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Classification/Measurement

Accuracy and Precision of Seven Radiography-Based Measurement Methods of Vertebral Axial Rotation in Adolescent Idiopathic Scoliosis

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Abstract

Study Design: Assessment of vertebral axial rotation measurement methods.
Objectives: To assess the accuracy and precision of seven radiography-based vertebral axial rotation measurement methods for typical scoliotic deformity before and after posterior instrumentation.
Summary of Background Data: Vertebral axial rotation is an important component to evaluate transverse plane scoliotic deformities. Several measurement methods were developed based on coronal plane radiographs or computerized 3D reconstruction. Their ability to accurately and precisely measure axial rotation, either pre- or postoperatively, is not well known.
Methods: Two synthetic vertebrae, with and without instrumentation, were fixed in a jig allowing 3D rotation manipulations. Fifty-three configurations of 3D rotations were radiographed. Two observers evaluated seven measurement methods: one visual estimation, two ruler-based (Nash-Moe and Perdriolle), one analytical (Stokes), and three 3D-reconstruction techniques (based on pedicles, based on eight vertebra landmarks, and a surface-based reconstruction software SterEOS). Measurements were repeated one week later.
Results: Intraobserver precision ranged from 2.0° (Perdriolle/SterEOS) to 3.6° (visual estimation) for the noninstrumented vertebra, and from 2.2° (SterEOS) to 9.7° (Nash-Moe) for the instrumented vertebra. Interobserver precision ranged from 1.2° (SterEOS) to 9.3° (Nash-Moe) for the noninstrumented vertebra, and from 1.7° (SterEOS) to 6.2° (Visual Estimation) for the instrumented vertebra. Accuracy of the methods ranged from 2.1° with SterEOS to 9.1° with Nash-Moe ruler. The measurement error was significantly associated with the level of axial rotation for Nash-Moe and 3D reconstruction techniques with low to moderate correlation.
Conclusions: The majority of radiography-based methods measured vertebral axial rotation with an average error of 2° to 5°. The Nash-Moe method should be avoided, considering its inaccuracy greater than 9°. The instrumentation did not compromise the precision or the accuracy of measurement. The measurement accuracy of 3D reconstruction methods was impaired by the severity of the axial rotation.
Level of Evidence: N/A.

Keywords: Adolescent idiopathic scoliosis; Transverse plane deformity; Instrumentation; Vertebral axial rotation; Measurement; Accuracy; Precision

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Introduction

Adolescent idiopathic scoliosis (AIS) is a complex 3D deformity of the spine, involving abnormal rotations of the vertebrae in the transverse plane [1]. Vertebral "axial rotation" is an index assessing the torsional component of the spine in the transverse plane [2]. Scoliotic spines typically involve axial rotation of the vertebrae up to 25°, rarely exceeding 40°, toward right or left sides [3]. The severity of the thoracic apical axial rotation has been associated to the rib hump [4]. Axial rotation quantification has proven clinical utility for scoliosis pathomechanism comprehension [5,6] and curve progression monitoring [7,8]. With contemporary vertebral derotation surgical maneuvers, which aim to improve the transverse plane deformity, axial rotation is an important parameter to quantitatively assess surgical correction [9].

Vertebral axial rotation is a challenging index to quantify because it is mainly observable in a plane not accessible on a typical radiograph. Measurements on coronal and sagittal radiographs were developed based on the interpretation of vertebral features. Nash-Moe developed one of the first methods that associated the degree of rotation to the percentage of displacement of the concave pedicle shadow across the vertebral body [10]. Perdriolle further improved this method by considering the effect of the projection of the pedicles in the coronal plane, and designed a ruler called "torsiometer" [11]. Stokes proposed an analytical method based on the trigonometric relationship between vertebral shape parameters [12]. The most recent methods are based on stereoradiographic computational techniques that create 3D vertebral geometrical models. 3D coordinates of specific vertebral landmarks are obtained through their identification on biplanar calibrated radiographs [13]. Axial vertebral rotation can be computed based on different anatomical reconstructed landmarks. In the last few years, commercial software has been developed to assist users in the reconstruction process and enhance automation. Methods using computed tomography (CT) were proposed to assess axial rotation [14,15], but CT examination is not often used in AIS because of the high radiation exposure, and the modification of the spine vertebral rotations due to the supine position imposed by CT examination.

Measurement methods rely on the ability of the observer to identify different anatomical landmarks, not always fully visible and easy to recognize. The bias due to the observer performing the measurement refers to the precision of the method. Intra-observer precision (repeatability) refers to the ability of one measurer to repeat the measurement between trials, and interobserver precision (reproducibility) to the ability of different measurers to reproduce the same measurement. The proximity of the measurement to the true axial rotation refers to the accuracy. Many studies have assessed the precision and/or accuracy of measurement methods [3,16], but rarely report both accuracy and precision. There is insufficient comparison between different methods in the literature. Further comparison between studies is often limited by the differences in the quantitative indices reported to assess accuracy and precision [16].

Previous studies reporting measurement method accuracy often assessed pure axial rotation only [17-19]. However, when the scoliotic spine is radiographed, the projected vertebral shape appeared deformed because of the axial rotation, but also to the lateral tilting and forward-backward inclinations present in scoliotic vertebrae [20,21]. This may further challenge the identification of the landmarks and alter axial vertebral rotation measurement accuracy. Contemporary surgical correction of scoliosis involves spinal metallic instrumentation, which is likely to obstruct the visibility of vertebral anatomical structures on radiographs, and further alter axial rotation measurement. To provide a better appreciation of the rotational correction achieved with surgical intervention, the capacity of current measurement methods to assess axial rotation using postoperative radiographs remains to be determined.

The objective of this study was to assess the accuracy and precision (intra- and interobservers) of seven radiography-based vertebral axial rotation measurement methods for typical vertebral scoliotic 3D deformity, before and after posterior instrumentation.

Materials and Methods

Two identical L3 synthetic vertebrae composed of polyurethane foam, including a cortical shell and a cancellous inner material, were used (Sawbone; Pacific Laboratories, Vashon, WA). These vertebrae mimic the human structures in shape, size, and function and produce a realistic and user-friendly image in x-ray environments (Fig. 1). One vertebra was instrumented with 5.0×50-mm titanium polyaxial pedicle screws and 5.5-mm Cobalt-Chrome rods. The vertebrae were fixed in a radio-translucent vertebral 3D rotation manipulation device that allowed to position them with the same 3D inclinations, with an accuracy of 0.5° as assessed with a coordinate measuring machine (CMM Microscribe, Immersion Corp., San Jose, CA) (Fig. 2). Fifty-three different 3D rotation sequences found in typical scoliotic spines were applied to both vertebrae. Vertebrae were successively rotated in the transverse, frontal and sagittal planes, around the local axis of the device, designed to rotate with the vertebrae (Fig. 2) [21]. The axial rotations ranged from −30° to 30° with 5° increments, with combined frontal and sagittal planes inclinations ranging from −20° to +20° with 10° increments. Each resulting configuration was radiographed using a biplanar radiographic system (EOS Imaging, Paris, France). For each of the 53 combinations of rotations, the vertebral axial rotation relatively to the sagittal plane (stationary plane of reference) was measured for each one of the two vertebrae using seven methods: