Point:Counterpoint: Skeletal muscle mechanical efficiency does/does not increase with age

**POINT: SKELETAL MUSCLE MECHANICAL EFFICIENCY DOES INCREASE WITH AGE**

We thank Dr. Ortega for the opportunity to debate the concept that aging affects exercise efficiency. From the outset we must acknowledge that, indeed, some studies report an age-related reduction task efficiency during walking and other rather complex tasks (2, 12, 20, 21). However, in contrast, our recent study of leg cycling in centenarians (28), as well as other work focused more specifically on skeletal muscle function (17, 27), suggests that healthy aging is actually associated with increased mechanical efficiency, likely caused primarily by the age-dependent shift toward an aerobic muscle phenotype (5, 15).

**Systems energy conservation and efficiency.** Important in terms of background, the law of the conservation of energy, first formulated in the nineteenth century, states that total energy in an isolated system remains constant over time. Energy can change its characteristics within the system; for instance, chemical energy can become kinetic energy but that energy can be neither created nor destroyed. Additionally, in terms of energy conversion, the first law of thermodynamics indicates that energy output cannot exceed the input, and the ratio of these two forms of energy describes the efficiency of a system (24): efficiency = output energy/input energy.

**Muscle energy demand, supply, and efficiency.** Although, the well accepted energy-related laws of physics are clearly applicable to isolated systems, human energy supply, demand, and efficiency during exercise, each a consequence of numerous biological systems, are significantly more complex. All the energy required for cellular function, including contractile activity, is provided by the hydrolysis of ATP to ADP and Pi. To balance the significant consumption of ATP during physical activity, efficient pathways of ATP resynthesis are needed. Three main mechanisms facilitate ATP resynthesis in skeletal muscle fibers: creatine kinase activity, glycolysis, and mitochondrial oxidative phosphorylation. Finally, to ensure that all metabolic processes continue to work during sustained exercise, energetic substrates and oxygen must be readily available at the cellular level or supplied via the circulation (23).

Previous physiological studies have defined mechanical efficiency as the ratio of the work performed and the amount of oxygen consumed during sustained exercise (8, 22). With this approach, there are convincing data that both in vitro (29) and in vivo (6) the energetic cost of force production is fiber type dependent, with type I or slow-twitch fibers being more efficient than type II or fast-twitch fibers. The mechanisms responsible for the lower cost of developing tension with slow-twitch fibers include higher chemical-to-mechanical coupling efficiency and lower energy cost of the adenosine triphosphatase (ATPase) driven calcium pump whose activity is 5 to 10 times slower in the lower energy cost of the adenosine triphosphatase (ATPase) the lower cost of developing tension with slow-twitch fibers than type II or fast-twitch fibers. The mechanisms responsible for dependent, with type I or slow-twitch fibers being more efficient in vivo (6) the energetic cost of force production is fiber type approach, there are convincing data that both in vitro (29) and in vivo (6) the energetic cost of force production is fiber type dependent, with type I or slow-twitch fibers being more efficient in vivo (6) the energetic cost of force production is fiber type dependent, with type I or slow-twitch fibers being more efficient than type II or fast-twitch fibers. The mechanisms responsible for the lower cost of developing tension with slow-twitch fibers include higher chemical-to-mechanical coupling efficiency and lower energy cost of the adenosine triphosphatase (ATPase) driven calcium pump whose activity is 5 to 10 times slower in the type I compared with type II fibers (29). The heterogeneity of skeletal muscle metabolic efficiency is also influenced by muscle mitochondrial volume, which varies from ~6% in type I fibers to ~4% in type II fibers, and the wide-ranging mitochondrial enzymatic activity in slow- and fast-twitch fibers (14). Thus slow-twitch muscle fibers are designed to generate ATP by oxidative mitochondrial processes, and their relatively low ATP consump-
effect of sarcopenia in the locomotor muscles occurs after the 8th decade of life (3). In line with this observation, the older subjects in this study exhibited a maintained percentage of type I fibers and a greater number of type IIx fibers of vastus lateralis compared with young subjects. In contrast, centenarians, an example of extreme human aging, who are likely to exhibit pronounced age-related changes in muscle phenotype, did, in fact, demonstrate enhanced mechanical efficiency during cycling exercise (28), as previously reported in young subjects with a greater percentage of type I muscle fibers (6). The second difference between the studies that have reported decreased rather than increased mechanical efficiency with age is exercise modality: Dr. Ortega et al. (21), as well other studies (12, 20), demonstrated a significantly reduced efficiency during walking in ~75-year-old subjects. However, as recognized by the authors, this reduced efficiency exhibited by older subjects is likely caused by the utilization of ancillary muscles during walking and may not be a consequence of muscular metabolic efficiency itself. In contrast, somewhat more simple exercise such as cycling or knee extension appear to be more appropriate models with which to assess skeletal muscle mechanical efficiency, as these paradigms are less biased by both technique and the recruitment of additional muscles not directly involved in the exercise.

In summary, aging results in a progressive shift in skeletal muscle phenotype resulting in a greater fraction of type I muscle fibers. As type I fibers exhibit a greater metabolic efficiency and altered activation patterns it is likely that this translates to a greater skeletal muscle mechanical efficiency with advancing age.

REFERENCES


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COUNTERPOINT: SKELETAL MUSCLE MECHANICAL EFFICIENCY DOES NOT INCREASE WITH AGE

Aging is associated with impaired movement performance and reduce exercise capacity characterized by such physiological and...