

Supplementary material S2

Additional data

Item Table of contents

Modified from existing literature

Table S1 Normalised cervical vertebrae measurements

Table S2 Normalised thoracic vertebrae measurements

Table S3 Normalised lumbar vertebrae measurements

Extrapolated from the digital model

Table S4 Minimum full ROM angular values of the entire spine (°)

Table S5 Average full ROM angular values of the entire spine (°)

Table S6 Cervical spine inter-vertebral motion percentage calculations (%)

Table S7 Thoracic spine inter-vertebral motion percentage calculations (%)

Table S8 Lumbar spine inter-vertebral motion percentage calculations (%)

For abbreviations see (1).

Table S1. Normalised cervical vertebrae measurements (modified from (2-8))

mm / (°)	C1	C2	C3	C4	C5	C6	C7
VRHa	16.0						
VRHp	10.4						
VRTa	6.9						
VRTp	8.3						
VRD	47.9						
FDD	33.5	25.1	17.5	16.2	16.1	16.1	16.0
FDW	32.1	21.1	24.6	25.6	26.5	26.9	26.4
LMa-VRa	5.4						
TP-LM	8.9						
C1Fac-D	21.8						
VBHa		20.5	14.2	13.5	12.8	13.1	14.7
VBHp		16.7	14.6	14.1	13.7	13.7	15.0
VBHpc			12.2	11.9	11.9	11.4	13.4
H		41.0					
DH		17.8					
DDD_s		12.2					
DDDi		11.1					
DDW_s		11.1					
DDWi		10.2					
ASH		16.0					
EPLH		4.2					
DI		13.4					
EPWi		19.7	20.8	21.7	22.8	25.2	29.5

EPWs							16.7
EPDs		12.7	15.0	15.6	15.6	16.2	16.7
EPDi		16.1	16.2	16.4	16.8	17.3	16.8
SPL-pi		36.8	30.8	30.6	29.9	35.8	46.7
SPL-ps		40.2	24.6	33.8	35.6	41.7	49.9
SPL		35.5	31.0	31.8	29.9	35.8	47.9
TPW	82.6	57.5	56.0	56.7	58.2	61.1	73.7
EPI-ti (°)		4.2	2.0	2.1	2.7	2.7	1.8
EPI-ts (°)			2.7	3.5	1.7	4.7	2.2
SPI (°)		19.8	22.0	20.0	20.0	13.9	14.3
DBHa		4.8	5.3	5.5	5.4	5.2	4.7
DBHp		4.2	3.3	3.0	3.0	3.3	3.5
D-Gap		1.7					
V-ind		1.0	0.8	0.8	0.8	0.9	0.8
L		53.6	46.5	46.7	49.3	55.9	63.3
PDI (°)			42.3	43.3	40.3	31.9	29.9
UJI (°)			43.0	43.9	39.8	45.0	53.6
PDW			5.9	5.7	5.9	6.2	6.9

Table S2. Normalised thoracic vertebrae measurements (modified from (9,10))

Mm/ (°)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
VBHa	17.1	18.2	18.3	19.1	19.2	19.1	19.1	19.6	20.8	22.7	23.8	25.5
VBHp	17.5	18.2	19.2	20.0	20.6	20.9	21.6	22.0	22.6	24.1	26.5	28.2
VBHpc	14.8	16.3	16.5	17.0	17.0	18.2	19.1	19.6	20.2	21.2	22.3	23.8
EPWi	29.1	28.7	27.1	27.2	28.3	29.6	30.5	32.0	34.6	37.1	41.0	44.1
EPWs	25.7	26.1	25.8	25.7	26.1	27.5	29.1	30.9	32.1	33.4	36.6	40.9
EPDi	20.6	22.6	24.4	25.7	27.0	28.2	29.9	30.8	32.5	33.1	33.3	35.0
EPDs	19.4	20.5	23.8	24.4	25.5	27.2	28.7	29.2	30.7	32.0	33.4	34.4
SPL	52.5	54.6	54.2	53.6	54.6	56.4	52.9	55.3	53.8	51.7	47.8	49.7
FDW	22.8	20.4	19.2	17.8	17.9	18.1	18.1	18.6	18.8	19.1	20.3	23.3
FDD	17.2	16.0	16.7	17.0	17.1	17.3	16.9	16.7	16.5	16.2	16.8	19.1
TPW	78.9	72.7	63.7	59.6	64.0	64.2	63.3	62.8	62.1	61.2	54.7	49.2
EPI-ti (°)	3.9	1.9	2.1	2.3	2.0	1.8	2.2	2.3	1.2	1.2	2.2	1.8
EPI-ts (°)	1.8	1.7	2.4	1.5	2.1	2.1	1.6	1.3	0.9	0.5	2.3	2.2
SPI (°)	14.7	15.1	15.5	15.9	16.4	16.8	17.2	17.6	18.0	18.4	18.8	19.2
DBHa	3.5	3.3	2.6	2.9	2.8	3.3	3.9	4.2	4.5	5.3	6.6	5.1
DBHp	3.7	3.8	3.6	3.8	3.9	4.3	4.3	4.4	4.4	4.9	5.2	5.6
V-ind	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8

Table S3. Normalised lumbar vertebrae measurements (modified from (7,11-13))

mm / (°)	L1	L2	L3	L4	L5
VBHa	25.6	27.4	28.1	27.6	28.5
VBHp	27.1	28.0	27.8	26.9	25.5
VBHc	24.9	25.5	24.9	25.3	24.0
EPWi	45.4	47.7	50.3	51.9	51.8
EPWs	43.2	44.6	46.2	48.8	49.6
EPDi	34.5	35.0	34.9	35.1	34.2
EPDs	33.8	34.7	35.0	34.7	34.5
SPL-ps	53.0	56.2	57.1	55.2	51.7
SPL-pi	47.3	50.3	50.9	48.7	44.2
SPL	70.9	75.1	75.1	73.5	71.6
FDW	24.8	24.9	25.5	26.6	28.4
FDD	19.9	19.1	18.3	19.5	20.6
TPW	74.6	79.8	89.8	83.2	96.9
EPI-ti (°)	4.0	2.1	2.7	2.7	1.8
EPI-ts (°)	2.7	3.5	1.7	4.7	2.2
SPI (°)	19.6	19.8	20.1	20.9	21.3
DBHa	7.6	9.0	10.4	12.1	14.2
DBHp	6.6	9.0	10.4	12.1	14.2
V-ind	1.7	1.8	1.7	1.8	1.7
L	81.4	85.1	85.7	83.8	77.9

Table S4 Minimum full ROM angular values of the entire spine (°)

Region	C0-C2	C3-T1	C0-T1	T1-T12	T12-S1
Flexion (Rx)	14.7	30.8	45.5	27.6	15.1
Extension (-Rx)	-15.6	-32.9	-48.5	-12.4	-38.5
Lateral bending (\pmRy)	\pm 6.3	\pm 18.2	\pm 24.5	\pm 52.0	\pm 13.65
Axial rotation (\pmRz)	\pm 32.8	\pm 25.2	\pm 58.0	\pm 49.0	\pm 6.65

Table S5 Average full ROM angular values of the entire spine (°)

Region	C0-C2	C3-T1	C0-T1	T1-T12	T12-S1
Flexion (Rx)	20.3	42.6	42.9	52.4	22.4
Extension (-Rx)	-21.6	-45.5	-67.1	-23.6	-57.0
Lateral bending (\pmRy)	\pm 10.9	\pm 31.3	\pm 42.2	\pm 76.0	\pm 26.5
Axial rotation (\pmRz)	\pm 42.6	\pm 32.7	\pm 75.3	\pm 71.0	\pm 18.85

Table S6 Cervical spine inter-vertebral motion percentage calculations (%)

	C0-C1	C1-C2	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-T1
Rx	19.1	13.2	7.9	11.7	12.2	13.3	11.4	11.4
Ry	11.6	14.3	13.6	14.0	12.8	11.9	10.9	10.9
Rz	4.7	51.9	7.7	8.6	7.7	7.7	6.8	5.8

Table S7 Thoracic spine inter-vertebral motion percentage calculations (%)

	T1- 2	T2- 3	T3- 4	T4- 5	T5- 6	T6- 7	T7- 8	T8- 9	T9- 10	T10- 11	T11- 12
Rx	6.0	6.0	6.0	6.0	6.0	8.0	8.0	9.0	9.0	15.0	21.0
Ry	6.0	9.0	9.0	7.0	7.0	7.0	10.0	9.0	9.0	12.0	15.0
Rz	15.0	12.0	11.0	11.0	11.0	11.0	11.0	7.0	5.0	3.0	3.0

Table S8 Lumbar spine inter-vertebral motion percentage calculations (%)

	T12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Rx	9.1	13.0	15.8	18.2	21.6	22.3
Ry	11.6	16.5	19.9	24.6	16.3	11.0
Rz	11.6	16.6	19.5	22.0	18.9	11.4

REFERENCES

- (1) Magee JDM, McClelland B, Winder RJ. (2012) [Current issues with standards in the measurement and documentation of human skeletal anatomy](#). Journal of Anatomy;221(3):240-251.
- (2) Doherty BJ, Heggeness MH. (1994) [The Quantitative Anatomy of the Atlas](#). Spine Nov 15;19(22):2497-2500.
- (3) Doherty BJ, Heggeness MH (1995) [Quantitative Anatomy of the Second Cervical Vertebra](#). Spine Mar 1;20(5):513-517.
- (4) Frobin W, Leivseth G, Biggemann M, Brinckmann P (2002) [Vertebral Height, Disc Height, Posteroanterior Dand Dens-Atlas Gap in the Cervical Spine: Precision Measurement Protocol and Normal Data](#). Clin Biomech (Bristol, Avon) Jul;17(6):423-431.
- (5) Francis C. [Dimensions of the Cervical Vertebrae](#). Acat Rec 1955;122:603-609.

- (6) Naderi S, Cakmakci H, Acar F, Arman C, Mertol T et al (2003) [Anatomical and Computed Tomographic Analysis of C1 Vertebra](#) . Clin Neurol Neurosurg Sep;105(4):245-248.
- (7) Nissan M, Gilad I (1984) [The Cervical and Lumbar Vertebrae an Anthropometric Model](#). Eng Med Jul;13(3):111-114.
- (8) Panjabi MM, Duranceau J, Goel VK, Oxland T, Takata K. (1991) [Cervical Human Vertebrae. Quantitative Three-Dimensional Anatomy of the Middle and Lower Regions](#). Spine Aug;16(8):861-869.
- (9) Harrison DD, Harrison DE, Janik TJ, Cailliet R, Haas JW. (2003) [Do Alterations in Vertebral and Disc Dimensions Affect an Elliptical Model of Thoracic Typhosis?](#) Spine Mar 1;28(5):463-469.
- (10) Panjabi MM, Takata K, Goel VK, Federico D, Oxland T, Duranceau J, et al. (1991) [Thoracic Human Vertebrae. Quantitative Three-Dimensional Anatomy](#). Spine Aug;16(8):888-901.
- (11) Frobin W, Brinckmann P, Biggemann M, Tillotson M, Burton K. (1997) [Precision Measurement of Disc Height, Vertebral Height and Sagittal Plane Displacement from Lateral Radiographic Views of the Lumbar Spine](#). Clin Biomech (Bristol, Avon);12 Suppl 1:S1-S63.
- (12) Janik TJ, Harrison DD, Cailliet R, Troyanovich SJ, Harrison DE (1998) [Can the Sagittal Lumbar Curvature be Closely Approximated by an Ellipse?](#) J Orthop Res Nov;16(6):766-770.
- (13) Panjabi MM, Goel VK, Oxland T, Takata K, Duranceau J, Krag MH, et al. (1992) [Human Lumbar Vertebrae. Quantitative Three-Dimensional Anatomy](#). Spine Mar;17(3):299-306.