

Supplementary Information of the manuscript

Experimental *ex vivo* characterization of the biomechanical effects of laminectomy and posterior fixation of the lumbo-sacral spine

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Additional details about the preparation and testing of the spine segments.

Table S1 – Details about specimens' preparation and mechanical tests. The first column reports if relevant osteophytes were present, and how they were treated. The last three columns indicate the offsets applied in flexion, extension, and lateral bending. The three specimens indicated with * had nearly no lordosis and in extension it was necessary to apply an offset of 150% of the antero-posterior length of L4-vertebra, instead of 100%. Median and interquartile range (IQR) are reported for the offsets.

Specimen	Presence of relevant osteophytes	Offset		
		Flexion (mm)	Extension (mm)	Lateral Bending (mm)
#1	L5-S1 left and right, removed	10.2	34.0	21.9
#2	L4-L5 left, removed; bridge L5-S1 left, removed	10.6	35.5	24.7
#3	none	9.2	45.8*	21.8
#4	none	8.7	43.5*	18.7
#5	none	8.6	42.8*	22.3
#6	L4-L5 left and right, removed	12.6	42.0	25.6
#7	L5-S1 right, removed	8.8	29.2	17.9
#8	none	8.9	31.6	19.3
#9	L2-L3 right, removed	10.4	34.7	23.1
#10	none	9.4	31.4	21.3
#11	L5-S1 left and right, removed	9.4	31.3	21.3
#12	L5-S1 right, removed	10.5	35.0	21.9
Median	-	9.4	34.0	21.9
IQR	-	1.6	3.6	1.7

Additional details on the analysis of the impact of the choice of the facet size and grid spacing on the precision and spatial resolution of the strain measurements.

The zero strain analysis on two consecutive unloaded images allows to quantify the intrinsic uncertainties of the DIC measurements, a zero-strain analysis was performed on two consecutive unloaded images of each specimen²⁹. If no loads are applied, no displacements and strain should be theoretically measured. So, any value of displacement and strain different from zero should be accounted as measurement error. In order to choose the optimal DIC correlation parameters, a detailed analysis of the variation of the precision (quantified by the random error) of the strain measurements at different facet sizes, grid spacing, and resolution was performed.

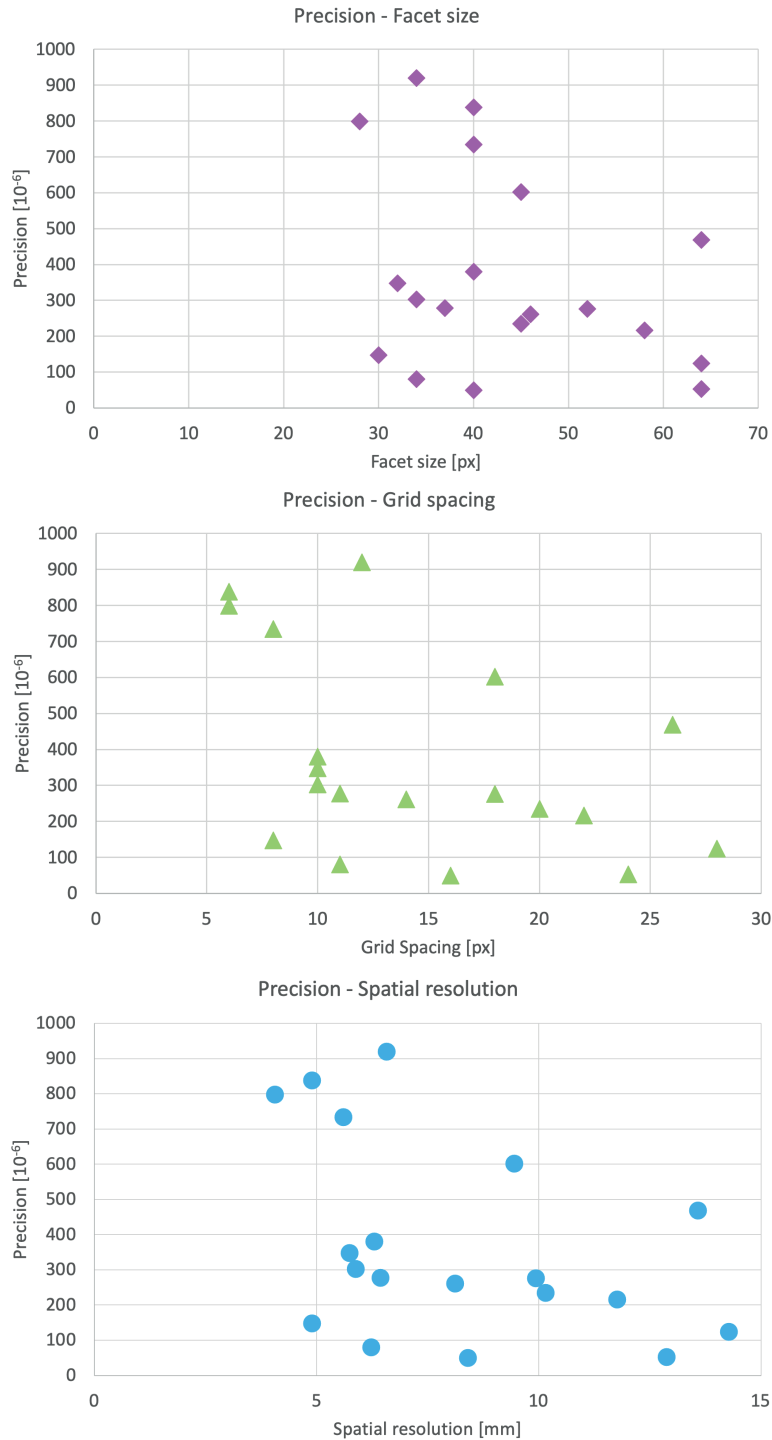


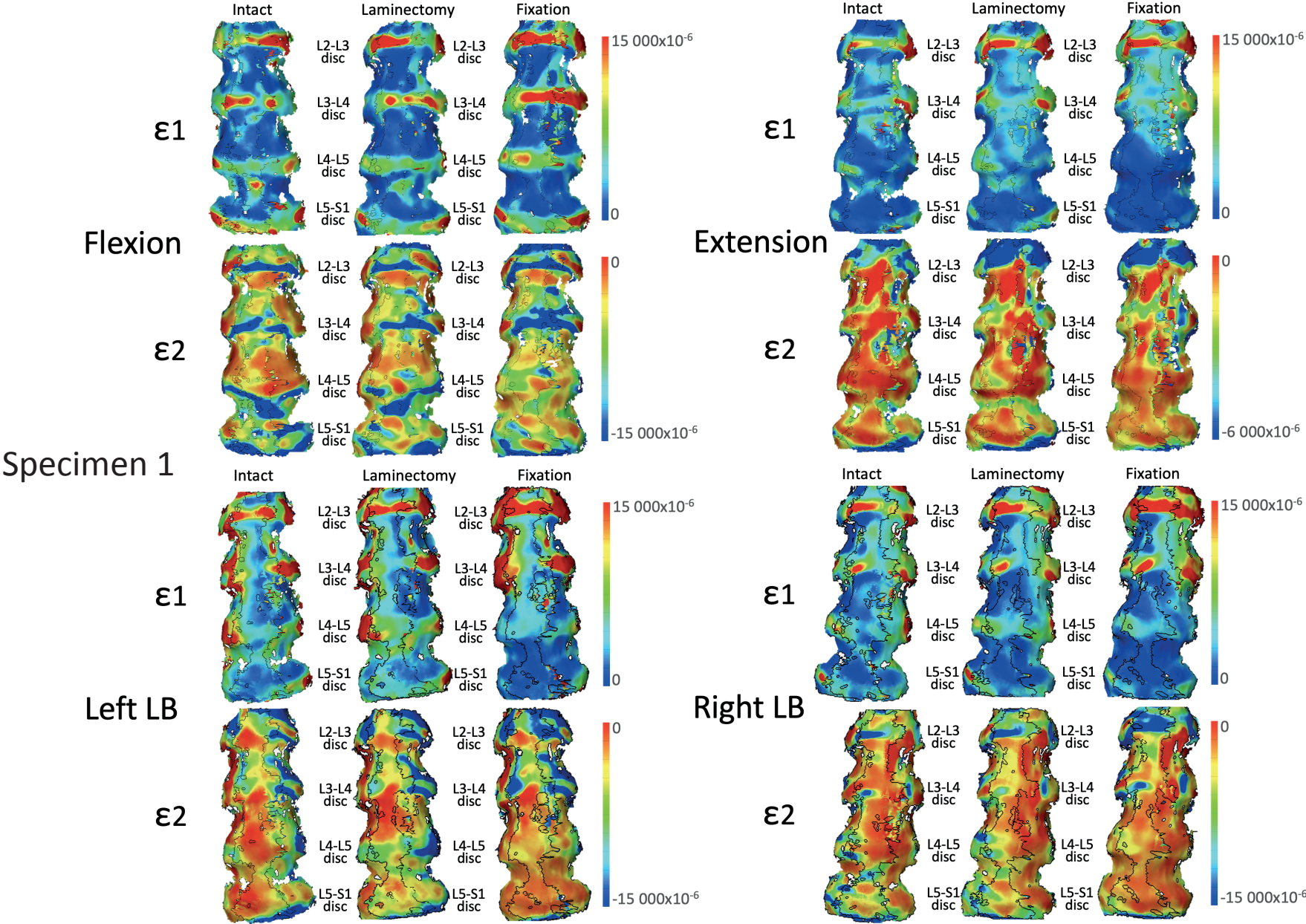
Fig. S1 – Analysis of the variation of the precision of strain measurements with respect to different facet sizes (top), grid spacing (middle), and spatial resolutions (bottom). One pixel corresponded on average to 0.07 mm on the specimen surface.

Quantitative analysis of mean strains on the surface of the intervertebral discs.

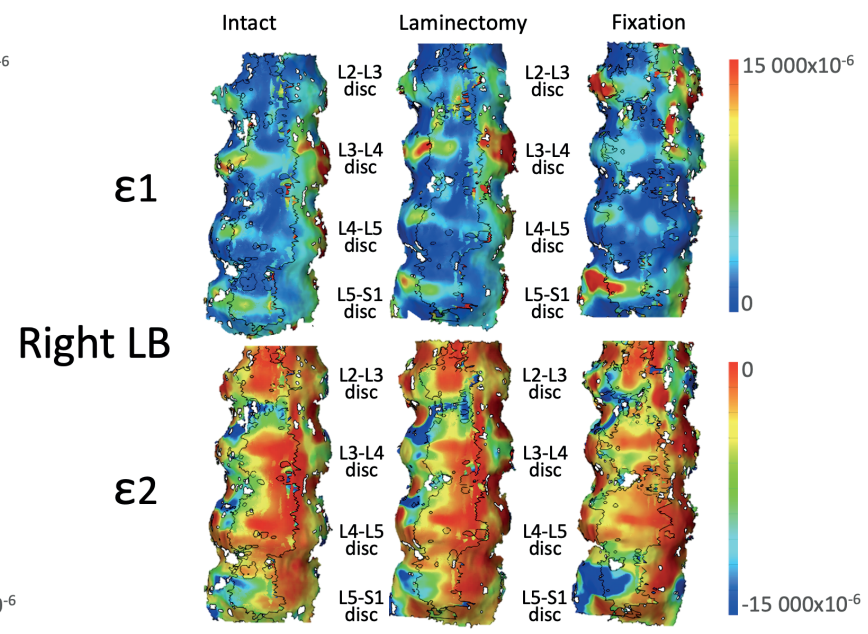
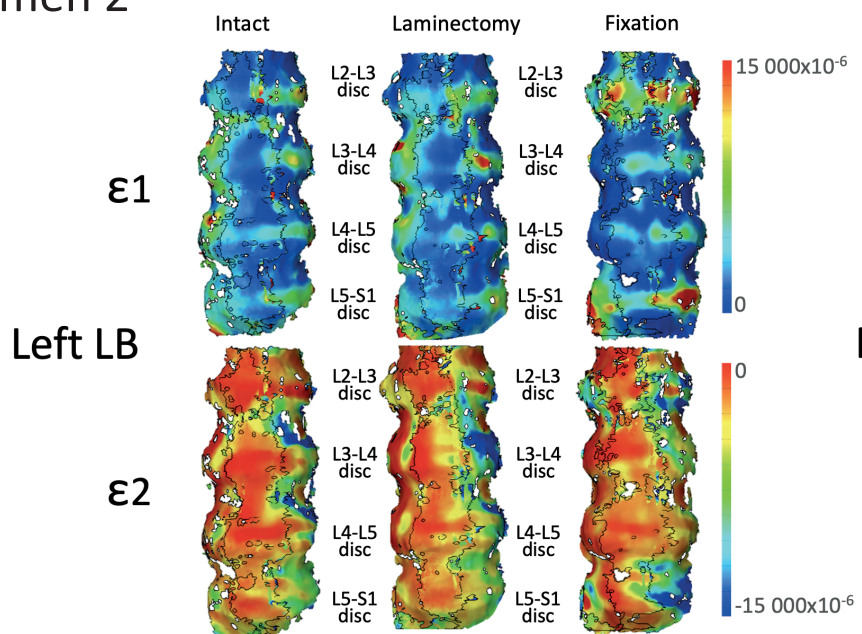
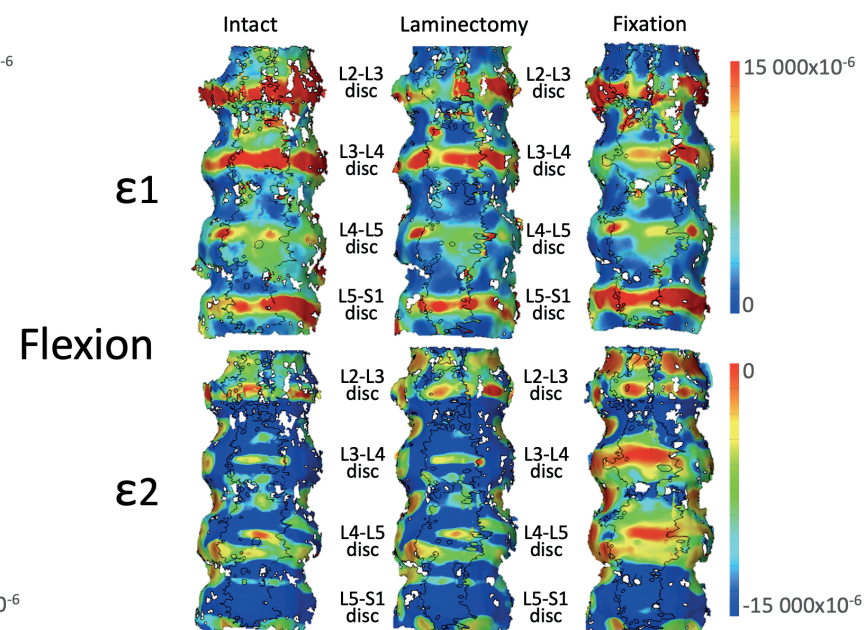
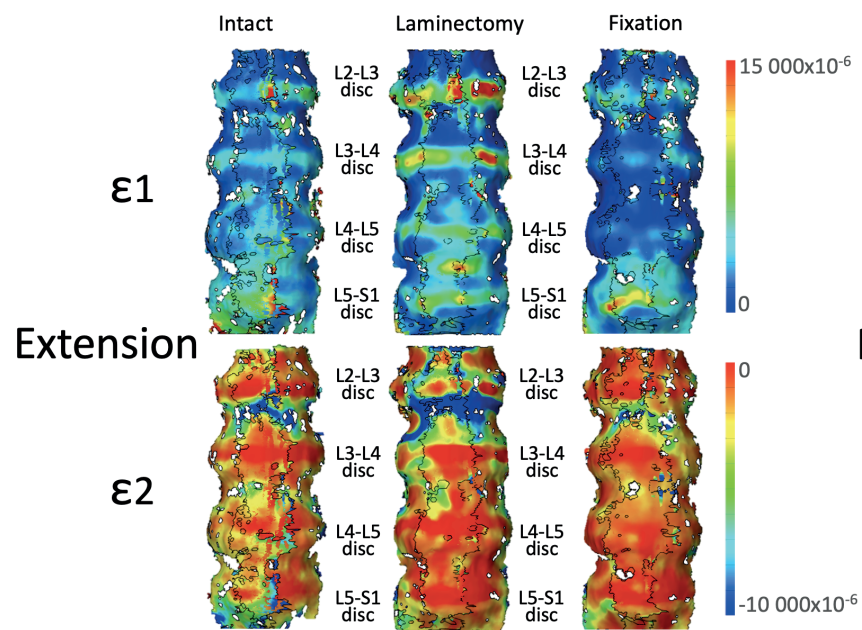
Table S2 – Mean tensile (ϵ_1) and compressive (ϵ_2) strain in each intervertebral disc for each spine condition and loading configuration. The values reported are normalized with respect to the intact condition. A value of 1.0 indicates no change with respect to the intact condition. Values greater than 1.0 indicate that larger strains were measured after laminectomy/fixation, if compared to the intact. These data are referred to Fig. 11 in the main manuscript. Median and interquartile range (IQR) among all the specimens are reported.

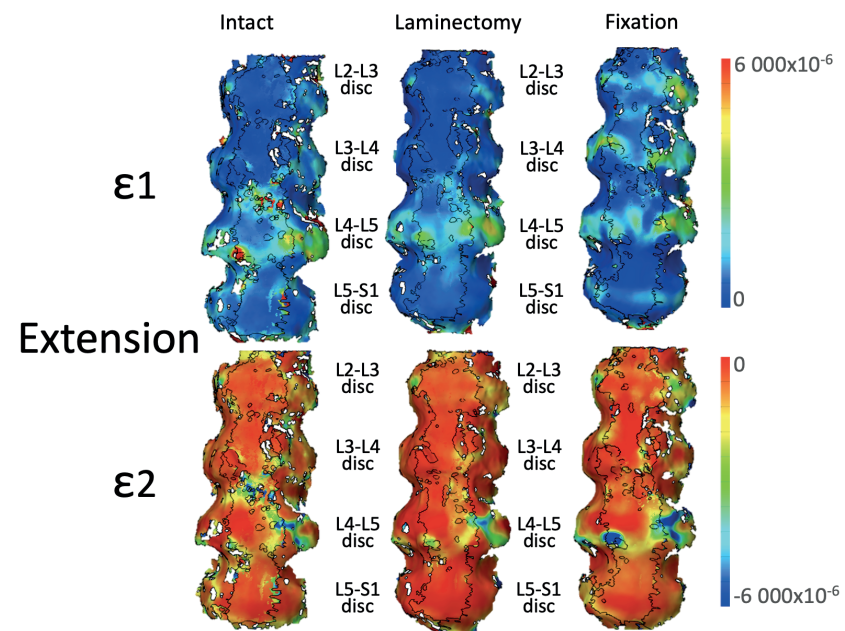
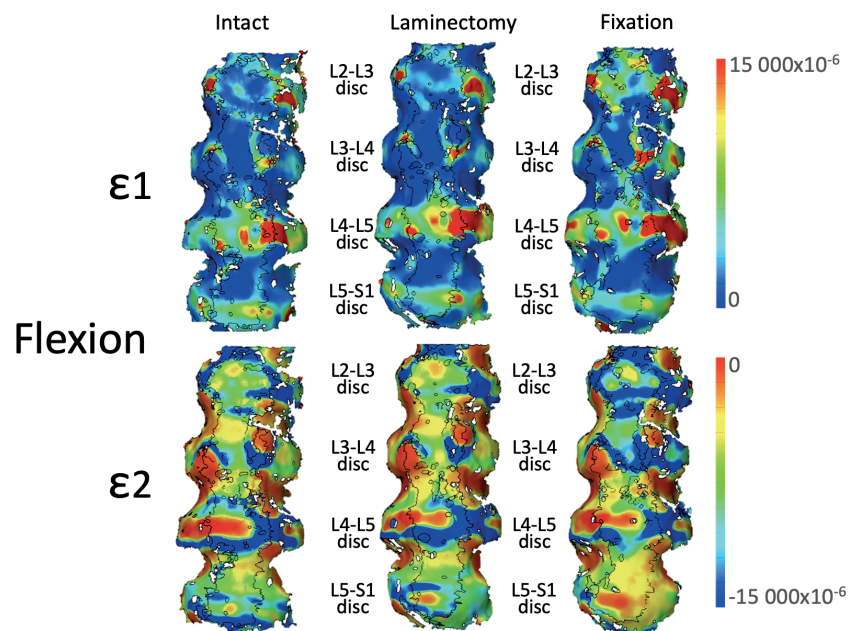
		ϵ_1				ϵ_2			
		Laminectomy		Fixation		Laminectomy		Fixation	
		Median	IQR	Median	IQR	Median	IQR	Median	IQR
L2-L3	Flexion	0.94	0.43	1.24	0.93	1.03	0.09	1.46	0.33
	Extension	1.16	0.80	1.94	0.63	1.66	0.79	1.25	0.73
	Lateral Bending	0.88	0.49	1.46	0.46	1.04	0.29	1.39	1.03
L3-L4	Flexion	0.88	0.26	1.11	1.30	0.93	0.25	1.22	0.58
	Extension	1.06	1.09	0.99	1.11	0.63	1.67	0.65	0.15
	Lateral Bending	0.95	0.16	1.45	0.47	1.05	0.40	1.51	0.69
L4-L5	Flexion	0.82	0.15	0.70	0.31	0.86	0.27	0.36	0.21
	Extension	1.61	0.99	0.59	0.09	0.97	0.72	1.15	0.96
	Lateral Bending	1.03	0.12	0.55	0.10	1.22	0.24	0.68	0.27
L5-S1	Flexion	0.80	0.16	0.76	0.18	0.95	0.22	0.75	0.60
	Extension	1.04	0.32	0.66	0.34	0.57	0.29	0.88	0.40
	Lateral Bending	0.95	0.05	0.76	0.14	0.97	0.29	0.73	0.18

Qualitative analysis of the strain distribution on the surface of the intervertebral discs

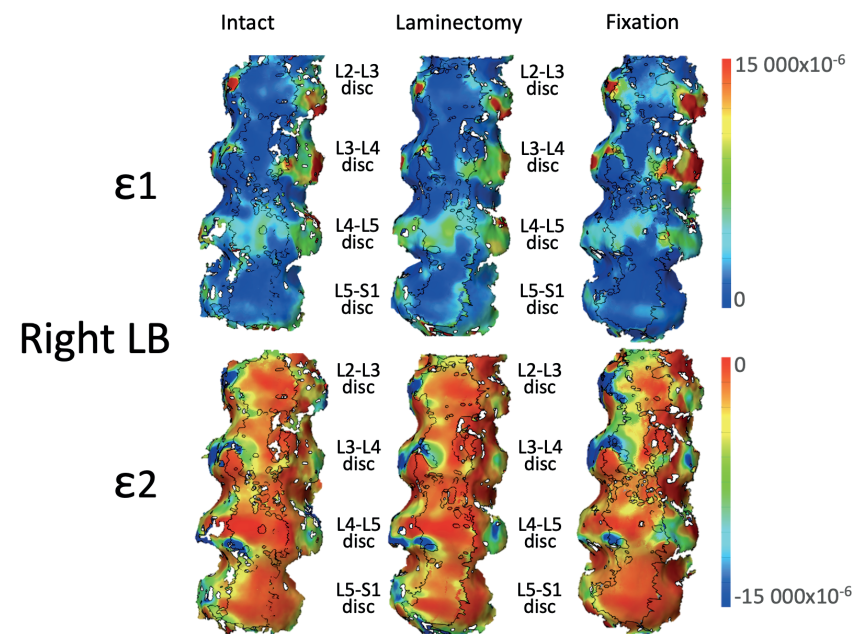
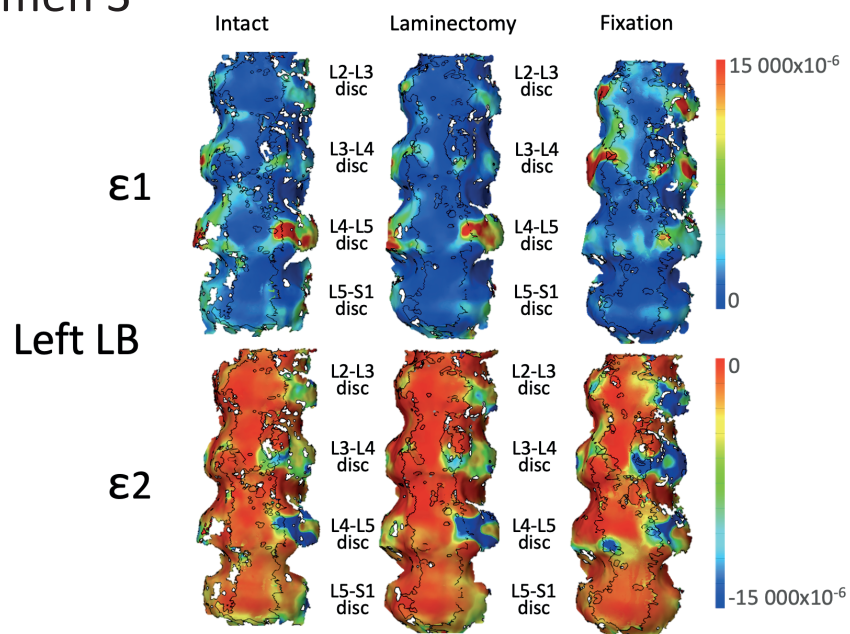


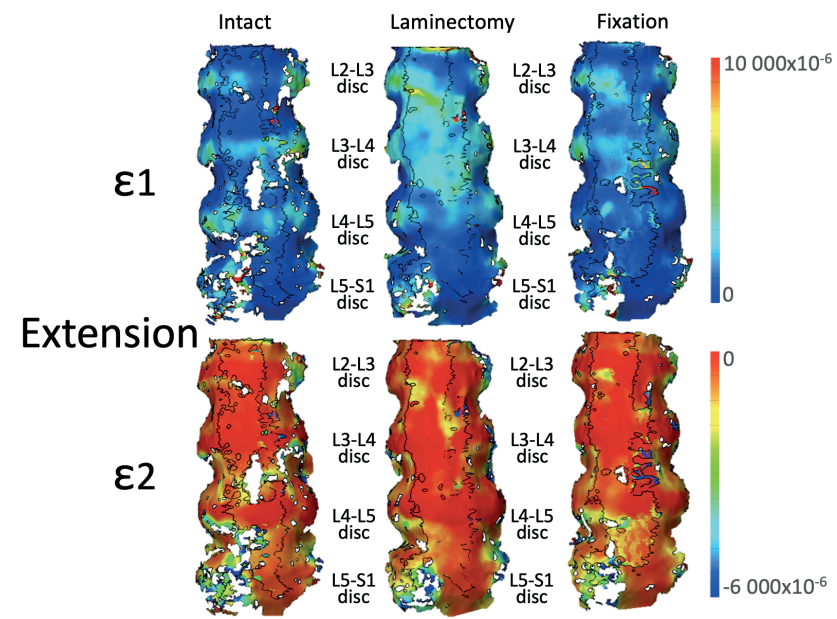
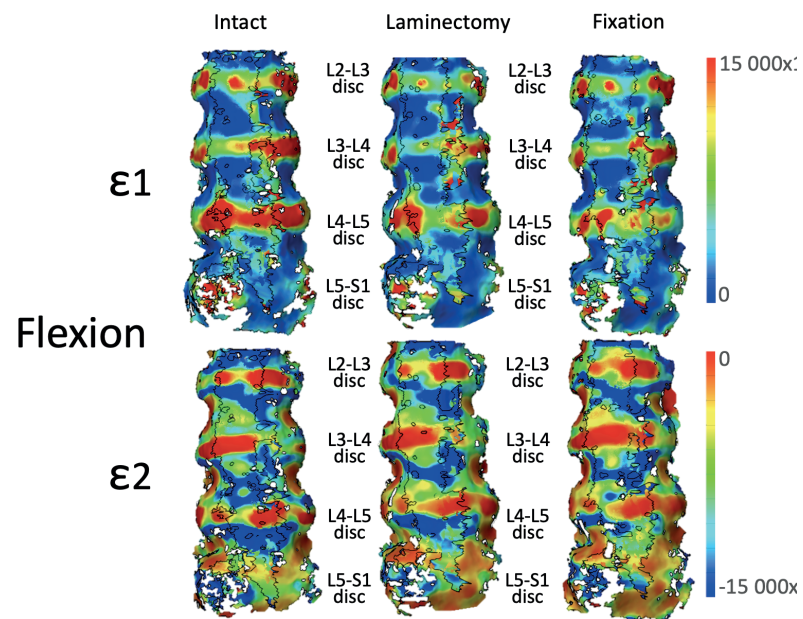
Specimen 2



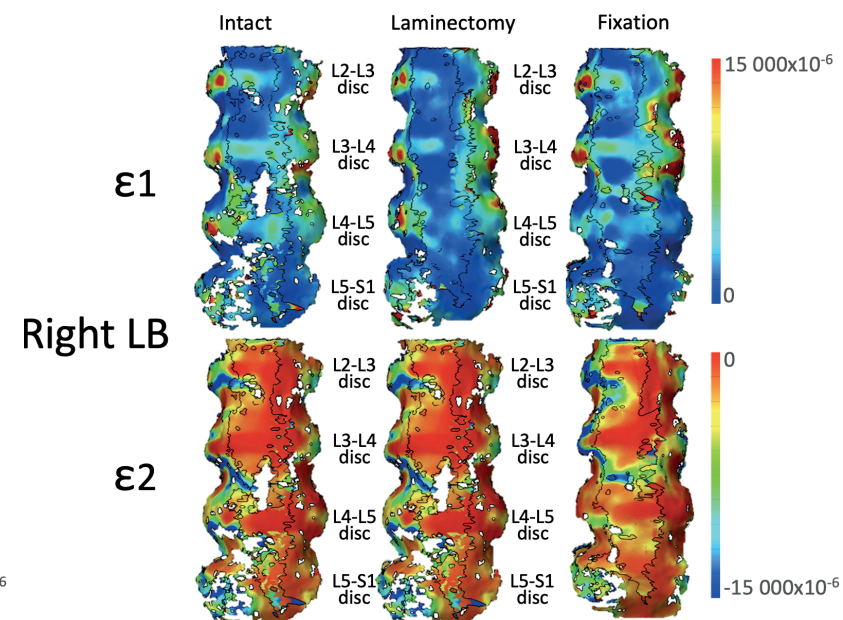
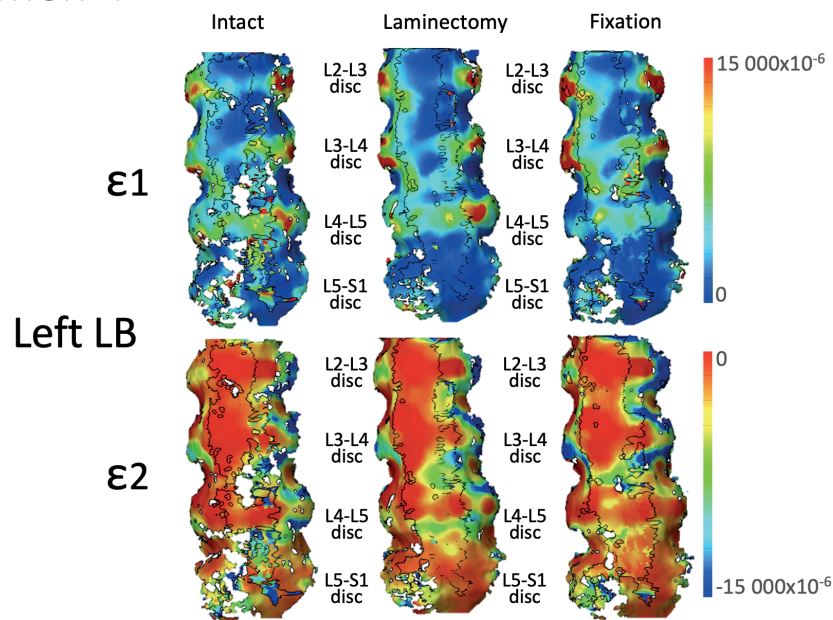


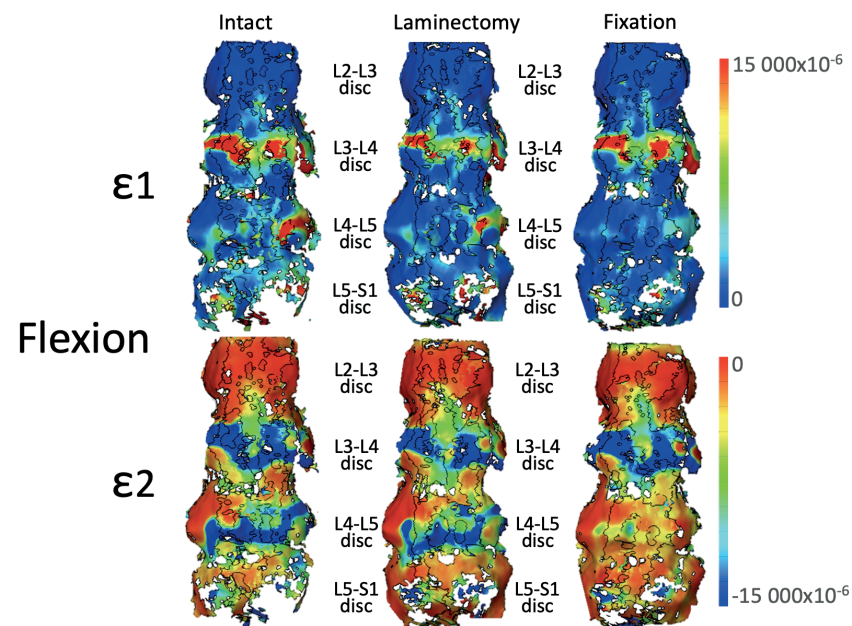
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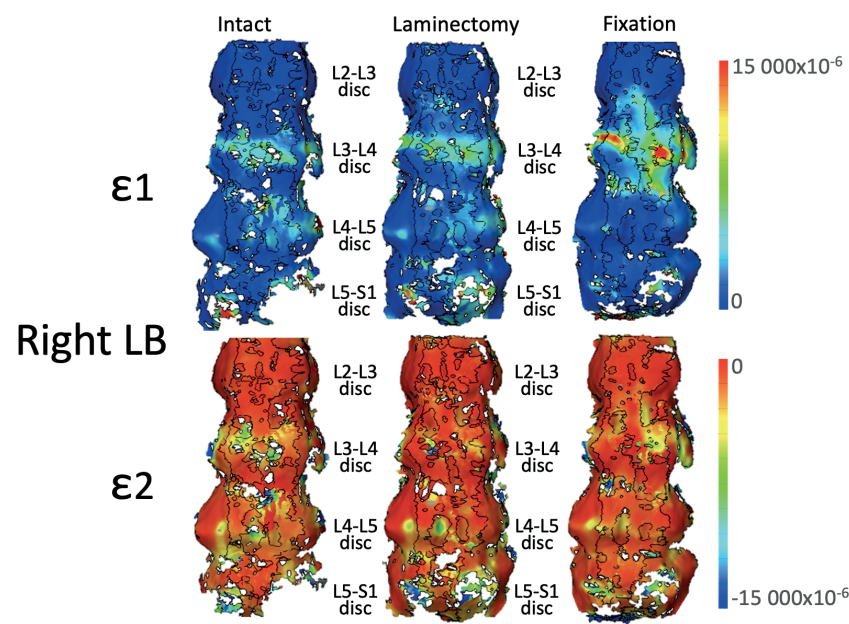
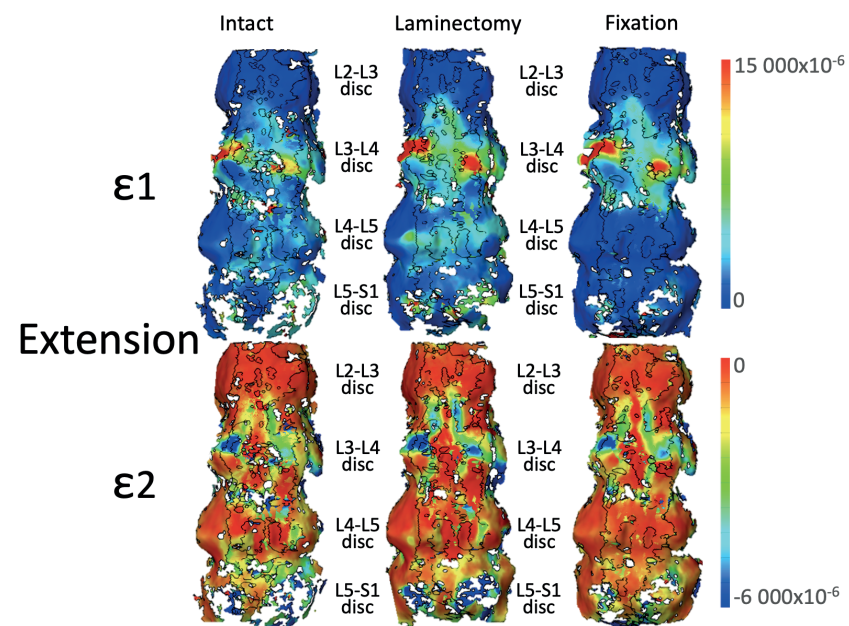
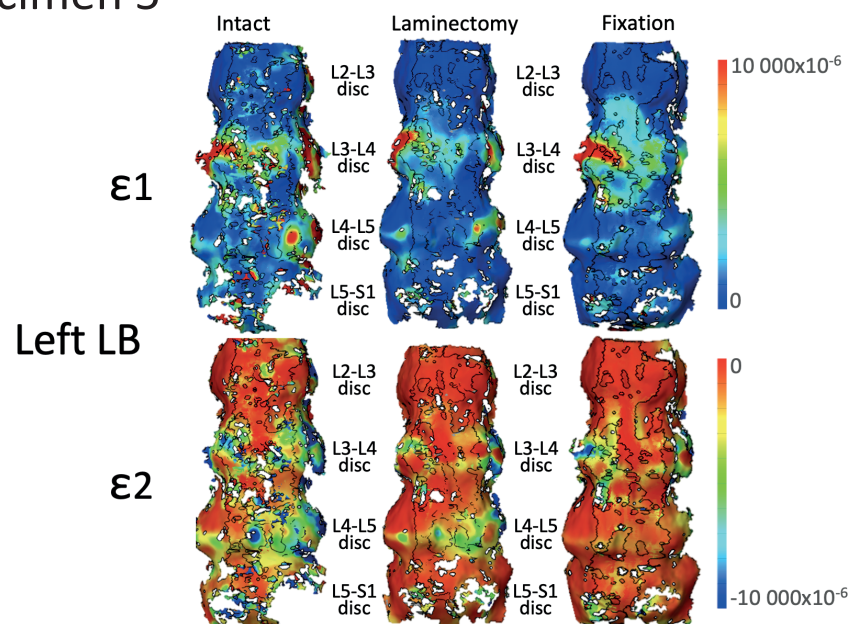


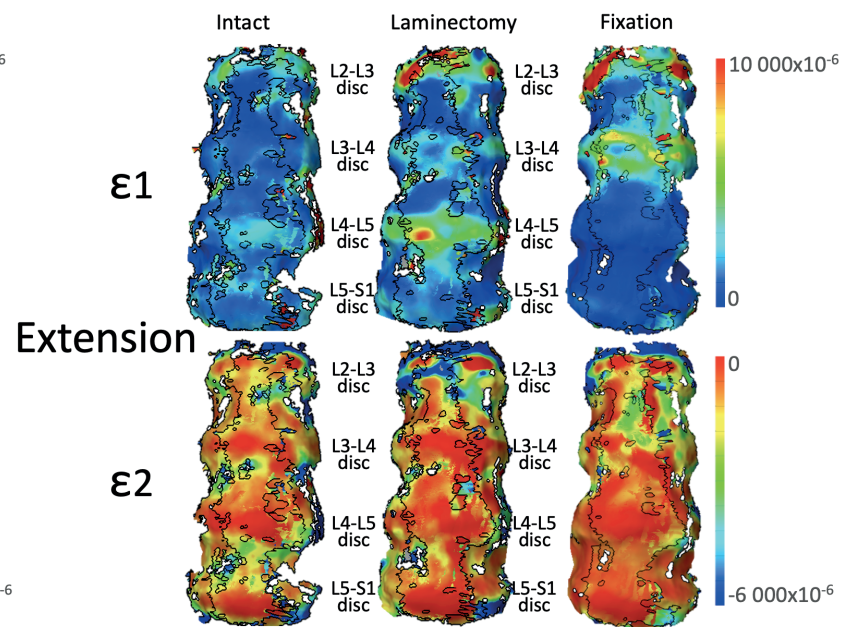
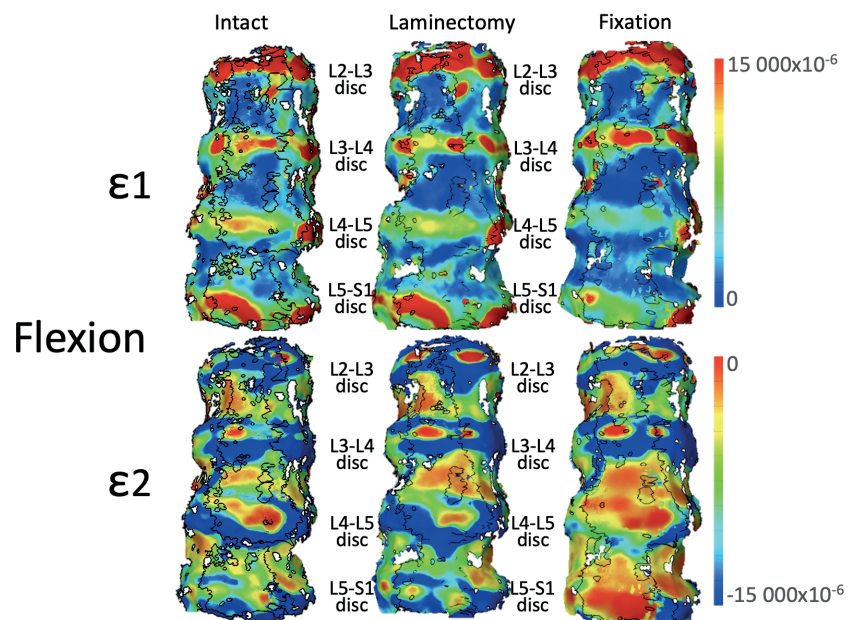
Specimen 4





Specimen 5





Specimen 6

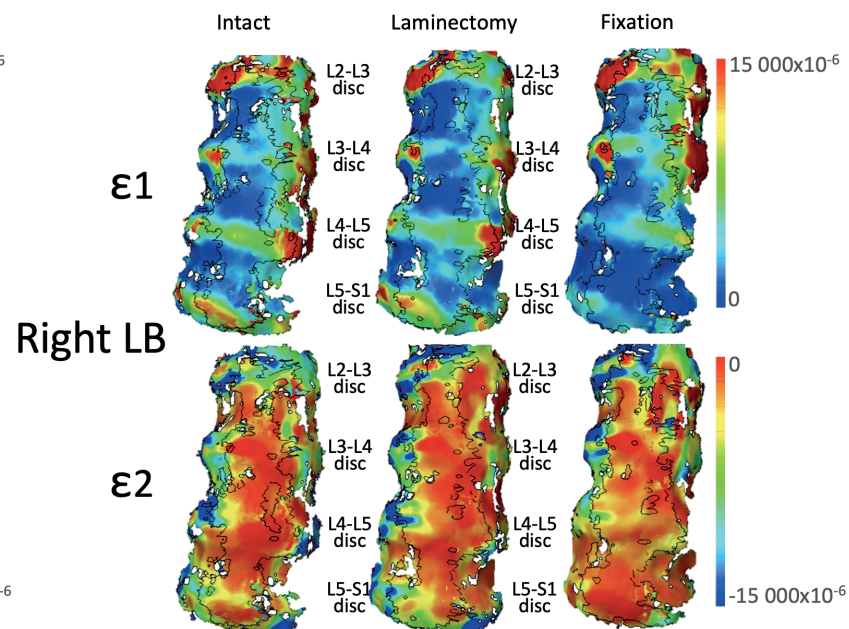
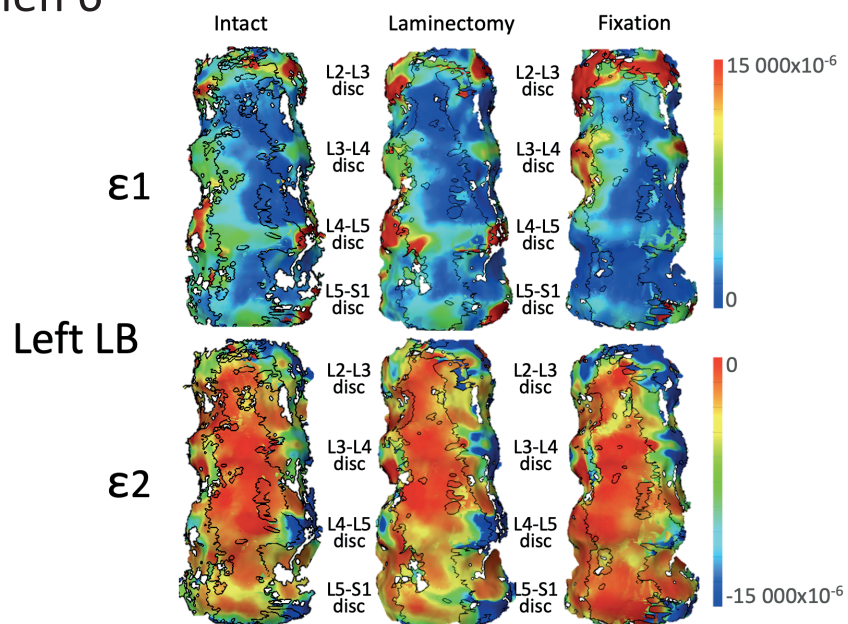


Fig. S2 –Full-field distribution of the maximum (tensile, ϵ_1 , top) and minimum (compressive, ϵ_2 , bottom) strains on the anterior and lateral surface of a typical specimen: Flexion, extension, left lateral bending and right lateral bending. The strain maps in the intact condition, after laminectomy, and after posterior fixation are reported. The false-colour maps indicate the magnitude of the measured natural (true) strains (legend on the far right). Some strain peaks are also visible on the anterior longitudinal ligament in front of some of the vertebrae, but these were not relevant for this study. The alignment of the principal strains is shown by the black tensile arrows (ϵ_1) and by the white ones (ϵ_2).

The first specimen is the same specimen reported in the paper.

Quantitative analysis of largest strains on the surface of the intervertebral discs.

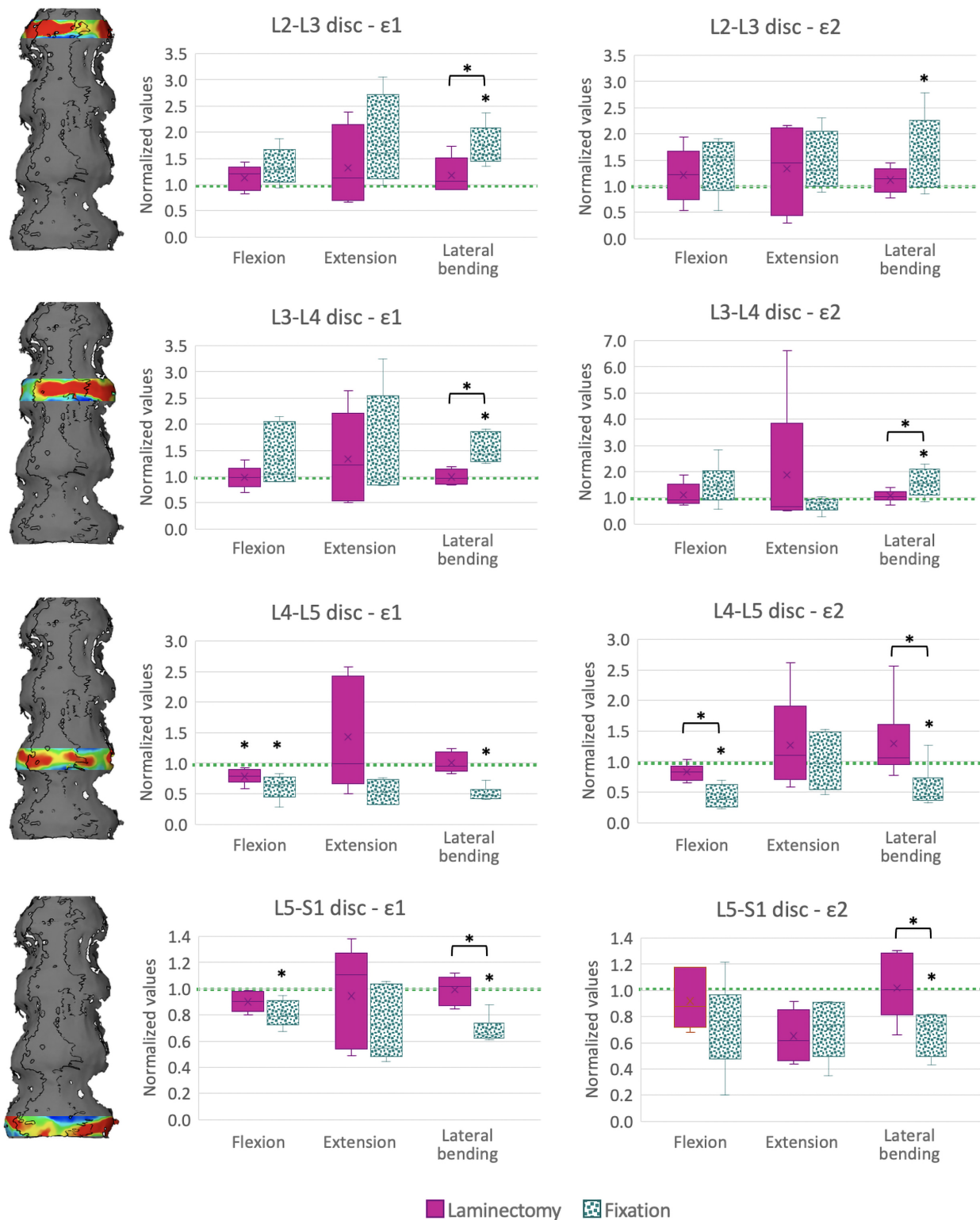


Fig. S3 - Largest tensile (ϵ_1 , left plots) and compressive (ϵ_2 , right plots) strains on the L2-L3, L3-L4, L4-L5 and L5-S1 intervertebral discs, in flexion, extension, and lateral bending after the two-level laminectomy, and after posterior fixation. Largest strains on the surface of each intervertebral disc were computed as the 95% and 5% percentile for tensile and compressive stain, respectively, in order to avoid local measurements artifacts. All the data were normalized with respect to the intact condition (dashed green line), and averaged between all the specimens. A value larger than 1.0 indicates an increase of strain magnitude with respect to the intact condition. The bottom of the box represents the first quartile (25th percentile) of the data; the horizontal line inside the box represents the median of the data and the top of the box represents the third

quartile (75th percentile). The “X” cross represents the mean of the data. The top and bottom whiskers include the maximum and the minimum data, excluding the outliers which are shown as dots.

The asterisks * above the box indicate a statistically significant differences (post-hoc) with respect to the intact condition ($p < 0.05$). The asterisks * above the squared brackets indicate a significant difference between the laminectomy and fixation conditions.