce arterial oxygen content. More effective redistribution of cardiac output to muscles by increased capillarization and more efficient oxygen diffusion to cells may also be an important means of increasing oxygen uptake after training.

PMID: 3877552 [PubMed - indexed for MEDLINE]

1: Exerc Sport Sci Rev. 1986;14:269-302. Links

Cardiovascular adaptation to exercise at high altitude.

- **Grover RF**,
- **Weil JV**,
- **Reeves JT**.

To exercise at high altitude means working in an environment with reduced atmospheric pressure. The oxygen tension of the inspired air is therefore decreased, that is, there is atmospheric hypoxia. Exercise increases oxygen requirements which must now be met in the face of this decreased oxygen driving pressure. The initial handicap is less complete oxygenation of blood within the lung. In an effort to preserve oxygen delivery, a greater volume of blood is circulated, that is, cardiac output is increased. However, this pattern of compensation is only temporary. Within days, hemoconcentration increases the oxygen-carrying capacity of the blood, and as a consequence, less cardiac output is required to maintain oxygen delivery. In fact, cardiac output decreases to levels lower than existed prior to ascent. This reduction in cardiac output results primarily from a decrease in stroke volume due to less venous return secondary to the smaller blood volume produced by hemoconcentration. The hypoxia of high altitude produces sustained stimulation of the sympathetic nervous system. Initially, this increases heart rate, but, with time, the responsiveness of the heart decreases, so the initial tachycardia may not be sustained. Other consequences of sympathetic stimulation include an increase in resting metabolic rate, a shift away from glycogen toward free fatty acids as primary energy sources, and bone marrow stimulation to increase red cell production. The parasympathetic nervous system may also be stimulated at high altitude, which may explain the reduction in maximum heart rate. Upon arrival at high altitude, aerobic working capacity is reduced. Although this may or may not be attenuated following adaptation, endurance capacity does seem to improve. Several parallels therefore emerge between adaptation to the hypoxia of high altitude and adaptation to the struggle for oxygen created by exercise training at low altitude. Sympathetic stimulation is common to both forms of hypoxic stress, and similar responses, particularly metabolic, result. Not surprisingly, then, exercise training provides an advantage to adaptation to high altitude.