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Research article

Functional differentiation of the human lumbar perivertebral musculature revisited by means of muscle fibre type composition

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SUMMARY

Human back muscles have been classified as local stabilizers, global stabilizers and global mobilizers. This concept is supported by the distribution of slow and fast muscle fibres in quadrupedal mammals, but has not been evaluated for humans because detailed information on the fibre type composition of their perivertebral musculature is rare. Moreover, such information is derived from spot samples, which are assumed to be representative for the respective muscle. In accordance with the proposed classification, numerous studies in animals indicate great differences in the fibre distribution within and among the muscles due to fibre type regionalization. The aims of this study were to (1) qualitatively explore the applicability of the proposed functional classification for human back muscles by studying their fibre type composition and (2) evaluate the representativeness of spot sampling techniques. For this, the fibre type distribution of the whole lumbar perivertebral musculature of two male cadavers was investigated three-dimensionally using immunohistochemistry. Despite great local variations (e.g., among fascicles), all muscles were composed of about 50% slow and 50% fast fibres. Thus, contradicting the concepts of lumbar muscle function, no functional differentiation of the muscles was observed in our study of the muscle contractile properties. The great similarity in fibre composition among the muscles equips each muscle equally well for a broad range of tasks and therefore has the potential to allow for great functional versatility of the human back musculature. Spot samples do not prove to be representative for the whole muscle. The great intraspecific variability observed previously in single-spot samples is potentially misleading.

1. Introduction

In 1989, Bergmark proposed a classification of human back muscles in local and global muscles based on their topography (Bergmark, 1989). Local muscles originate and insert at the vertebrae, span only few intervertebral joints and ensure the structural integrity of the spine. Global muscles link the thorax and the pelvis and can produce great forces via long lever arms. Other authors suggested a classification into stabilizers and mobilizers (Goff, 1972; Janda, 1985; Sahrmann, 1992, 2001). Stabilizers are deep, mono- to oligosegmental and work eccentrically to control spinal movements. Mobilizers are superficial, multisegmental and work concentrically.

Integrating these concepts with details on the functional roles of the back muscles (Panjabi et al., 1989; Panjabi, 1992; Hides et al., 1994, 1996; Comerford and Mottram, 2000), Gibbons and Comerford (2001) suggested a classification of the human back musculature as local stabilizers, global stabilizers and global mobilizers. Local stabilizers show continuous activity independent of the direction of movement with only minimal changes in length. They provide stiffness to control segmental motion (e.g., deep part of the lumbar multifidus muscle, dorsal fascicles of the psoas major muscle). Global stabilizers are active discontinuously depending on the direction of movement and contract eccentrically. They generate force to control the range of spinal motion (e.g., spinalis muscle). Global mobilizers are also characterized by a non-continuous, direction-dependent activity, but they contract concentrically. They generate force to produce movements of the trunk (e.g., iliocostalis muscle). Because a muscle's function is reflected by its contractile properties, local muscles can be expected to comprise high proportions of slow, fatigue-resistant fibres, while global muscles should contain high proportions of fast contracting fibres to meet the functional demands implied by the classification.

These predictions were confirmed for quadrupedal animals. The classification of local stabilizers and global stabilizers and mobilizers is reflected by the fibre type composition of the respective

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muscles in a wide range of therian mammals (reviewed in Schilling, 2009) and can even be transferred to the perivertebral musculature of other vertebrates (reviewed in Schilling, 2011). Accordingly, local stabilizers were composed of a high proportion of slow, oxidative fibres to provide the continuous activity needed to maintain the integrity of the spine ('static stabilization'). Global stabilizers and mobilizers contained high proportions of fast, glycolytic fibres to either counterbalance forces acting on the body by quick responses and thus restrict and counteract movements ('dynamic stabilization') or to produce movements ('mobilization').

Our present knowledge of the fibre type composition of the human back musculature is first and foremost derived from single spot sampling data from only some perivertebral muscles (e.g., Johnson et al., 1973; Sulemana and Suchenwirth, 1972; Polgar et al., 1973; Fidler et al., 1975; Jowett et al., 1975; Sirca and Kostevc, 1985; Mattila et al., 1986; Thorstensson and Carlson, 1987; Havenith et al., 1990; Jorgensen and Nicolaisen, 1991; Zheng et al., 1992; Jorgensen et al., 1993; Parkkola et al., 1993; Rantanen et al., 1994; Mannion et al., 1997; Kimura, 2002; Crossman et al., 2004; Arbanas et al., 2009, 2010). Because these studies focussed on only a few locations, muscles and/or vertebral levels (Fig. 1), a comprehensive understanding of the fibre type composition throughout human perivertebral musculature is hindered. Nevertheless, when taken together, these previous studies indicate high interindividual variability, but, on average, slow fibres comprise a proportion of about 50–65% independent of the muscle investigated. They further assume these values to be representative of the whole muscle sampled. Not only is this finding in contrast to the expectations derived from the functional categories suggested by Gibbons and Comerford (2001), this observation should also be taken with caution because many studies demonstrated that most mammalian muscles show a heterogeneous fibre distribution with regional accumulations of one fibre type ('regionalizations'; Kernell, 1998) and that fibre composition is not at all homogenous across the cross-sections (e.g., Yokoyama, 1982; Bagnall et al., 1983; Ford et al., 1986; Kojima and Okada, 1996; Schilling, 2005, 2009; Schilling et al., 2005; Hesse et al., 2010). Somewhat more detailed studies on the fibre type distribution pattern of human muscles are available for the vastus lateralis of the quadriceps femoris muscle. But the results are controversial, supporting or rejecting a correlation of fibre type composition and location (e.g., Lexell et al., 1983 and Elder et al., 1982, respectively). For human back muscles, this has not been investigated systematically as only single spot samples have been studied so far.

Based on the proposed functional classifications (Gibbons and Comerford, 2001) and our previous studies on non-human mammals (Schilling, 2009), we assumed that the human perivertebral musculature is regionalized. Furthermore, we expected the muscles acting as local stabilizers (e.g., deep multifidus muscle) to be comprised of great proportions of slow, fatigue-resistant fibres, whereas muscles acting as mobilizers (e.g., iliocostalis muscle) should first and foremost be comprised of fast contracting fibres. As no previous study has investigated all perivertebral muscles, we examined the fibre type distribution throughout the musculature's cross-section, as well as along its longitudinal axes, in order to re-evaluate: (1) the significance of local sampling methods and their adequacy for representation of whole muscles and (2) the proposed functional concepts of the human back muscles in the light of the herein collected information on fibre contractile properties. For this, we studied the three-dimensional distribution patterns of the two main muscle fibre types – slow and fast – in the complete lumbar perivertebral musculature in two male cadavers. Because of the low sample size, this study is first and foremost exploratory and descriptive aiming at providing qualitative information that will facilitate the generation of hypotheses in future studies. Nevertheless, publication of such information even from single specimens is important as it may contribute to building a broader database in the future.

2. Materials and methods

2.1. Investigated muscles

The muscles associated with the lumbar vertebral column were investigated in two male donors, neither of whom had suffered from musculoskeletal disease nor been bedridden or particularly athletic (cadaver I: 64 years, 100 kg, 1.89 m; cadaver II: 95 years, 75 kg, 1.55 m). Both cadavers were provided by the Institute of Anatomy I of the University Hospital Jena. The study was approved by the local ethics committee of the University Hospital (3308-11/11).

In both cadavers, the perivertebral muscles of the right body side were examined at the mid-vertebral levels from L1 to L5. Because some muscles were indistinguishable in the cross-sections, they were grouped as follows: The investigated dorsovertebral musculature comprised the lumbar interspinal and the transversospinal muscles (i.e., rotatores and multifidus lumborum) ('dorsomedial musculature', dm), as well as the erector spinae muscle (longissimus thoracis and iliocostalis lumborum) and the lumbar medial intertransversarii muscles ('dorsolateral musculature', dl). The spinalis muscle, which is only present in its tendinous origin in the cranial part of the lumbar region, was not considered. The ventrovertebral muscles under study were the psoas major and minor ('ventromedial musculature', vm) as well as the quadratus lumborum and intertransversarii laterales lumborum ('ventrolateral musculature', vl).

2.2. Preparation and histology

The cadavers were embalmed with a solution containing 70% ethanol and 1.1% formalin with additives such as salicylic acid, thymol and glycerol (pH 7.0). For the current study, the lumbar region was dissected from the body (i.e., the vertebral column plus part of the ilium and the associated perivertebral musculature). The obtained specimens were frozen and bisected sagittally using a band saw. The right half was further divided into cross-sectional slices (Fig. 2a). Of these, the slices covering the mid-vertebral region (i.e., containing the second and the third fourth of the vertebral body) were studied. For the ventrovertebral musculature of cadaver II, the slices from the intervertebral levels (i.e., containing the last fourth of one vertebra, the intervertebral disc and the first fourth of the next vertebra) were used. The slices were thawed and the muscles thoroughly detached from the bone (Fig. 2b). Afterwards, the musculature was divided into tissue blocks adequate in size for conventional histological sectioning (edge length max. 3.5 cm) and embedded in paraffin. Preparing muscle blocks from slices instead of sampling the whole muscle from the cadaver prevented distortion and excessive tissue loss.

Serial cross-sections (10 μm) were collected near the cranial, middle and caudal aspects of each block and stained using Heidenhain's azan method (Fig. 2b, top). Digital photographs of these sections were taken and reassembled to comprehend the topographical relationship of the muscle fascicles throughout the lumbar region. Two consecutive sections from the middle of the blocks of each slice were used for the immunohistochemical differentiation of slow and fast muscle fibres (Fig. 2b, bottom). Hence, fibre type analysis was carried out at mid-vertebral height of each lumbar level (except the ventrovertebral muscles of the cadaver II, whose fibre type results correspond to the level of the intervertebral disc, see above). Slow fibres were marked by a skeletal anti-slow antibody (clone NOQ 7.5.4D) and fast fibres by