Supplementary A: Material Definitions

The definitions in this paper correspond to VIVA+ version 0.3.2. The definitions of the latest version can be found on the online documentation (https://vivaplus.readthedocs.io/)

Table A1 Supplementary table of the VIVA+ model parts and their parameters sorted by body regions

Body Region	Body Part	Material Model	Parameters	Reference	ELTYPE	ELFORM	HG model
Whole Body	Skin	FABRIC	RO=1E-6 BETA=0 EA=curve EB=curve PRBA=0.49 DAMP=0.05 GAB=0.0033	(Manschot and Brakkee, 1986)	SHELL	9	
	Flesh	OGDEN_RUBBER	RO=1E-6 PR=0.49998 ALPHA1=20 MU1=3.5E-8 BETAI_1=0.006 GI_1=8E-7 GI_2=1.8E-6 BETAI_2=0.05 GI_3=2.2E-6 BETAI_3=0.6	(Naseri, 2022)	SOLID	1	900001
Head	Skull	PIECEWISE_LINEAR_PLASTICITY	RO=2E-6 E=40 RO=0.3 SIGY=10 ETAN=0	(tuned to Loyd et al., 2014)	SHELL	2	

	Oral Cavity	OGDEN_RUBBER	RO=2E-6 RO=0.4999 G=0 ALPHA1=20 MU1=3E-8 ALPHA2=0 MU2=0 BETAI_1=0.31 GI_1=3E-6	(Engelbrektsson, 2011)	SOLID	1	900001
Neck	Vertebrae - cortical bone	PIECEWISE_LINEAR_PLASTICITY	RO=2E-6 BETA=0 E=17.1 SIGY=1E+20 ETAN=0.89668	(Reilly and Burstein, 1975)	SHELL	13	
	Vertebrae - trabecular bone	PLASTIC_KINEMATIC	RO=2E-6 E=0.495 SIGY=1E+20 ETAN=0.051	(Kopperdahl and Keaveny, 1998) (Yoganandan et al., 2006)	SOLID	4	-
	Neck spine ligaments	FABRIC	RO=1E-6 BETA=0 EA=1E-6 EB=1E-6 PRBA=0.3 DAM=0.05 GAB=individual	(Östh et al., 2016)	SHELL	9	
	Stylohyoid ligament	CABLE_DISCRERE_BEAM	RO=1E-8 E=1.2	(Zajac, 1989)	BEAM	6	
	Intervertebral Discs - Nucleus	VISCOELASTIC	RO=1E-6 BETA=0.001 G0=1.78E-5	(Yang and Kish, 1988; Iatridis et al., 1996)	SOLID	1	900001
	Anulus ground	HILL_FOAM	RO=1E-6 Experimental data	(Panzer and Cronin, 2009)	SOLID	1	900001
	Anulus fibers	FABRIC	RO=1E-6 BETA=±45-60 EA & EB - individual PRBA=0.3	(Östh et al., 2016)	SHELL	9	

			DAMP=0.05 GAB - individual				
	Vertebra articular cartilage	FU_CHANG_FOAM	RO=1E-6 E=0.01 DAMP=0.05	(Östh et al., 2020)	SOLID	1	900001
	Tracheal cartilage	ELASTIC	RO=1E-6 E=0.091 v=0.4	(Roberts et al., 1997)	BEAM	1	
Neck	Neck intervertebral muscles	MUSCLE	RO=1E-8 Experimental curves	(Östh et al., 2017b)	BEAM	3	
Upper Extremity	Cortical bone	PIECEWISE_LINEAR_PLASTICITY	RO=1.973E-6 E=12.516 PR=0.2 SIGY=0.1 ETAN=1	(Östh et al., 2017a)	SOLID	2	-
	Trabecular bone	PLASTICITY_COMPRESSION_TENSION	RO=1E-6 E=0.829 PR=0.3	(Östh et al., 2017a)	SOLID	1	900001
	Trapezoid & Conoid ligament	SPRING_NONLINEAR_ELASTIC	Experimental curves	(Harris et al., 2000)	DISCRETE		
	Finger interphalanges	OGDEN_RUBBER	RO=1E-6 PR=0.49998 ALPHA1=16 MU1=3E-6	(Mohammadkhah et al., 2016)	SOLID	1	900001
	Subscapularis muscle	OGDEN_RUBBER	RO=1E-6 PR=0.495 ALPHA1=13 MU1=1.08E-7 BETAI_1=0.2 GI_1=2.9E-4 GI_2=3e-4 BETAI_2=100 GI_3=1.9E-4 BETAI_3=1E+6	(Mohammadkhah et al., 2016)	SOLID	1	900001
Thorax	Ribs and sternum – cortical	PIECEWISE_LINEAR_PLASTICITY	RO=2E-6 E=14.7 PR=0.3 ETAN=0	(Iraeus et al., 2020)	SHELL	16	900003

	Ribs and sternum – trabecular	PIECEWISE_LINEAR_PLASTICITY	RO=8.615E-7 E=0.04 PR=0.45 SIGY=0.0018 ETAN=0	(Iraeus et al., 2020)	SOLID	1	900001
	Intervertebral discs	GENERAL_NONLINEAR_6DOF_DISCRETE_BEAM	RO=1E-6 Experimental curves	(Östh et al., 2017a)	BEAM	6	
Thorax	Rib cartilage – exterior shells	PIECEWISE_LINEAR_PLASTICITY	RO=1E-6 E=0.049 PR=0.4 SIGY=4.85E-3 ETAN=0	(Iraeus et al., 2020)	SHELL	2	900002
	Rib cartilage - solid	PIECEWISE_LINEAR_PLASTICITY	RO=1E-6 E=0.049 PR=0.4 SIGY=4.85E-3 ETAN=0	(Iraeus et al., 2020)	SOLID	1	403602
	Intercostal external muscle	SIMPLIFIED_RUBBER/FOAM	RO=1E-6 Experimental curves	(Östh et al., 2017a)	SOLID	1	900001
	Rhomboideus, Trapezius and Serratus anterior muscle	MUSCLE	RO=1E-8 Experimental curves	(Östh et al., 2017a)	BEAM	3	
	Simplified lungs	LOW_DENSITY_FOAM	RO=5E-7 E=0.1 BETA=0 DAMP=0.5	(Rater, 2013)	SOLID	1	900001
Abdomen	Lumbar Intervertebral discs	GENERAL_NONLINEAR_6DOF_DISCRETE_BEAM	RO=1E-6 Experimental curves	(Östh et al., 2017a)	BEAM	6	
	Simplified abdominal organs	OGDEN_RUBBER	RO=1E-6 PR=0.49998 ALPHA1=20 MU1=3.5E-8 BETAI_1=0.006 GI_1=8E-7 GI_2=1.8E-6 BETAI_2=0.05	(Naseri, 2022)	SOLID	1	900001

			GI_3=2.2E-6 BETAI_3=0.6				
	Abdominal muscle	OGDEN_RUBBER	RO=1E-6 PR=0.49998 ALPHA1=16 MU1=3E-6	(Mohammadkhah et al., 2016)	SOLID	1	900001
Pelvis	Pelvis - cortical bone	PLASTICITY_COMPRESSION_TENSION	RO=2E-6 E=10.84148 PR=0.3	(Kemper et al., 2008)	SHELL	16	900003
	Pelvis - trabecular bone	PIECEWISE_LINEAR_PLASTICITY	RO=3.45E-7 E=0.0236 PR=0.2 SIGY=1 ETAN=0	(Dalstra et al., 1993)	SOLID	1	900001
	Pubic symphysis	HYPERELASTIC_RUBBER	RO=1.2E-6 G=0 PR=0.495	(Li et al., 2006)	SOLID	1	900001
	Sacroiliac Joint	OGDEN_RUBBER	RO=1.2E-6 PR=0.495 ALPHA1=2 MU1=3.224	(Miller et al., 1987)	SOLID	1	900001
	Hip joint ligament – shell	ELASTIC	RO=1E-6 E=0.1368 PR=0.45	(Hewitt et al., 2001)	SHELL	16	
	Hip joint ligament – beam	GENERAL_NONLINEAR_1DOF_DISCRETE_BEAM	RO=1E-6 Experimental curves	(Ito et al., 2009)	BEAM	1	
	Pelvic cavity tissue	OGDEN_RUBBER	RO=1E-6 G=0 PR=0.4999983 Alpha=20 MU1=3E-8	(Engelbrektsson, 2011)	SOLID	1	900001
	Pelvis floor muscle	ELASTIC	RO=1E-6 E=0.15 PR=0.4	(Meyer et al., 1998)	SHELL	16	
Lower Extremity	Femur - cortical	PLASTICITY_COMPRESSION_TENSION	RO=1.8E-6 E=7.21 - 16.38 PR=0.3	(Schubert et al., 2021)	SOLID	-2	

	Femur – trabecular	FU_CHANG_FOAM	RO=2.7E-7 E=0.974 DAMP=0.05	(Enns-Bray et al., 2018)	SOLID	1	900001
	Tibia and Fibula – cortical	PLASTICITY_COMPRESSION_TENSION	RO=2E-6 E=22.2 PR=0.3	(Reilly and Burstein, 1975)	SOLID	2	
Lower Extremity	Tibia – trabecular	PLASTICITY_COMPRESSION_TENSION	RO=1E-6 E=0.829 PR=0.3	(Ding, 2000)	SOLID	1	900001
	Knee cartilage	OGDEN_RUBBER	RO=1E-6 PR=0.49 ALPHA1=2 MU1=0.012	(Robinson et al., 2016)	SOLID	1	900001
	Meniscus	OGDEN_RUBBER	RO=1E-6 PR=0.49 ALPHA1=2 MU1=0.114	(Peña et al., 2006)	SOLID	1	900001
	Knee ligaments	SPRING_NONLINEAR_ELASTIC	Experimental curves	(Kunitomi et al., 2017)	DISCR.		
	Patellar ligament	SPRING_NONLINEAR_ELASTIC	Experimental curves	(Müller et al., 2004)	DISCR.		
	Quadriceps femoris muscle	SPRING_MUSCLE	Predefined curves	(Mukherjee et al., 2007)	DISCR.		
	Crural interosseous membrane fibers and proximal tibiofibular ligaments	ELASTIC	RO=1E-6 E=1.17 PR=0.3	(Minns and Hunter, 1976)	BEAM	2	

Rigid parts	Skull, mandible, teeth, occipital condyles	RIGID
	Hyoid bone	RIGID
	Clavicle, Scapula, Wrist bones	RIGID
	Thoracic and Lumbar vertebrae	RIGID
	Patella, Calcaneus, Talus, Tarsal bones	RIGID

* The naming of material models is taken from LS-DYNA keyword library.

** ELTYPE, ELFORM and HG models are not acquired from references.

Table A2 Definitions of parameters used in Table A1

Parameter	Definition	Units
RO	Mass density	kg/mm^3
E	Young's modulus.	GPa
PR	Poisson's ratio.	/
G	Shear modulus	GPa
G0	Short-time shear modulus	GPa
BETA	Material angle for AOPT=3	degrees
ALPHA1	alpha-1, first exponent.	/
ALPHA2	alpha-2, second exponent.	/
MU1	mu-1, first shear modulus.	GPa
MU2	mu-2, second shear modulus.	GPa
GI_1	Shear relaxation modulus for the 1st term	GPa
GI_2	Shear relaxation modulus for the 2nd term	GPa
GI_3	Shear relaxation modulus for the 3rd term	GPa
BETAI_1	Decay constant for the 1st term	/
BETAI_2	Decay constant for the 2nd term	/
BETAI_3	Decay constant for the 3rd term	/
SIGY	Yield stress	GPa
ETAN	Tangent modulus	GPa
EA	Young's modulus in longitudinal direction	GPa
EB	Young's modulus in transverse direction	GPa
PRBA	Minor Poisson's ratio in BA direction.	/
PRCA	Major Poisson's ratio in CA direction	/
DAMP	Rayleigh damping coefficient	/
GAB	Shear modulus in AB direction	GPa

Table A3 Hourglass models definitions

HG model	Description	HG control type (IHQ)	Parameters
403602	Hourglass model for rib cartilage	2	QM=0.1, Q1=1.5, Q2=0.6, QB/VDC=0.1, QW=0.1
900001	Default hourglass model for solids with exact volume integration	5	QM=0.1, Q1=1.5, Q2=0.6, QB/VDC=0.1, QW=0.1
900002	Default hourglass model for shells with exact volume integration	3	QM=0.1, Q1=1.5, Q2=0.6, QB/VDC=0.1, QW=0.1
900003	Default hourglass type for shells in cortical bones	8	QM=0.1, Q1=1.5, Q2=0.6, QB/VDC=0.1, QW=0.1

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