Regarding the test setup used by Kleck et al. [1], the kinematic constraints applied to test specimens were not described, and these constraints are an important consideration given that a biaxial test machine was used for the study. Were the specimens free to move inherently in off-axis or unloaded directions? This consideration is particularly relevant in axial rotation wherein constraint to rotate about a single vertical test machine axis, that additionally may or may not be aligned with the inherent specimen axis of rotation, can build up aberrant artifact forces that may affect study results.

Concerning the different load conditions, the Materials and Methods section states: "Flexion and extension were assessed using a triangular waveform, 0.25 Hz, 8 cycles, 6 Nm. Axial rotation test was conducted with a triangular waveform, 0.25 Hz, 8 cycles, 6 Nm, with 40% body weight compression load." On the basis of this description, we interpreted that compression was applied with axial rotation bending but not with other directions of bending. If so, a rationale for this atypical protocol choice is not presented by the authors. From the study description, it may have simply been a limitation of the test equipment and test setup that were used. The description of the load condition is noteworthy since, in the Discussion section, the authors go on to state, "It was shown that the direction of motion is a powerful factor, which impacts the device strain; in particular, the highest level of strain was caused by axial rotation, specifically in S1 screws and iliac bolt connectors" (in comparison to flexion and extension movements). Similar statements are made in the Conclusions section. The reader is led to interpret that maximal strain in the surgical constructs investigated is found during axial rotation movements. However, in addition to the possibility of overconstraint of specimens during axial rotation testing, as mentioned above, it is also possible that the noted differences were due to axial compressive loads that were paired with axial rotation and not investigated separately, or due to some effect of combining these loads. None of these alternative conclusions are critically addressed by the authors.

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Reply to Letter to Editor: Strain in Posterior Instrumentation Resulted by Different Combinations of Posterior and Anterior Devices for Long Spine Fusion Constructs

We are grateful to our colleagues for their attention and interest in this study. The questions and notes presented in the letter to the editor are thoughtful and we are grateful for the chance to elucidate. In particular, it was noted that important details of the performed mechanical tests were not described in the manuscript and that magnitude, units, and variables of strain are not clear. They further state that this made interpretation of the presented results difficult, and that it was also assumed that higher strain measured during rotation, revealed in the study, may be explained by additional axial load applied during rotation rather than simply the rotation itself, and thus the corresponding conclusions concerning higher strain caused by rotation may not be appropriate.

We agree that some important details of the study were not presented in the publication to avoid redundancy and diminish the article size. We provide the omitted information in the current reply in the following order: 1) details of the mechanical testing; 2) details of the strain evaluation and presentation; and 3) comparison of the obtained results with those presented in other publications. We do hope that this additional information will contribute to better understanding of the published results.

Details of the Mechanical Testing

The selection and preparation of specimens was described in the Materials and Method section of the article (first paragraph), and specimens' motion (flexion, extension, and rotation) with the applied torque of 6 Nm (the last paragraph of the section) [1]. Further details are presented

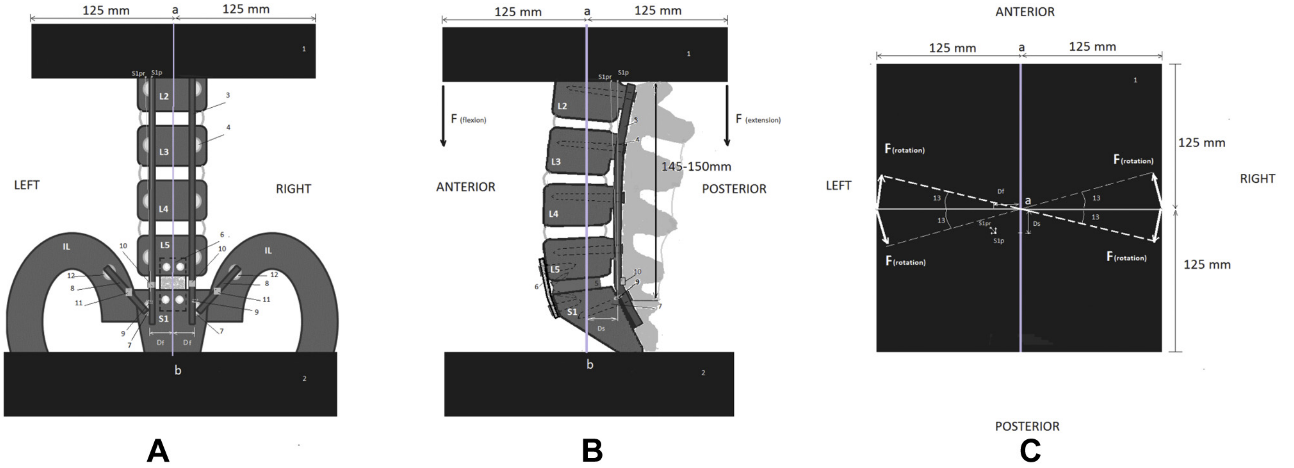

Fig. 1. Description of the studied fusion constructs and application of force during testing in the AP (A), sagittal (B), and axial (C) plane: 1, upper (cranial) fixing plate; 2, lower (caudal) fixing plate; L2−S1, vertebral numbers; IL, ilium; 3, posterior rods; 4, pedicle screws; 5, intervertebral cage depending on the test: TLIF (T-Pal, DePuy/Synthes, Fig. 2 of the article) or ALIF (SynFix-LR, DePuy/Synthes, Fig. 4 of the article); 6, ATB plate with screws (Fig. 3 of the article); 7, S1 screws; 8, iliac bolt connectors; 9, location of the SI strain gages (C2A-06-015LW-120; Micro-Measurements, Raleigh, NC); 10, location of strain gages on the L5−S1 rods (C2A-06-015LW-120; Micro-Measurements, Raleigh, NC); 11, location of strain gages (C2A-06-015LW-120; Micro-Measurements, Raleigh, NC) on the iliac bolt connectors; 12, iliac screws; 13, angle of maximum angular displacement during rotation test, 13.4° (SD, 0.9); F, place and vector of force application; Df, distance between S1 screws and vertical axis in frontal projection, varied from 23 to 26 mm; Ds, distance between S1 screws and vertical axis in sagittal projection, varied from 22 to 25 mm; S1p, projection of left S1 screw strain gage located on the proximal surface; S1pr, location of S1p at maximum displacement to the right during the axial rotation test.

in Fig. 1, in particular, the general schema of the force application, specimen displacement, and location of the strain gauges in the anteroposterior (AP) (A), sagittal (B), and axial (C) planes. The force was applied to the upper fixation plate (1) which was mobile, whereas the lower fixation plate (2) was immobile. Flexion of the specimen was performed by shifting of the anterior end of the upper plate down, whereas extension was performed by the same shifting of the opposite (posterior) end of the plate (Fig. 1, B). Additional axial load was not applied during flexion and extension because the vector of the applied force was directed down. The maximum linear displacement at flexion and extension ranged from 4.5 to 5.7 mm depending on the specimen anatomy. Theoretically, this displacement corresponds with angular sagittal motion of the specimen axis (Fig. 1, B) from 1.6° to 2.2° at the S1 level, if this angular motion was the same at each spinal level. Unfortunately, we did not define sagittal displacement at each spinal level; however, the attached video shows that upper levels were more mobile than lower ones during the test (Video 1). The rotation was performed around the specimen axis (Fig. 1). Vectors of the force action were directed horizontally (Fig. 1, C). Therefore, the additional axial load (40% of the body weight) was applied to imitate impact of the body weight. The maximum angular displacement (13°; Fig. 1, C) was relatively constant with a mean of 13.4° (min., 13.3°; max., 13.5°). The angular displacement (13°) of the upper plate caused linear displacement of the S1 strain gauge projection (S1p to S1pr; Fig. 1, C) on ≈5.8 mm. This linear displacement had sagittal and frontal projections (Fig. 1, A-C). This linear dislocation corresponds with summary angular motion at S1 of ≈2.2° (Fig. 1, A and B). This means that the absolute level of motion (linear and angular) at the top of the specimens, caused by flexion, extension, and rotation, did not differ significantly. Strain gauges at the S1 screws were placed on the proximal surface of the screw below the tulip and the screw-bone interface (9; Fig. 1, A and B). Strain gauges on the posterior rods were placed on the posterior surface of the rods between L5 and S1 screws (10; Fig. 1, A and B). Strain gauges on the iliac bolt connectors were placed on the posterior surface of the iliac bolt connectors between S1 and the iliac screws (11; Fig. 1, A and B).

Details of the Strain Evaluation and Presentation

The classical definition of engineering strain is “the ratio of change of the material’s length (ΔL) to the initial length (L) after application of force ($\varepsilon = \Delta L/L$)” (Fig. 2) [2]. The magnitude of strain is small, and strain may be expressed mathematically as a percentage ($\varepsilon = \Delta L/L \times 100\%$), or in micro-strain ($\varepsilon = \Delta L/L \times 10^6 \mu\varepsilon$) [2]. In bending, strain depends on the bending conditions such as location of force application, bending radius, angular dislocation, and localization within the specimen. A simplified example is shown in Fig. 3. This example shows that if the force applied is small (L), even small angular displacement can cause large strain at the tensile surface of the material; this strain decreases on the compressive side of the specimen. If the lever arm of the applied force is longer, even a relatively small force may lead to angular displacement, which corresponds with strain at the specimen’s surface. For example, if the thickness (diameter) of a material is equal to the bending radius (R = 6mm) such as the diameter of screws and rods