Paradoxical variation of strength determinants with different rotation axes in trunk flexion and extension strength tests

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Abstract. The aim of this study was to illustrate the influence of different levels of the fulcrum (the axis of sagittal rotation) on measured trunk flexion and extension strength and compare force and torque as a unit of measure. The isometric trunk strength was measured in 16 healthy female subjects. The dynamometer was kept at the shoulder level and the moment arm was lengthened step by step by moving the fulcrum caudally from the level of the posterior superior iliac spine to the level of the gluteal fold. The moment of force (torque) increased from 117.0 to 208.5 N·m in flexion and from 182.2 to 292.5 N·m in extension, P<0.0001. An attempt to quantify this change was made. Paradoxically, the measured force remained at a constant level (in flexion) or slightly decreased (in extension). We concluded that torque as a measure of trunk flexion and extension strength is highly dependent on the level of the rotation axis and force appears to be less sensitive for variations with the height of the fulcrum. We would suggest that the observed increase in torque is physiological and reflects to what extent hip flexor or extensor muscles are recruited. The force, on the other hand, may better characterize a person’s capability to perform functional tasks. Force and torque should strictly be distinguished from one another.

Key words: Anatomy - Back - Biomechanics - Muscle physiology - Spinal pathology

Introduction

The strength of the trunk muscles is often measured as a part of the determination of general fitness. It is also used as a measure of the success of treatment in patients with chronic low back pain (LBP) and a person’s ability to perform functional tasks. The strength of trunk extensor and flexor muscles is often diminished in patients with LBP. Poor trunk muscle function may also contribute to the risk of low back disorders, but the association is not yet fully understood (Biering-Sørensen 1984; Leino et al. 1987; Mooney 1987). A considerable overlap of muscle strength data between LBP patients and healthy controls (Alston et al. 1966; Biering-Sørensen 1984; Langrana et al. 1984; Nachemson and Lindh 1969) may, in part, explain the poor agreement between diminished muscle strength and the incidence of LBP. A generally accepted method, which reduces intersubject variability in healthy subjects, is lacking (Delitto et al. 1989).

The methods used for measurement have been either isometric (Alston et al. 1966; Biering-Sørensen 1984; Holmström et al. 1992; Khalil et al. 1992; Nachemson and Lindh 1969) or isokinetic (Langrana et al. 1984; Mayer et al. 1985; Smidt et al. 1963). An isometric method may be appropriate for patients with moderate pain and fear of increasing pain in spinal movement (Hasue et al. 1980). The subjects have usually been placed in a standing (Biering-Sørensen 1984; Mayer et al. 1985; Nachemson and Lindh 1969; Smith et al. 1985), sitting (Langrana et al. 1984; Smidt et al. 1983), recumbent (Alston et al. 1966; Hasue et al. 1980; Nachemson and Lindh 1969; Nordin et al. 1987) or sidelying position (Mayer and Greenberg 1942; Thorstensson and Arvidsson 1982) and the axis of rotation has varied from L2-L3 (Thorstensson and Arvidsson 1982), iliac crest (Biering-Sørensen 1984), L5-S1 (Langrana et al. 1984; Mayer et al. 1985; Smidt et al. 1983; Smith et al. 1985) to the hip joint level (Hasue et al. 1980; Thorstensson and Arvidsson 1982).

The units of measurement have also varied. The force (newton, kilopond, pound) comprises the direct pull away from the dynamometer in the usual isometric trunk muscle strength test. The moment of force or torque (newtonmetre, kilopondmetre, foot-pound) is the measured force multiplied by its perpendicular distance (lever arm) from the axis of rotation or fulcrum. Both force (Alston et al. 1966; Biering-Sørensen 1984; Khalil et al. 1992; Nachemson and Lindh 1969; Sipilä et al. 1991; Viitasalo et al. 1985) and torque (Holmström et al. 1992; Viljanen et al. 1991) have been used as a
measure of isometric trunk muscle strength. In contrast, torque or its ‘derivative’ work (joule) is the only unit of measure used in dynamic trunk strength measurement systems (Hasue et al. 1980; Langrana et al. 1984; Mayer et al. 1985; Nordin et al. 1987; Smidt et al. 1983; Smith et al. 1985; Thorstensson and Arvidsson 1982; Thorstensson and Nilsson 1982) with the exception of Mayer and Greenberg (1942) who have used a spring-balanced swivel table measurement system and force as a unit.

Trostensson and Nilsson (1982) have shown that the torque of the trunk flexor or extensor muscles depends on the axis of rotation. They eliminated the influence of gravity by constructing a special device which enabled the isokinetic measurement of flexion and extension force in a side-lying position. Two axes of rotation located at both L2-3 and trochanter major levels were used. As the axis of rotation became more caudal, the moment of force increased. It was assumed that the change in the moment of force was caused by the increased action of the hip flexor and extensor muscles. We have not been able to find studies which report a possible alteration in force.

The aim of the present study was to compare force and torque as a measure of trunk strength and an attempt was made to quantify the change in the force and torque when different levels of the fulcrum were used in the isometric trunk flexion-extension strength test.

Methods

Subjects. The study group comprised 16 healthy volunteer female medical students with variable habitual physical activity but normal body-shape. Their mean age was 22 (range 21–24) years and mean body mass 60.7 kg [range 48–77 (SD 7.22) kg]. The volunteers had no symptoms or signs of LBP.

Procedure. The trunk flexion and extension forces were measured in a widely used manner (Biering-Sørensen 1984; Khalil et al. 1992; Nachemson and Lindh 1969; Viitasalo et al. 1985) by an isometric analogous strain-gauge dynamometer (Digitest Ltd., Muurame, Finland), connected to a graphic plotter (Linseis L6514-3, Linseis GmbH, Selb, Germany). A minimal mechanical delay of the graphic plotter eliminated the possible ‘overshoot’ artifact from initial impulse (acceleration peak). The equipment was calibrated according to the instructions provided by the manufacturer. A 5-cm wide strap was tightened around the shoulders just below the medial end of the clavicle and horizontally connected to the dynamometer through a steel chain. The vertical distance (the lever arm) between the shoulder strap and the adjustable, 5-cm wide pelvic supporting board was measured to the nearest 5 mm.

The participants were acquainted with the measurement system prior the proper measurements. They stood on a nonslip material with their socks on or bare foot, with their back against the pelvic supporting board as trunk flexion strength was measured or their front against the supporting board as trunk extension strength was measured. The midpoint of the board was placed at the posterior superior iliac spine (SIPS), the highest position, i.e. level one, and at the gluteal fold (GF), the lowest position, i.e. level six. The distance between the highest and lowest position was divided into five equal parts so that there were six different levels for the fulcrum, Fig. 1. The force which was produced by trunk flexor muscles was measured with the supporting board initially at level one, and then the board was lowered step by step as measurements were taken until the lowest level, i.e. level six, was reached. The measurements at each level were conducted until maximal force and a small fatigue effect were seen on the graphic plotter. This occurred in 2 s with every subject. To minimize the influence of fatigue due to repeated measurements there was only one maximal contraction for each position with about 1-min rest before the next measurement. This recovery time was also needed to move the fulcrum to a new position. The force produced by trunk extensor muscles was measured in the same manner.

The maximal force was multiplied by the length of the lever arm used at any given time for calculating the moment of force (torque) (Rasch and Burke 1978). The change of torque per metre ($\Delta T \cdot m^{-1}$) and the change of force per metre ($\Delta F \cdot m^{-1}$) were calculated for each subject by using the following formula:

$$\frac{\sigma_6 - \sigma_1}{l_6 - l_1},$$

where $\sigma$ is the torque or the force and $l$ is the length of the moment arm at the indicated level.

Statistic. The BMDP software library for microcomputers (Davidson and Toporek 1990) was used for the statistical analyses. The analyses were started by testing the normality of the results. A univariate analysis of variance for repeated measures was used for estimating the equality of the force or torque means at different levels of the fulcrum. The results are expressed as means and 99% confidence intervals (CI99%, Altman and Gardner 1989) or ranges.

Results

The average distance between the dynamometer and the pelvic support was initially 30.4 cm (range 24–34 cm). The pelvic support was lowered on average 5.3 cm (range 4.5–6 cm) at each step until the lowest