Strength Decline in Aging: A Modeling-Based Analysis of Muscle Activity and Fatigue

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Abstract

Age-related strength decline compromises postural stability, yet its biomechanical implications remain poorly understood. The aim of study was to evaluate, using mathematical musculoskeletal modeling, how strength decline affects total muscle activity (TMA) and muscle fatigue during upright standing across strength percentiles (P20, P50, P80) in males and females. Musculoskeletal simulations were performed in the AnyBody Modeling System using a whole-body standing model with ground reaction force prediction. Age-related strength reductions were implemented by scaling muscle StrengthParameters based on normative handgrip-strength data from 2.4 million adults (Tomkinson et al., 2024). TMA (sum of normalized muscle activations) and muscle fatigue (optimization-based index) were analyzed across 16 age groups (20–24 to 100+ years). Age-related trends were quantified using percentage changes and piecewise regression with AICc-based breakpoint identification. TMA increased nonlinearly with age, remaining stable until mid-adulthood and rising markedly beyond ~60 years, with the greatest increases in the lowest strength percentile (P20). A shared age-related breakpoint was identified, after which TMA slopes increased 7–8-fold. Muscle fatigue showed a similar pattern, with pronounced late-life increases, particularly in individuals with lower strength capacity. These findings demonstrate that age-related strength decline substantially increases muscular demands during standing, especially in dynapenic individuals.