

# **Load-sharing biomechanics of lumbar fixation and fusion with pedicle subtraction osteotomy**

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**Supplementary Table 1:** Local (L3-L5) range of motion (RoM) and neutral zone (NZ) for each specimen in every loading condition for each instrumentation step.

Specimen	Condition	Flexion/Extension		Lateral Bending		Axial Torsion	
		RoM (°)	NZ (°)	RoM (°)	NZ (°)	RoM (°)	NZ (°)
#1	Intact	12.0	3.7	13.6	5.3	8.5	1.8
	PSO-2	0.6	0.1	0.0	0.0	1.7	0.1
	PSO-2+Cages	0.3	0.1	0.0	0.0	1.5	0.0
	PSO-4+Cages	0.2	0.0	0.0	0.0	1.2	0.1
#2	Intact	9.7	1.9	12.4	4.4	7.8	0.8
	PSO-2	0.5	0.0	-0.1	0.0	1.4	0.1
	PSO-2+Cages	0.3	0.1	0.0	0.0	1.5	0.2
	PSO-4+Cages	0.4	-0.1	0.0	0.0	1.4	0.2
#3	Intact	14.5	5.5	12.8	3.7	5.4	0.8
	PSO-2	0.0	-0.1	-0.3	0.0	1.5	0.1
	PSO-2+Cages	-0.5	0.1	0.0	0.1	1.5	0.2
	PSO-4+Cages	-0.4	-0.1	0.0	0.1	1.4	0.1

**Supplementary Table 2:** Median [min; max] tensile ( $\epsilon_1$ ) and compressive ( $\epsilon_2$ ) strains measured on the ventral spine, on the sub-ROIs at PSO level (L4 VB) and the IVD below (L4-L5), and on primary rods at full load ( $\pm 7.5\text{Nm}$ ) for each loading condition and instrumentation step.

**VENTRAL STRAINS - PSO LEVEL (L4 VB)**

Condition		Flexion	Extension	Lateral Bending		Axial Torsion	
		Median [min; max] ( $\mu\text{strains}$ )	Median [min; max] ( $\mu\text{strains}$ )	Ipsilateral Median [min; max] ( $\mu\text{strains}$ )	Contralateral Median [min; max] ( $\mu\text{strains}$ )	Ipsilateral Median [min; max] ( $\mu\text{strains}$ )	Contralateral Median [min; max] ( $\mu\text{strains}$ )
<b>Intact</b>	$\epsilon_1$	4419 [3404; 5077] (*)	11796 [5595; 17996] (*)	5357 [1595; 10642] (*)	7076 [2063; 17813] (*)	8297 [2187; 18756] (*)	6488 [5057; 20052] (*)
	$\epsilon_2$	-15321 [-19389; -15011] (*)	-10550 [-19208; -1892] (*)	-7679 [-19532; -2055] (*)	-3160 [-12002; -39]	-6622 [-10023; -1504] (*)	-5066 [-11254; -3328] (*)
<b>PSO-2</b>	$\epsilon_1$	1059 [451; 2322]	1524 [450; 3136]	734 [357; 2325] (§)	897 [531; 1922] (#)	2821 [1647; 4156]	2620 [663; 3686]
	$\epsilon_2$	-2362 [-6970; -450]	-440 [-1875; -399]	-1074 [-2625; -570] (§)	-944 [-1576; -284]	-2554 [-4933; -550]	-2428 [-4761; -1505]
<b>PSO-2+Cages</b>	$\epsilon_1$	1449 [1237; 1660]	2369 [1793; 2945]	1178 [190; 1733]	1136 [780; 7850]	3009 [2001; 5815]	2145 [1438; 10367]
	$\epsilon_2$	-2692 [-3403; -1980]	-1245 [-1325; -1164]	-939 [-2754; -437] (§)	-970 [-1629; -672]	-1935 [-3321; -1603]	-2719 [-4931; -1982]
<b>PSO-4+Cages</b>	$\epsilon_1$	1534 [855; 1963]	2222 [1963; 3108]	910 [378; 1695] (§)	915 [575; 1736] (§)	2816 [1196; 3916]	1878 [1078; 2177] (#)
	$\epsilon_2$	-2244 [-2591; -2058]	-1479 [-1609; -865]	-959 [-1742; -494] (§)	-813 [-1594; -303]	-1742 [-2436; -949] (§)	-2256 [-4271; -1586] (§)

(\*):  $p < 0.05$  vs. all "PSO" cases.

(#):  $p < 0.017$  vs. "Intact".

(§):  $p < 0.05$  vs. "Intact".

Supplementary Table 2: ...continuation

VENTRAL STRAINS - BELOW PSO LEVEL (L4-L5 IVD)

Condition		Flexion	Extension	Lateral Bending		Axial Torsion	
		Median [min; max] ( $\mu$ strains)	Median [min; max] ( $\mu$ strains)	Ipsilateral Median [min; max] ( $\mu$ strains)	Contralateral Median [min; max] ( $\mu$ strains)	Ipsilateral Median [min; max] ( $\mu$ strains)	Contralateral Median [min; max] ( $\mu$ strains)
<b>Intact</b>	$\epsilon_1$	18613 [12948; 19711] (*)	20878 [18730; 23025] (*)	12048 [2214; 35789] (*)	9741 [890; 14448] (*)	23552 [5338; 48700] (*)	27312 [16590; 50985] (*)
	$\epsilon_2$	-23009 [-23264; -11530] (*)	-8319 [-10714; -5923] (*)	-11022 [-22819; -4262] (*)	-10436 [-27986; -2149] (*)	-30291 [-44627; -15277] (*)	-22255 [-45939; -7354] (*)
<b>PSO-2</b>	$\epsilon_1$	3889 [508; 8800]	1510 [481 ;2365]	2056 [884; 6463]	1450 [1191; 3560]	5245 [3580; 7134]	6362 [2857; 12835] (§)
	$\epsilon_2$	-1392 [-7237; -605]	-1150 [-5014; -565]	-1583 [-3016; -1006] (#)	-1796 [-9345; -1237]	-6317 [-14297; -3423]	-5870 [-8309; -4544]
<b>PSO-2+Cages</b>	$\epsilon_1$	1521 [890; 2151]	2275 [1804; 2745]	2502 [1640; 4113]	2097 [1276; 3001]	5556 [2999; 11971]	6337 [3490; 13776] (§)
	$\epsilon_2$	-1954 [-2188; -1720]	-1344 [-1774; -914]	-1949 [-2721; -1380]	-2536 [-4630; -1220]	-5909 [-14516; -4140]	-5946 [-10714; -2039]
<b>PSO-4+Cages</b>	$\epsilon_1$	1334 [1244; 1968]	2071 [1496; 2358]	1558 [1011; 3602] (§)	1514 [1003; 1997]	4071 [2944; 8718] (§)	5391 [3213; 11280] (#)
	$\epsilon_2$	-1880 [-2227; -1728]	-1713 [-1860; -981]	-1545 [-3539; -1004] (#)	-1730 [-2770; -913] (§)	-4207 [-6409; -1076] (#)	-4681 [-8704; -3061] (§)

(\*):  $p < 0.05$  vs. all "PSO" cases.

(#):  $p < 0.017$  vs. "Intact".

(§):  $p < 0.05$  vs. "Intact".

Supplementary Table 2: ...continuation

POSTERIOR STRAINS - PRIMARY RODS

Condition		Flexion	Extension	Lateral Bending		Axial Torsion	
		Median [min; max] ( $\mu$ strains)	Median [min; max] ( $\mu$ strains)	Ipsilateral Median [min; max] ( $\mu$ strains)	Contralateral Median [min; max] ( $\mu$ strains)	Ipsilateral Median [min; max] ( $\mu$ strains)	Contralateral Median [min; max] ( $\mu$ strains)
PSO-2	$\epsilon_1$	392 [221; 447]	109 [81; 161]	185 [ 80; 349]	66 [38; 121]	282 [211; 351]	229 [169; 367]
	$\epsilon_2$	-120 [-139; -74]	-381 [-567; -266]	-78 [-167; -45]	-231 [-402; -130]	-250 [-358; -182]	-283 [-338; -220]
PSO-2+Cages	$\epsilon_1$	291 [178; 383]	96 [70; 137]	175 [81; 325]	64 [34; 122]	296 [236; 344]	237 [149; 362]
	$\epsilon_2$	-85 [-116; -59]	-329 [-483; -218]	-58 [-157; -36]	-197 [-433; -82]	-238 [-355; -178]	-283 [-346; -210]
PSO-4+Cages	$\epsilon_1$	189 (**) [128; 235]	66 (**) [48; 94]	155 [86; 267]	53 [26; 79]	188 (**, §§) [101; 211]	130 [88; 262]
	$\epsilon_2$	-60 (**) [-68; -43]	-232 (**) [-315; -156]	-51 [-89; -28]	-172 [-240; -75]	-168 [-313; -101]	-173 (**, ##) [-240; -115]

(\*\*):  $p < 0.017$  vs. "PSO-2".

(§§):  $p < 0.017$  vs. "PSO-2+Cages".

(##):  $p < 0.05$  vs. "PSO-2+Cages".

**Supplementary Table 3:** Tensile ( $\epsilon_1$ ) and compressive ( $\epsilon_2$ ) strains measured on the ventral spine, on the sub-ROIs at PSO level (L4 VB) and the IVD below (L4-L5), and on primary rods at full load ( $\pm 7.5\text{Nm}$ ) for each specimen in every loading condition and instrumentation step.

**VENTRAL STRAINS - PSO LEVEL (L4 VB)**

Specimen	Condition		Flexion ( $\mu\text{strains}$ )	Extension ( $\mu\text{strains}$ )	Lateral Bending				Axial Torsion			
					Right		Left		Right		Left	
					ipsilateral ( $\mu\text{strains}$ )	contralateral ( $\mu\text{strains}$ )	contralateral ( $\mu\text{strains}$ )	ipsilateral ( $\mu\text{strains}$ )	ipsilateral ( $\mu\text{strains}$ )	contralateral ( $\mu\text{strains}$ )	contralateral ( $\mu\text{strains}$ )	ipsilateral ( $\mu\text{strains}$ )
#1	Intact	$\epsilon_1$	4419	5595	4347	11351	11975	1945	14965	12233	20052	18756
		$\epsilon_2$	-19389	-19208	-19532	-2938	-652	-12332	-9103	-9278	-11254	-10023
	PSO-2	$\epsilon_1$	1059	3136	1664	918	876	575	3350	1874	3686	2470
		$\epsilon_2$	-2362	-1875	-1384	-761	-1126	-803	-2381	-1936	-3988	-2726
	PSO-2+Cages	$\epsilon_1$	not available	not available	190	780	1252	808	3760	1990	2300	3318
		$\epsilon_2$	not available	not available	-827	-773	-672	-437	-1603	-2180	-3258	-2472
	PSO-4+Cages	$\epsilon_1$	855	2222	388	896	608	378	3057	1078	1655	3115
		$\epsilon_2$	-2058	-865	-494	-303	-488	-1066	-949	-2334	-2493	-1514
#2	Intact	$\epsilon_1$	3404	17996	1595	17813	2659	8705	2187	7449	5390	6451
		$\epsilon_2$	-15321	-1892	-2779	-39	-3935	-12985	-1504	-5419	-3328	-6113
	PSO-2	$\epsilon_1$	2322	1524	758	726	531	357	1647	663	1570	2217
		$\epsilon_2$	-6970	-399	-579	-284	-530	-570	-1596	-1840	-1505	-550
	PSO-2+Cages	$\epsilon_1$	1660	2945	1177	1020	832	1178	2001	1438	3303	2699
		$\epsilon_2$	-3403	-1325	-794	-1015	-972	-1050	-1949	-1997	-1982	-1797
	PSO-4+Cages	$\epsilon_1$	1534	3108	918	933	575	916	1196	1466	2101	2089
		$\epsilon_2$	-2591	-1609	-761	-821	-804	-851	-1717	-2060	-1586	-1766
#3	Intact	$\epsilon_1$	5077	not available	10642	2800	2063	6367	10144	5527	5057	6400
		$\epsilon_2$	-15011	not available	-2055	-12002	-3383	-3026	-7130	-4409	-4712	-5214
	PSO-2	$\epsilon_1$	451	450	2325	1496	1922	709	4156	3366	3523	3171
		$\epsilon_2$	-450	-440	-2625	-1576	-1179	-1346	-3384	-2920	-4761	-4933
	PSO-2+Cages	$\epsilon_1$	1237	1793	1733	1533	7850	1271	5815	10367	1988	2651
		$\epsilon_2$	-1980	-1164	-2754	-1629	-967	-1194	-3321	-4931	-4615	-1921
	PSO-4+Cages	$\epsilon_1$	1963	1963	903	1736	1735	1695	3916	2120	2177	2575
		$\epsilon_2$	-2244	-1479	-1742	-1594	-1169	-1707	-1956	-2178	-4271	-2436

Supplementary Table 3: ...continuation.

**VENTRAL STRAINS - BELOW PSO LEVEL (L4-L5 IVD)**

Specimen	Condition		Flexion ( $\mu$ strains)	Extension ( $\mu$ strains)	Lateral Bending				Axial Torsion			
					Right		Left		Right		Left	
					ipsilateral ( $\mu$ strains)	contralateral ( $\mu$ strains)	contralateral ( $\mu$ strains)	ipsilateral ( $\mu$ strains)	ipsilateral ( $\mu$ strains)	contralateral ( $\mu$ strains)	contralateral ( $\mu$ strains)	ipsilateral ( $\mu$ strains)
#1	Intact	$\epsilon_1$	19711	23025	35789	12980	6502	14658	23331	25069	48320	48700
		$\epsilon_2$	-11530	-10714	-14506	-13797	-27986	-22819	-36727	-45939	-35396	-35254
	PSO-2	$\epsilon_1$	3889	2365	2115	1832	1601	1997	5852	8225	5338	5343
		$\epsilon_2$	-1392	-5014	-3016	-3539	-1237	-1200	-4934	-4615	-6682	-10263
	PSO-2+Cages	$\epsilon_1$	not available	not available	2783	2885	3001	2221	7305	13776	7079	11971
		$\epsilon_2$	not available	not available	-2721	-3313	-3608	-1986	-7009	-10714	-7584	-14516
	PSO-4+Cages	$\epsilon_1$	1968	2071	1011	1855	1595	3077	7053	11280	6772	8718
		$\epsilon_2$	-2227	-1860	-1004	-2491	-1572	-2444	-6409	-8704	-7857	-1076
#2	Intact	$\epsilon_1$	12948	18730	2214	14298	14448	10910	23772	23541	50985	19954
		$\epsilon_2$	-23264	-5923	-6044	-7074	-2149	-19971	-44627	-17515	-21595	-23263
	PSO-2	$\epsilon_1$	8800	1510	1868	1299	1191	884	7134	2857	6990	4622
		$\epsilon_2$	-7237	-1150	-2122	-1240	-1255	-1006	-7206	-4544	-8309	-3423
	PSO-2+Cages	$\epsilon_1$	2151	2745	1800	1823	1858	1640	5779	4084	5594	5332
		$\epsilon_2$	-2188	-1774	-2315	-1759	-1524	-1820	-4432	-4202	-7161	-5581
	PSO-4+Cages	$\epsilon_1$	1334	2358	1832	1003	1997	1231	4340	3213	4009	3782
		$\epsilon_2$	-1880	-1713	-3539	-913	-1200	-1141	-3627	-3433	-5360	-4174
#3	Intact	$\epsilon_1$	18613	not available	13186	4023	890	4885	5338	16590	29554	31269
		$\epsilon_2$	-23009	not available	-7538	-16266	-3397	-4262	-15277	-22914	-7354	-25328
	PSO-2	$\epsilon_1$	508	481	4113	3560	1214	6463	3580	12835	5734	5148
		$\epsilon_2$	-605	-565	-1418	-9345	-2337	-1748	-5428	-5059	-7888	-14297
	PSO-2+Cages	$\epsilon_1$	890	1804	2203	2335	1276	2835	2999	8596	3490	3838
		$\epsilon_2$	-1720	-914	-1911	-4630	-1220	-1380	-4140	-4730	-2039	-6238
	PSO-4+Cages	$\epsilon_1$	1244	1496	1284	1148	1433	3602	2944	7848	3267	3802
		$\epsilon_2$	-1728	-981	-1321	-2770	-1888	-1770	-4240	-4002	-3061	-5767

Supplementary Table 3: ...continuation.

**POSTERIOR STRAINS - PRIMARY RODS**

Specimen	Condition		Flexion		Extension		Lateral Bending				Axial Torsion			
			right rod ( $\mu$ strains)	left rod ( $\mu$ strains)	right rod ( $\mu$ strains)	left rod ( $\mu$ strains)	Right		Left		Right		Left	
							ipsilat. ( $\mu$ strains)	contralat. ( $\mu$ strains)	contralat. ( $\mu$ strains)	ipsilat. ( $\mu$ strains)	ipsilat. ( $\mu$ strains)	contralat. ( $\mu$ strains)	contralat. ( $\mu$ strains)	ipsilat. ( $\mu$ strains)
#1	PSO-2	$\epsilon_1$	318	221	112	81	228	63	69	139	351	367	245	241
		$\epsilon_2$	-94	-74	-395	-266	-75	-186	-223	-52	-273	-261	-311	-336
	PSO-2+Cages	$\epsilon_1$	285	178	94	70	205	62	66	146	344	341	246	240
		$\epsilon_2$	-83	-59	-327	-218	-66	-188	-207	-49	-258	-257	-313	-328
	PSO-4+Cages	$\epsilon_1$	152	128	52	48	184	56	51	126	209	195	144	146
		$\epsilon_2$	-45	-43	-181	-156	-61	-172	-172	-41	-313	-156	-191	-193
#2	PSO-2	$\epsilon_1$	447	394	107	104	80	38	39	141	294	213	210	270
		$\epsilon_2$	-134	-139	-367	-324	-81	-130	-240	-45	-227	-259	-304	-209
	PSO-2+Cages	$\epsilon_1$	294	289	97	106	81	51	34	122	280	200	229	323
		$\epsilon_2$	-87	-96	-330	-309	-41	-170	-82	-36	-218	-255	-309	-210
	PSO-4+Cages	$\epsilon_1$	235	170	94	82	86	34	26	112	211	88	117	196
		$\epsilon_2$	-68	-57	-315	-234	-28	-112	-75	-33	-143	-132	-204	-134
#3	PSO-2	$\epsilon_1$	439	389	161	115	327	104	121	349	211	360	169	337
		$\epsilon_2$	-133	-107	-567	-473	-95	-241	-402	-167	-182	-338	-220	-358
	PSO-2+Cages	$\epsilon_1$	383	316	137	82	287	93	122	325	236	362	149	312
		$\epsilon_2$	-116	-84	-483	-350	-87	-225	-433	-157	-178	-346	-210	-355
	PSO-4+Cages	$\epsilon_1$	207	226	79	50	267	79	66	213	101	262	95	181
		$\epsilon_2$	-66	-62	-292	-230	-81	-228	-240	-89	-101	-240	-115	-200