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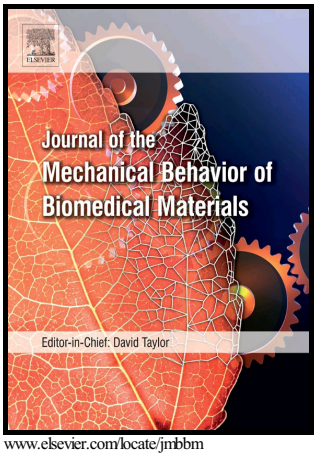

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Changes in three-dimensional muscle structure of rabbit *gastrocnemius*, *flexor digitorum longus*, and *tibialis anterior* during growth

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Abstract

Muscular contraction dynamics depends on active and passive muscle properties (e.g., the force-velocity relation) as well as on the three-dimensional (3D) muscle structure (e.g., the muscle fascicle architecture and aponeurosis dimensions). Much is known about active muscle force generation and the muscle architecture at a particular age (mostly for adult specimens), but less is known about changes in muscle structure during growth. The present study analyzed growth-related changes in the muscle structure of rabbit *gastrocnemius lateralis* (GL), *gastrocnemius medialis* (GM), *flexor digitorum longus* (FDL), and *tibialis anterior* (TA). Changes in tendon length, muscle belly dimensions (length, width, thickness), as well as aponeurosis length, width, and area were determined using 55 rabbits between 18 and 108 days old. Additionally, the 3D muscle fascicle architecture of five rabbits of different ages (21, 37, 50, 70, 100 days) was determined using a manual digitizer.

We found an almost linear increase over time in most of the geometrical parameters observed. GL and GM showed very similar growth characteristics. In contrast to the pronounced increase in muscle belly length of GL and GM, FDL and TA exhibited more uniform muscle belly growth in length, width, and thickness. In general, the aponeuroses of the muscles exhibited lower growth rates in width than in length, and aponeurosis areas were larger than physiological cross-sectional areas. There were almost no changes in fascicle lengths with increasing age for GL, GM, and FDL. In contrast, there was a clear increase in TA fascicle length from about 20 to over 40 mm. Pennation angles of TA (11.0±2.1°) and FDL (16.7±3.2°) remained almost unchanged but increased for GL from 13.4±3.3° to 24.3±6.5° from the youngest to the oldest animal. For all muscles observed, the tendon-muscle fascicle length ratio (r_{TFL}) changed during growth. GL and GM exhibited similar increases in r_{TFL} from about 4 to 8. FDL showed the highest ratio, which increased from about 8 to 13, whereas TA had the lowest ratio, which decreased slightly from 2 to 1.5.

The outcomes demonstrate new findings regarding changes in 3D muscle architecture and aponeurosis shape during growth, and they provide information for muscle force generation, functional relevance, and adaptation with respect to animal age. Therefore, the results help to improve understanding of muscle growth processes and can be used as input data for muscle growth modeling.