Supplementary material

Table i. Papers included in qualitative synthesis – studies using cancellous bone specimens; articles are ordered according to method of strain measurement and secondly according to author (alphabetical order); where "Not reported in paper" is written, no information has been provided regarding that subject

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Augat et al[1] (1998)	Anisotropy of the elastic modulus of trabecular bone specimens from different anatomical locations	Cancellous femur, vertebras, calcaneus	Servohydraulic (MTS), 500 N load cell	Extensometer (MTS)	Cubic 12 mm	Defatted in ethanol and water irrigation, stored in saline at 4°C	Not reported in paper	Not reported in paper	0.05%/s between 5 N and 0.4% strain D+ ND	5 N preload, 5 cycles between 0.01% and 0.1% strain
Banse et al[2] (2002)	Mechanical properties of adult vertebral cancellous bone: Correlation with collagen intermolecular cross-links	Cancellous vertebras	Screwdriven machine (Zwick), 2 kN load cell, test at RT	Extensometer (Zwick)	Cylinder 8.2 mm diameter, varied height (19 mm to 29 mm)	Frozen	Not reported in paper	Brass endcaps	Up to 2% strain D	Not reported in paper
Burgers et al[3] (2008)	Compressive properties of trabecular bone in the distal femur	Cancellous femur	Universal testing machine (Enduratec), 12.5 kN load cell (Enduratec)	Extensometer (Epsilon)	Cylinder 8.1 mm diameter, 35 mm height	Frozen airtight in saline at -20°C, thawed at RT	Not reported in paper	Stainless-steel endcaps with adhesive	0.005/s D	Not reported in paper
Cendre et al[4] (1999)	High-resolution computed tomography for architectural characterization of human lumbar cancellous bone: relationships with histomorphometry and biomechanics	Cancellous vertebras	Screwdriven machine (Schenck), 5 kN load cell, tested in saline bath	Immersed extensometer	Cubic 9 mm	Frozen at -20°C	Not reported in paper	Not reported in paper	0.5 mm/min D	10 cycles
Ding et al[5] (2001)	Bone density does not reflect mechanical properties in early-stage arthrosis	Cancellous tibia	Hydraulic machine (MTS), 1 kN load cell	Extensometer (MTS)	Cylinder 7.5 mm diameter, 7.5 mm height	Frozen at -20°C	Not reported in paper	Not reported in paper	0.002/s D	Not reported in paper
Ducheyne et al[6] (1977)	The mechanical behaviour of intracondylar cancellous bone of the femur at different loading rates	Cancellous femur	Test machine (Instron), hydraulic device for high loading rate with steel ring	Extensometer	Cylinder 5 mm diameter, 8 mm height	Frozen at -35°C	Not reported in paper	Not reported in paper	0.1 cm/min and 5 cm/ min (Instron), 440 cm/min (hydraulic)	Not reported in paper
Frich et al[7] (1997)	Bone strength and material properties of the glenoid	Cancellous glenoid	Materials testing machine (Instron), 1 kN load cell	Extensometer	Cylinder 6.5 mm diameter, 7.5 mm height	Not reported in paper	Not reported in paper	Not reported in paper	0.01/s ND up to 0.6% strain	Preload of 2 N, 8 non-destructive cycles
Giesen et al[8] (2003)	Reduced mechanical load decreases the density, stiffness, and strength of cancellous bone of the mandibular condyle	Cancellous mandible	Materials testing machine (MTS), 1 kN load cell, steel loading rods	Extensometer (MTS)	Cylinder 3.6 mm diameter, 4.9 mm height	Stored in embalming fluid for 5 mths	Not reported in paper	Low viscosity mineral oil as lubricant	0.2%/s D up to 3% strain	Yes, protocol unclear
Haddock et al[9] (2004)	Similarity in the fatigue behavior of trabecular bone across site and species	Cancellous vertebras	Servohydraulic load frame (MTS), 1 KN load cell, wrapped in wet gauze and cellophane during testing, test at RT	Extensometer (12 mm)	Cylinder 8.3 mm diameter, 25 mm to 40 mm height	Frozen	Not reported in paper	Brass end caps with PMMA	Multicyclic: 10 cycles 1500 µstrain at 1500 µstrains/s D	Not reported in paper
Hans et al[10] (1999)	Ultrasound velocity of trabecular cubes reflects mainly bone density and elasticity	Cancellous vertebras	Servohydraulic machine (MTS), 500 N load cell	Extensometer (MTS)	Cubic 12 mm	Marrow removed, degassed for several hours, stored in 1.5 mM Gd-DTPA doped physiological saline	Not reported in paper	Not reported in paper	0.05%/s ND up to 0.4% strain	5 N preload, 5 cycles

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Hernandez et al[11] (2014)	Quantitative relationships between microdamage and cancellous bone strength and stiffness	Cancellous vertebras	Servohydraulic machine (MTS), 1 kN load cell	Extensometer (25 mm, MTS)	Cylinder 8.2 mm diameter, 26.2 mm height	Marrow removed using water jet, stained with alizarin complexone in saline for 2 hrs, rinsed for 10 mins with deionized water, frozen in saline at -20°C, stored at 4°C, thawed at RT	Not reported in paper	Brass endcaps with cyanoacrylate glue	0.5%/s up to varied strains, then unload at 0.05% strain/s Stained with calcein and reloaded to 4% strain D	10 cycles up to 0.2% strain
Hvid et al[12] (1989)	X-ray quantitative computed tomography: the relations to physical properties of proximal tibial trabecular bone specimens	Cancellous tibia	Universal testing machine (Instron), 1 kN load cell	Extensometer	Cylinder 7.5 mm diameter, 7.5 mm height	Frozen at -21°C	Not reported in paper	Not reported in paper	0.01/s D+ ND	ND: 7 to 15 cycles until steady state between 5 N and 0.6% strain
Jensen et al[13] (1988)	Strength pattern of cancellous bone at the ankle joint	Cancellous tibia, talus	Materials testing machine (Instron)	Extensometer	Cylinder 7.5 mm diameter, 6 mm height	Frozen at -25°C, moistened with Ringer's solution before testing	Not reported in paper	Moistened steel columns with Ringer's solution	5 mm/min D	Not reported in paper
Jensen et al[14] (1991)	Topographical distribution of trabecular bone strength in the human os calcanei	Cancellous calcaneus	Universal testing machine (Instron)	Extensometer	Cylinder 6.5 mm diameter, 6.5 mm height	Frozen at -25°C, moistened with Ringer's solution	Not reported in paper	Not reported in paper	0.01/s D	Up to 0.45% strain at 0.01/s and 0.2Hz (10 cycles) Preload 2.5 N
Karim and Vashishth[15] (2012)	Heterogeneous glycation of cancellous bone and its association with bone quality and fragility	Cancellous tibia	Materials testing machine (MTS), tested at 37°C in physiological saline	Extensometer (MTS)	Cylinder 7.5 mm diameter, 10.5 mm height	Frozen in saline at -80°C	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper
Keaveny et al[16] (1997)	Systematic and random errors in compression testing of trabecular bone	Cancellous vertebras	Not reported in paper	Extensometer (1 inch)	Cylinder 8 mm diameter, 32 mm height	Frozen -20°C	Not reported in paper	Group 1. Brass endcaps with glue Group 2. no endcaps, polished platen	0.005 s^{-1}, endcap: ND test 10 cycles from 0 to 0.3% strain non-endcap: D test to 3% strain	5 N to 10 N preload 10 cycles of 0% to 0.8% strain
Keaveny et al[17] (1999)	Mechanical behavior of human trabecular bone after overloading	Cancellous vertebras	Not reported in paper	Extensometer (1 inch)	Cylinder 8.3 mm diameter, 20 mm to 30 mm height	Frozen	Not reported in paper	Brass endcaps	To 0.3% or 4% strain, at 0.5% strain/s, unload at 200 N/s to zero and reload at 0.5%/s to 4% strain	Not reported in paper
Kopperdahl and Keaveny[18] (1998)	Yield strain behavior of trabecular bone	Cancellous vertebras	Servohydraulic machine (MTS)	Extensometer (25 mm, MTS)	Cylinder 8 mm diameter, 25 mm height	Frozen	Not reported in paper	Brass end caps with glue	0.5% D up to 3% strain	5 cycles up to ±0.1% strain
Linde and Hvid[19] (1987)	Stiffness behaviour of trabecular bone specimens	Cancellous tibia	Universal testing machine (Instron), tested at RT	Extensometer	Cylinder 7.5 mm diameter, 7 mm height	Frozen at -20°C, thawed in saline	Not reported in paper	Not reported in paper	0.01/s, first up to 50%, then repeated for reproducibility after 3 hrs, then D test	Preload 2 N

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Linde and Sørensen[20] (1993)	The effect of different storage methods on the mechanical properties of trabecular bone	Cancellous tibia	Universal testing machine (Instron), 1 kN load cell	Extensometer	Cylinder 6.5 mm diameter, 6.5 mm height	Group 1: stored in 70% ethanol at 10°C for 100 days, Group 2: frozen at -20°C for 1 or 100 days then thawed in physiological saline at RT for 3 hrs, all defatted by jet air and 90% ethanol for 24 hrs	Not reported in paper	PMMA on ends, 2nd group: low viscous oil on ends, 3rd group: constrained in oiled cylinder	0.01/s, 5 cycles, between 5 N and 0.45% strain ND	Yes
Linde et al[21] (1992)	The effect of specimen geometry on the mechanical behaviour of trabecular bone specimens	Cancellous tibia	Testing machine (Instron), 1 kN load cell	Extensometer	Cylinder 6.5 mm diameter and height Cubic 5.8 mm	Frozen at -20°C, thawed in saline at RT for 2 hrs, stored in saline at 10°C between tests	Discussed but unclear whether corrected	Mineral oil for lubricant	0.01/s ND up to 0.4% strain	Preload 0.12 MPa cycles up to 0.4% strain until steady state
Linde et al[22] (1991)	Mechanical properties of trabecular bone. Dependency on strain rate	Cancellous tibia	Screwdriven and servohydraulic machine (Instron), second load cell 1 kN	Dynamic extensometer (Instron)	Cylinder 5.5 mm diameter, 8.25 mm height	Frozen, thawed at RT for 2 hrs in saline	Not reported in paper	Lubricant oil and metal disc	Varied strain rates in range 0.0001/s to 10/s D	Not reported in paper
Majumdar et al[23] (1998)	High-resolution magnetic resonance imaging: Three-dimensional trabecular bone architecture and biomechanical properties	Cancellous calcaneus, femur, vertebras	Servohydraulic machine (MTS), low capacity load cell (MTS)	Extensometer (MTS)	Cubic 12 mm	Defatted chemically, Stored in saline at 4°C	Not reported in paper	Not reported in paper	0.01%/s between 5N and up to 0.4% strain (3 cycles) D + ND	5 cycles up to 5 N
Majumdar et al[24] (1999)	Fractal analysis of radiographs: Assessment of trabecular bone structure and prediction of elastic modulus and strength	Cancellous femur, vertebras	Materials testing machine (MTS), low capacity load cell	Extensometer	Cubic 12 mm	Defatted chemically, stored in saline at 4°C	Not reported in paper	Not reported in paper	0.01% strain ND between 5 N and 0.4% strain	5 cycles up to 5 N
Martens et al[25] (1983)	The mechanical characteristics of cancellous bone at the upper femoral region	Cancellous femur	Hydraulic machine, load cell	Extensometer	Cylinder 8 mm diameter, height not reported in paper	Machined under liquid nitrogen, frozen at -20°C	Not reported in paper	Not reported in paper	7/s up to 15% deformation	Not reported in paper
Matsuura et al[26] (2008)	The role of fabric in the quasi-static compressive mechanical properties of human trabecular bone from various anatomical locations	Cancellous vertebras, femur, calcaneus, radius	Servohydraulic machine (MTS), load cell 1.5 kN	Extensometer (10 mm)	Cylinder 8 mm diameter, 12 mm height	Marrow removed in soap water at 40°C for 24 hrs, then in water/chloride solution, ultrasonic cleansing for 6 mins, rinsed with tap water, frozen at -18°C	Not reported in paper	Not reported in paper	0.005 mm/s up to 6% strain	12 cycles to 0.35% of strain
Morgan and Keveany[27] (2001)	Dependence of yield strain of human trabecular bone on anatomic site	Cancellous vertebras	Servohydraulic machine (MTS)	Extensometer (25 mm, MTS) to endcaps and to specimen (5 mm, MTS)	Cylinder 8 mm diameter, average 5:2 ratio (height to diameter)	Hydrated frozen airtight at -20°C	Not reported in paper	Endcaps	0.5%/s ND	10 cycles to 0.3% strain
Morgan et al[28] (2001)	Nonlinear behavior of trabecular bone at small strains	Cancellous tibia, femur	Materials testing machine (MTS), test at RT	Extensometer (25 mm)	Cylinder 8 mm diameter, 22 mm to 38 mm height	Frozen airtight at -20°C	Not reported in paper	Endcaps	0.5%/s strain rate D	3 cycles to 0.1% strain

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Morgan et al[29] (2005)	Damage in trabecular bone at small strains	Cancellous vertebras	Servohydraulic machine (MTS), 250 lb load cell, tested at RT	Extensometer (25 mm, MTS)	Cylinder 8 mm diameter, height not reported in paper	Frozen airtight at -20°C in wet paper towels	Not reported in paper	Endcaps	0.5%/s Multicyclic load to max. strain, unload to zero stress at 100 N/s	2 cycles to 0.1% strain
O'Mahony et al[30] (2000)	Anisotropic elastic properties of cancellous bone from a human edentulous mandible	Cancellous mandible	Testing machine (MTS), 1250 N load cell	Extensometer (5 mm)	Parallelepiped Average 4.4 mm × 4.4 mm × 4.8 mm	Frozen in physiological saline	Not reported in paper	Teflon tape on ends, spherical bearing platen	0.002/s up to 0.5% strain	Preload of 2 N, 6 to 20 conditioning cycles
Odgaard and Linde[31] (1989)	Compressive axial strain distributions in cancellous bone specimens	Cancellous tibia	Testing machine (Instron)	Extensometer	Cylinder 5.0 mm diameter, 7.5 mm height	Frozen at -20°C	Not reported in paper	Mineral oil on ends	0.00015/s D +ND	0.5 N or 5 N or 10 N
Odgaard et al[32] (1991)	The underestimation of Young's modulus in compressive testing of cancellous bone specimens.	Cancellous tibia	Materials testing machine (Instron)	Extensometer, optical device (Phillips)	Parallelepiped 7 mm × 6 mm × 6 mm	Frozen at -18°C	Not reported in paper	Not reported in paper	0.025 mm/min ND test up to 0.8% strain	Preload 3 N Cyclic preconditioning
Öhman et al[33] (2007)	Mechanical testing of cancellous bone from the femoral head: experimental errors due to off-axis measurements	Cancellous femur	Testing machine (Instron)	Extensometer (Instron)	Cylinder 10 mm diameter, 26 mm height	Stored in Ringer's solution for 1 hr at RT and 70% ethanol for at least 4 wks	Not reported in paper	Specimen cemented onto machine	0.01/s D	Not reported in paper
Ojanen et al[34] (2017)	Tissue viscoelasticity is related to tissue composition but may not fully predict the apparent-level viscoelasticity in human trabecular bone – An experimental and finite element study	Cancellous femur	Bi-axial servohydraulic testing device (Instron), 1 kN load cell	Extensometer (Instron)	Cylinder 10 mm diameter, 6.5 mm height	Not reported in paper	No	No	$0.01 s^{-1}$ ND to 0.6% strain, held for 10min, then cyclic loading	9 N preload
Ouyang et al[35] (1997)	Biomechanical characteristics of human trabecular bone	Cancellous vertebras	Materials testing machine (Instron)	Extensometer	Parallelepiped 10 mm × 10 mm × 24 mm	Frozen at -20°C, thawed in Ringer's solution for at least 2 hrs at RT	Not reported in paper	Not reported in paper	Varied strain rates in range of 1.0×10^{-5}/s to 5.0×10^{-4}/s to 0.4% strain (ND) or up to 1.0×10^{-3}/s (D)	Preload 2 N
Ouyang et al[36] (1997)	Biomechanical strength versus spinal trabecular bone structure assessed using contact radiography and texture analysis	Cancellous vertebras	Servohydraulic machine (MTS), low capacity load cell (MTS)	Extensometer (MTS)	Cubic 12 mm	Not reported in paper	Not reported in paper	Not reported in paper	0.01%/s ND up to 0.4% strain for 3 cycles, YM from last 2 cycles	5 cycles, strain rate 0.01%/s up to 5 N preload
Ouyang et al[37] (1998)	Morphometric texture analysis of spinal trabecular bone structure assessed using orthogonal radiographic projections	Cancellous vertebras	Servohydraulic machine (MTS), low capacity load cell (MTS)	Extensometer on platens	Cubic 12 mm	Not reported in paper	Not reported in paper	Not reported in paper	0.01%/s ND up to 0.4% strain for 3 cycles, YM from last 2 cycles	5 cycles, strain rate 0.01%/s up to 5 N preload
Perilli et al[38] (2008)	Dependence of mechanical compressive strength on local variations in microarchitecture in cancellous bone of proximal human femur	Cancellous femur	Testing machine (Instron)	Extensometer (8.6 mm, Instron)	Cylinder 10 mm diameter, 26 mm height	Fixed in 70% ethanol before machining, then stored in Ringer's solution for 25 hrs	Not reported in paper	Endcaps	0.01/s D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Rapillard et al[39] (2006)	Compressive fatigue behavior of human vertebral trabecular bone	Cancellous vertebras	Servohydraulic machine (MTS), 2.5 kN load cell, HBSS around sample, cellophane membrane to prevent evaporation, 37°C water bath	Extensometer	Cylinder 8 mm diameter, 10 mm height	Marrow removed	Yes; compliance of PMMA layers, no correction for aluminium rod	3 mm thick PMMA layer on both ends (1.5 mm, embedded)	2 Hz sinusoidal stress control, 16% to 55% or 90% ultimate stress	Not reported in paper
Schwiedrzik et al[40] (2016)	Experimental validation of a nonlinear μFE model based on cohesive-frictional plasticity for trabecular bone	Cancellous femur, radius, vertebras	Servohydraulic machine (MTS)	Extensometer (MTS) mounted on steel rods	Cylinder 8 mm diameter, 10 mm height	Marrow removed using pulsed water jet, dried at RT for 1 hr, rehydrated for 2hrs in 0.9% saline	Not reported in paper	Glued specimens to polished rods	0.05%/s D	Not reported in paper
Schwiedrzik et al[41] (2011)	Fabric-mechanical property relationships of trabecular bone allografts are altered by supercritical CO_2 treatment and gamma sterilization	Cancellous femur	Servohydraulic machine (MTS)	Extensometer (15 mm, MTS)	Cylinder 8 mm diameter, 12 mm height	Sterilized with 31 kGy irradiation at RT, dried for several hours, rehydrated in saline for 1 hr before testing, stored in plastic bags at RT	Not reported in paper	Epoxy glue, custom alignment device	15 μm/s Unconfined: to 1.7 mm displacement, Confined: to 8 mm displacement	5 cycles of -50 μm at 15 μm/s
Stauber M. et al[42] (2006)	Importance of individual rods and plates in the assessment of bone quality and their contribution to bone stiffness	Cancellous vertebras	Not reported in paper	Extensometer (9.3 mm)	Cylinder 8 mm diameter, 10 mm height	Not reported in paper	Not reported in paper	Embedded in PMMA cement	0.05%/s Not reported in paper	5 cycles
Stoppie et al[43] (2007)	The validation of a compression testing method for cancellous human jawbone by high-resolution finite element modeling	Cancellous femur, mandible	Mechanical testing machine (Instron), load cell 1 kN	Series 1: no extensometer; series 2 + 3 + mandible: extensometer	Cylinders series 1 + 2: 6.1 mm diameter, 13 mm height; series 3: 5.5 mm diameter, 8 mm height; mandible: 5.7 mm diameter, 8 mm height	Mandible: embalmed tissue, frozen in saline at -20°C, thawed at RT Femur: fresh tissue, frozen at -20°C, thawed at RT	Not reported in paper	Spherical-seated bearing on lower platen; series 2 + 3 + mandible: brass endcaps with glue	5 mm/min D	Series 2 + 3 + mandible: preload 3 N, 10-15 cycles up to 0.6% strain or 3 N at 0.2 mm/ min
Tang et al[44] (2007)	Effects of non-enzymatic glycation on cancellous bone fragility	Cancellous femur	Servohydraulic testing machine (MTS), tested in constant saline flow at 37°C	Extensometer	Cylinder 8 mm diameter, 8 mm to 10 mm height	Stored in zwitterionic buffers, protease inhibitors, HBSS for 7 days, pH maintained as 7.3 to 7.6	Not reported in paper	Brass endcaps with glue	883 μstrains/s D	Not reported in paper
Van Lenthe et al[45] (2006)	Specimen-specific beam models for fast and accurate prediction of human trabecular bone mechanical properties	Cancellous vertebras	Not reported in paper	Extensometer (9.3 mm)	Cylinder 8 mm diameter, 10 mm height	Not reported in paper	Not reported in paper	Embedded in PMMA	0.05%/s Not reported in paper	5 cycles preconditioning
Wachter et al[46] (2001)	Predictive value of bone mineral density and morphology determined by peripheral quantitative computed tomography for cancellous bone strength of the proximal femur	Cancellous femur	Materials testing machine (Zwick), tested at RT	Extensometer (Zwick)	Cylinder 10.6 mm diameter, 5.35 mm to 13.7 mm height	Frozen at -20°C	Not reported in paper	Lubrication on specimen ends	0.6 mm/min up to 250 N D	3 cycles at 0.6 mm/min up to 20 N

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Wu et al[47] (2013)	In vivo microdamage is an indicator of susceptibility to initiation and propagation of microdamage in human femoral trabecular bone	Cancellous femur	Biaxial load frame (Instron), tested at RT	Biaxial extensometer (Epsilon)	Cylinder 8 mm diameter, height not reported in paper	Frozen at -20°C in buffered saline	Not reported in paper	Brass endcaps	Not reported in paper up to 2% strain	Not reported in paper
Aiyangar et al[48] (2014)	Dependence of anisotropy of human lumbar vertebral trabecular bone on quantitative computed tomography-based apparent density	Cancellous vertebras	Bone Loading and Bioreactor System (Physik Instrumente), load cell (Kistler), test at RT	Strain gauges	Cylinder 10 mm diameter, 5 mm height	Refrigerated in sterile saline	Yes	Cylindrical bone chambers (constraine-d)	Not reported in paper D	Preload of 10 N or 20 N, then 5 cycles up to 10µm strain
Brown et al[49] (1981)	Mechanical characteristics of bone in femoral capital aseptic necrosis	Cancellous femur	Load cell (Instron)	Strain gauge extensometer	Cubic 5 mm	Frozen at -10°C	5.29% stiffening artefact corrected	Not reported in paper	0.004/s D	Not reported in paper
Ding et al[50] (1997)	Age variations in the properties of human tibial trabecular bone	Cancellous tibia	Materials testing machine (Instron), 1 kN load cell	Static strain-gauge extensometer (Instron)	Cylinder 7.5 mm diameter, 7.5 mm height	Frozen in saline -20°C, thawed for 2 hrs in saline at RT	Not reported in paper	Mineral oil on specimen ends	0.002/s ND	10 cycles between preload of 3 N and 0.006 strain
Giesen et al[51] (2001)	Mechanical properties of cancellous bone in the human mandibular condyle are anisotropic	Cancellous mandible	Materials testing machine (MTS), 1 kN load cell	Strain gauge extensometer (MTS)	Cylinder 4 mm diameter, 5 mm height	Stored in embalming fluid	Not reported in paper	Low viscosity mineral oil as lubricant	0.2%/s D up to 3% strain	5 cycles between 3 N and 0.6% strain
Linde and Hvid[52] (1989)	The effect of constraint on the mechanical behaviour of trabecular bone specimens	Cancellous tibia	10 kN Universal screwdriven test machine (Instron), 1 kN load cell	Static strain gauge extensometer	Cylinder 7.5 mm diameter, 7.5 mm height	Frozen at -20°C	Not reported in paper	Group 1: no constraint; group 2: cement layer; group 3: excess cement removed; group 4: cement loosened	0.01/s ND cyclic test between 5 N and 0.8% strain	Preload 5 N
Rohl et al[53] (1991)	Tensile and compressive properties of cancellous bone	Cancellous tibia	Screwdriven machine (Instron), 10 kN load cell, wedge specimen grips	Dynamic strain gauge extensometer	Parallelepiped 9 mm × 9 mm × 20 mm	Marrow removed with air jet, embedded between 2cm of epoxy resin layers, frozen at -20°C	Not reported in paper	Not reported in paper	0.005/s D	Preconditioning 2 N to 0.2% strain until zero deformation (< 5 cycles usually)
Yahia et al[54] (1988)	A methodology for mechanical measurements of technical constants of trabecular bone	Cancellous vertebras	Universal test machine (J.J. Lloyd), pressurized chamber, triaxial test apparatus, test chamber filled with glycerin	4× resistance-type wire strain gauges	Cubic 10 mm	Frozen at -20°C, defatted in carbon tetrachloride for 48hrs and hydrogen peroxide for 40hrs, oven dried at 60°C for 72 hrs	Not reported in paper	Latex membrane to isolate specimen from glycerin	0.012/s ND	Preconditioned until steady state
Zhou et al[55] (2014)	Dependence of mechanical properties of trabecular bone on plate-rod microstructure determined by individual trabecula segmentation (ITS)	Cancellous femur, tibia, vertebras	Material testing system (MTS), test at RT	Strain gauge (8 mm, MTS), extensometer (25 mm, MTS)	Cylinder 8 mm diameter, height not reported in paper	Frozen wet airtight at -20°C	Not reported in paper	Brass end caps with glue	0.05%/s D	1 cycle of preconditioning to ± 0.1% strain

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Cyganik et al[56] (2014)	Prediction of Young's modulus of trabeculae in microscale using macro-scale's relationships between bone density and mechanical properties	Cancellous femur	Materials testing machine (MTS)	DIC (Dantec)	Cubic 10 mm	Stored in 70% ethanol at 4°C	Not reported in paper	Not reported in paper	0.5 mm/min D or up to 2000 N	Preload of 1 N
Cyganik et al[57] (2016)	Experimental verification of the relationships between Young's modulus and bone density using DIC	Cancellous femur	Test machine (MTS), test at RT (25°C)	DIC, full field (Dantec)	Cubic 10 mm	Not reported in paper	Not reported in paper	Not reported in paper	0.5 mm/min D or up to 2000 N	Not reported in paper
Cyganik et al[58] (2017)	Microscale's relationship between Young's modulus and tissue density. Prediction of displacements	Cancellous femur	Materials testing machine (MTS), test at RT	DIC	Cubic 1 cm × 1 cm × 1 cm	Fixed in 70% ethanol, stored in 4°C	No	No	0.04/min load range 0 to 2000 N or until failure	1 N preload
Kalouche et al[59] (2010)	Mechanical properties of glenoid cancellous bone	Cancellous shoulder	Compression device (Raith), 100 N load cell, test at RT	DIC	Cubic 6 mm	Frozen at -19°C, thawed at RT for 2 hrs	Not reported in paper	Not reported in paper	0.001/s, between 3 N and 0.6% strain D	7 cycles until 0.4% strain, preload 3 N
Sugita et al[60] (1999)	Anisotropy of osteoporotic cancellous bone	Cancellous femur	Servo-drive compression test machine (Aiko)	Displacement transducer on lower platen (Kyowadengyou), CCD video-camera (Hitachi)	Cubic 6.5 mm	Frozen at -20°C, thawed at RT in physiological saline	Compliance considered negligible (0.006\μm/N)	Not reported in paper	0.065 mm/s D	Preload of 8.5 N
Deligianni et al[61] (1994)	Stress relaxation behaviour of trabecular bone specimens	Cancellous femur	Motor driven machine (Schenck)	LVDT extensometer	Cubic 7 mm	Frozen in saline at -20°C, refrigerated in Ringer's solution before testing, thawed at RT	Not reported in paper	Not reported in paper	10/min (up to particular strains)	Preload 2 N
Rincón-Kohli and Zysset[62] (2009)	Multi-axial mechanical properties of human trabecular bone	Cancellous femur, tibia, radius, vertebras	Custom stainless-steel loading chamber, servohydraulic machine, 2.5 kN load cell	LVDT	Cylinder 8 mm diameter, 10 mm height	Frozen at -26°C	Tested for and assumed negligible	Aluminium endcaps with PMMA, nitrile membrane (8 mm diameter, 0.5 mm height) to isolate sample from oil, half-sphere platen	0.065%/s D	12 cycles to 0.4% strain
Townsend et al[63] (1975)	The distribution and anisotropy of the stiffness of cancellous bone in the human patella	Cancellous patella	Custom machine for 0-45lb load, beam deflection load cell	LVDT	Cubic 0.22 inches to 0.39 inches	Not reported in paper	Not reported in paper	Not reported in paper	5.3 x 10^{-4} cm/s D in one direction	Not reported in paper
Yamamoto et al[64] (2006)	Development of residual strains in human vertebral trabecular bone after prolonged static and cyclic loading at low load levels	Cancellous vertebras	Static: custom machine; cyclic: servohydraulic machine (MTS), both immersed in PBS and protease inhibitors at 37°C	Static: LVDT; cyclic: extensometer	Cylinder 8 mm diameter, 25 mm height	Marrow removed with water jet, frozen	Not reported in paper	End caps, cyanoacrylate glue, latex rubber and O rings	Static: ratio of stress/YM of 0.00075 or 0.0015 for 125 000 secs; cyclic: ratio of 0.0015 at 8 Hz for 1 mil cycles (125 000 cycles) D	Static: 10 preconditioning cycles 0 N to10 N; cyclic: 10 cycles 0 N to 10 N

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Follet et al[65] (2004)	The degree of mineralization is a determinant of bone strength: a study on human calcanei	Cancellous calcaneus	Screwdriven machine (Schenck), 5 kN Load Cell, tested in 37°C saline bath	Displacement transducer	Cubic 9 mm	Frozen before testing at -20°C, preserved in 50% ethanol-saline at 4°C for 3 to 4 days then RT for 4 hrs before testing	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper
Follet et al[66] (2005)	Relationship between compressive properties of human os calcis cancellous bone and microarchitecture assessed from 2D and 3D synchrotron microtomography	Cancellous calcaneus	Screwdriven machine (Schenck), 5 kN load cell, tested in saline bath at 37°C	Displacement transducer	Cubic 9 mm	Frozen then defrosted in 50% saline-ethanol solution for 3 days at 4°C, then at RT for 2 hrs to 4 hrs	Not reported in paper	Not reported in paper	0.5 mm/min D	10 cycles to 0.6% strain
Follet et al[67] (2007)	Intrinsic mechanical properties of trabecular calcaneus determined by finite-element models using 3D synchrotron microtomography	Cancellous calcaneus	Test machine (Schenck), 2 kN Load Cell, tested in saline solution at 37°C	Displacement transducer	Cubic 9 mm	Frozen, thawed in 50% saline-ethanol for 3 days at 4°C and at RT for 2 hrs to 4 hrs	Not reported in paper	Not reported in paper	0.5 mm/min D	10 cycles limited to 0.5% strain (in 3 directions)
Follet et al[68] (2011)	Effects of preexisting microdamage, collagen cross-links, degree of mineralization, age, and architecture on compressive mechanical properties of elderly human vertebral trabecular bone	Cancellous vertebras	Moving magnet linear motor machine (Bose-Enduratec), 2.25 kN load cell, tested at RT	Displacement transducer	Cylinder 8.25 mm diameter, 10 mm height	Frozen in saline at -20°C	Not reported in paper	Aluminium end caps embedded in methyl methacrylate resin	0.0005/s D to 3% strain	0.0005/s at 1 Hz for 10 cycles from 0.1% to 0.3% strain
Erivan et al[69] (2017)	Rehydration improves the ductility of dry bone allografts	Cancellous femur	Traction device (MTS) with compression plates	Machine crosshead displacement	Cubic 10 mm^3	Group 1: fresh wet frozen, thawed at RT for 12 hrs; group 2: dried/ sterilized (Osteopure technique); group 3: as group 2, then rehydrated in saline for 10 mins	No	Not reported in paper	3 mm/min D	Not reported in paper
Anderson et al[70] (1992)	Compressive mechanical properties of human cancellous bone after gamma irradiation	Cancellous tibia	Servohydraulic machine (MMED), 2200 N load cell, tested at 21°C	Not reported in paper	Parallelepiped 2 cm × 1 cm × 1 cm	Frozen at -80°C, stored at -20°C, thawed at RT in a water bath	Yes	Not reported in paper	1%/s D	Preload of 5 N, 5 cycles to 0.1 mm displacement
Badiei et al[71] (2007)	Influence of orthogonal overload on human vertebral trabecular bone mechanical properties	Cancellous vertebras	Screwdriven machine (Hounsfield)	Not reported in paper	Cubic 10 mm	Frozen in saline at -30°C	Measured, considered negligible	0.14 mm latex layer, pivoting platen	1 mm/min up to 10% strain D	Not reported in paper
Banse et al[72] (1996)	Comparative left-right mechanical testing of cancellous bone from normal femoral heads	Cancellous femur	Screwdriven machine (UTS), 100 kN load cell, compressed different locations on slice, test at RT	Not reported in paper	Varied cross-sectional shape, 9 mm height, 2 mm hole in centre	Embedded in polyurethane resin, frozen at -20°C	Measured, considered negligible (< 5%)	Not reported in paper	1 mm/min D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Baroud et al[73] (2003)	Material changes in osteoporotic human cancellous bone following infiltration with acrylic bone cement for a vertebral cement augmentation	Cancellous vertebras	Materials testing machine (MTS)	Not reported in paper	Cylinder 12 mm diameter, 12 mm height	Frozen at -20°C then thawed	Not reported in paper	Confined or free	1% strain in steps, then 5 min wait, max. displacement of 1.2 mm (~10% strain)	Not reported in paper
Bentzen et al[74] (1987)	Mechanical strength of tibial trabecular bone evaluated by X-ray computed tomography	Cancellous tibia	Universal testing machine (Instron)	Not reported in paper	Cylinder 8 mm diameter, 8 mm height	Frozen at -21°C in Ringer's solution, thawed at RT	Not reported in paper	Not reported in paper	5 mm/min (~0.01 s^{-1}) D	Not reported in paper
Bevill et al[75] (2009)	The influence of boundary conditions and loading mode on high-resolution finite element-computed trabecular tissue properties	Cancellous vertebras	Not reported in paper	Not reported in paper	Cylinder 8 mm diameter, 25 mm height	Not reported in paper	Not reported in paper	Group 1: PMMA and brass endcaps; group 2: brass rod wells, fixed in PMMA	ND (up to 0.2% strain) + D	Not reported in paper
Birnbaum et al[76] (2001)	Material properties of trabecular bone structures	Cancellous femur	Servohydraulic machine (Schenck), 16 kN micro-pulser, tested at 21°C	Not reported in paper	Cylinder 24 mm diameter, 11 mm height	Frozen at -20°C	Not reported in paper	Teflon plates (0.85 mm)	1 mm/min D	Preload of 7.5 N
Bollerslev et al[77] (1989)	Biomechanical competence of iliac crest trabecular bone in autosomal dominant osteopetrosis type I	Cancellous iliac crest	Materials testing machine (Alwetron)	Not reported in paper	Cylinder 7 mm diameter, 5 mm height	Frozen, thawed at 20°C in Ringer's solution for 30 mins	Not reported in paper	Not reported in paper	2 mm/min	Not reported in paper
Bone et al[78] (2015)	The influence of the strength of bone on the deformation of acetabular shells: A laboratory experiment in cadavers	Cancellous femur	Materials testing machine (Instron)	Not reported in paper	Cylinder mean 7.8 mm diameter, mean 12.7 mm height	Not reported in paper	Not reported in paper	Not reported in paper	20%/min D	Not reported in paper
Brown and Ferguson Jr[79] (1980)	Mechanical property distributions in the cancellous bone of the human proximal femur	Cancellous femur	Universal testing machine (Instron)	Not reported in paper	Cubic 5 mm	Frozen at -10°C, thawed before testing	Stiffening artefact corrected digitally	Not reported in paper	0.02 mm/s D + ND	Not reported in paper
Brown et al[80] (2002)	Regional differences in mechanical and material properties of femoral head cancellous bone in health and osteoarthritis	Cancellous femur	Materials testing machine (E.S.H.)	Not reported in paper	Cylinder 12 mm diameter, 16 mm height	Frozen	Not reported in paper	Not reported in paper	0.25 mm/min not reported in paper	Not reported in paper
Carter et al[81] (1980)	Tensile fracture of cancellous bone	Cancellous femur	Loading system (MTS), tested at 21°C	Not reported in paper	Cylinder 10 mm diameter, height 10 mm	Defatted in methanol and chloroform, frozen, thawed, dried overnight at RT, rehydrated with saline before test	Yes for embedded ends of specimen	Embedded in polyester resin, glued to platen	0.01/s D	Not reported in paper
Carter and Hayes[82] (1977)	The compressive behavior of bone as a two-phase porous structure	Cancellous tibia	Electrohydraulic machine (MTS), porous compression platen	Not reported in paper	Cylinder 20.6 mm diameter, 5 mm height	Half were defatted, frozen at -20°C, thawed before testing	Yes	Confined in steel annulus	Varied (0.001-10.0/s), D test up to > 50% of original thickness	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Cesar et al[83] (2017)	Axial compressive strength of human vertebras trabecular bones classified as normal, osteopenic and osteoporotic by quantitative ultrasonometry of calcaneus	Cancellous vertebras	Universal testing machine (Kratos), 981 N load cell	Not reported in paper	Cylinder 10 mm diameter, 20 mm height	Frozen -20°C in physiological saline, stored in amber vial at 4°C post-cut, kept at RT (21°C) in saline 1 hr before testing	Not reported in paper	Not reported in paper	5 mm/min	Not reported in paper
Charlebois et al[84] (2010)	The role of fabric in the large strain compressive behavior of human trabecular bone	Cancellous vertebras, radius, femur, calcaneus	Mechanical testing machine (MTS)	Not reported in paper	Cylinder 7.5 mm diameter, 11.5 mm height	Frozen, thawed overnight	Not reported in paper	Tested with or without confinement tubes, glued to rods	0.13%/s (0.015 mm/s) up to 1500 N or 10 mm displacement	10 preconditioning cycles
Chevalier et al[85] (2007)	Validation of a voxel-based FE method for prediction of the uniaxial apparent modulus of human trabecular bone using macroscopic mechanical tests and nanoindentation	Cancellous femur	Testing machine (MTS)	Not reported in paper	Cylinder 8 mm diameter, 12 mm height	Marrow removed in ultrasound bath with mild soap at 40°C, dried at RT for 1 day, thawed at RT	Not reported in paper	Glued with epoxy mix to stainless-steel rods and cured at 40°C for 24 hrs	0.083/s for 10 cycles ND	Not reported in paper
Christensen et al[86] (1981)	Mechanical testing of trabecular bone in knee replacement	Cancellous tibia	Hydraulic machine (Instron)	Not reported in paper	Cylinder 12 mm diameter, 8 mm height	Frozen at -18°C, thawed at RT	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper
Du et al[87] (2006)	An experimental study on the biomechanical properties of the cancellous bones of distal femur	Cancellous femur	Multiple automatic electronic testing machine (Shimadzu), saline bath	Not reported in paper	Parallelepiped ~16 mm × ~10 mm × ~10 mm	Frozen in saline at -20°C, thawed at RT	Not reported in paper	Not reported in paper	2 mm/min D	Not reported in paper
Ciarallo et al[88] (2006)	An approach to compare the quality of cancellous bone from the femoral necks of healthy and osteoporotic patients through compression testing and microcomputed tomography imaging	Cancellous femur	Materials testing system (Instron), 50 kN load cell	Not reported in paper	Cylinder, 7.5 mm diameter, 14 mm height	Stored in 70% ethanol, frozen in saline at-30°C, thawed overnight at 4°C	Not reported in paper	Not reported in paper	1 mm/min D	Not reported in paper
Ciarelli et al[89] (1991)	Evaluation of orthogonal mechanical properties and density of human trabecular bone from the major metaphyseal regions with materials testing and computed tomography	Cancellous tibia, femur, radius, humerus	Materials testing machine (Instron), test at RT	Not reported in paper	Cubic 8 mm	Frozen at -10°C in Ringer's solution	Yes	Embedded in aluminium block with plaster mix	1%/s, loaded to incipient yield in two directions, then loaded to failure in third direction	3 to 6 cycles to 40% to 60% of ultimate load until repeatable load-displacement curve produced
Cody et al[90] (1996)	Predictive value of proximal femoral bone densitometry in determining local orthogonal material properties	Cancellous femur	Materials testing machine (MTS)	Not reported in paper	Cubic 8 mm	Frozen at -30°C, thawed in water bath for 1hr, refrozen in Ringer's solution then thawed at RT	Not reported in paper	Not reported in paper	1%/s up to 1% strain or 1%/s up to 15% strain ND	10 cycles to 1% strain at 1%/s
Conrad et al[91] (1993)	The effects of freeze-drying and rehydration on cancellous bone	Cancellous tibia, femur	Hydraulic machine (MTS)	Not reported in paper	Cylinder 14 mm diameter, 15 mm height	Frozen at -80°C before freeze drying, thawed for 10 mins, varied rehydration protocols	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Cornu et al[92] (2011)	Synergetic effect of freeze-drying and gamma irradiation on the mechanical properties of human cancellous bone	Cancellous femur	100 kN screwdriven model (UTS)	Not reported in paper	8 mm slices	Various freeze-drying protocols, all samples then frozen and thawed at RT for 2 hrs before test, freeze dried samples rehydrated for 30min in saline	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper
Ding et al[93] (2012)	Three-dimensional microarchitecture of adolescent cancellous bone	Cancellous tibia	Materials testing machine (MTS), 1 kN load cell	Not reported in paper	Cubic 8 mm × 8 mm × 8 mm	Frozen at -20°C, thawed at RT for 2 hrs	Not reported in paper	Not reported in paper	0.002/s ND up to 0.6% strain	10 cycles between 3 N and 0.006 strain
Ding et al[94] (2002)	Age-related variations in the microstructure of human tibial cancellous bone	Cancellous tibia	Hydraulic machine (MTS), 1 kN load cell	Not reported in paper	Cylinder 7.5 mm diameter, 7.5 mm height	Frozen at -20°C	Not reported in paper	Not reported in paper	0.002/s ND to 0.6% strain	10 cycles between preload of 3 N
Fazzalari et al[95] (1998)	Assessment of cancellous bone quality in severe osteoarthrosis: Bone mineral density, mechanics, and microdamage	Cancellous femur	Materials testing machine (Hounsfield)	Not reported in paper	Cylinder 10 mm diameter, 10 mm height	Frozen at -20°C, thawed at RT in saline	Not reported in paper	Pivoted lower platen, latex on specimen ends	0.017/s Until failure, 25% deformation or 200 N load	Not reported in paper
Goldstein et al[96] (1983)	The mechanical properties of human tibial trabecular bone as a function of metaphyseal location	Cancellous tibia	Materials testing machine (Instron)	Not reported in paper	Cylinder 7 mm diameter, 10 mm height	Frozen in -20°C, then in Ringer's solution for 20 mins	Not reported in paper	Not reported in paper	0.1%/s D	Preload of 1.3 MPA
Goulet et al[97] (1994)	The relationship between the structural and orthogonal compressive properties of trabecular bone	Cancellous tibia, femur, iliac crest, radius, humerus, vertebras	Materials Testing machine (Instron)	Not reported in paper	Cubic 8 mm	Stored in lactated Ringer's solution, frozen at -20°C	Yes	Not reported in paper	0.01/s D	10 cycles to 50% to 60% of ultimate strength
Grieb et al[98] (2005)	Effective use of optimized, high-dose (50 kGy) gamma irradiation for pathogen inactivation of human bone allografts	Cancellous origin not reported in paper	Servohydraulic machine (MTS)	Not reported in paper	Cylinder 12 mm to 18 mm diameter, 10 mm height	Freeze-dried to residual moisture of ~8%, rinsed in deionized water for 30s, rehydrated in 0.9% saline	Not reported in paper	Not reported in paper	5 mm/min Not reported in paper	Not reported in paper
Han et al[99] (1997)	The ability of quantitative ultrasound to predict the mechanical properties of trabecular bone under different strain rates	Cancellous tibia	Not reported in paper	Not reported in paper	Cylinder 10 mm diameter, 14.5 mm height	Not reported in paper	Not reported in paper	Self-levelling platens	0.0004/s or 0.08/s or 200 times faster D	Not reported in paper
Hvid[100] (1985)	Cancellous bone at the knee: A comparison of two methods of strength measurement	Cancellous femur, tibia	Universal testing machine (Instron), test at RT	Not reported in paper	Cylinder mean 5.29 mm diameter, mean 6.38 mm height	Frozen in saline at -30°C, thawed before testing	Not reported in paper	Not reported in paper	0.013/s D	Not reported in paper
Hvid and Jensen[101] (1984)	Cancellous bone strength at the proximal human tibia	Cancellous tibia	Testing Machine (Instron), test at RT	Not reported in paper	Cylinder 7.5 mm diameter, 8.5 mm height	Frozen in Ringer's solution at -30°C	Not reported in paper	Not reported in paper	0.01/s D	No
Hvid et al[102] (1983)	Compressive strength of tibial cancellous bone: *Instron* and osteopenetrometer measurements in an autopsy material	Cancellous tibia	Testing machine (Instron)	Not reported in paper	Cylinder 8 mm diameter, 8 mm height	Frozen at -18°C	Not reported in paper	Not reported in paper	2 mm/min D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Keyak et al[103] (1996)	Postfailure compressive behavior of tibial trabecular bone in three anatomic directions	Cancellous tibia	Servohydraulic machine (Matco)	Not reported in paper	Cubic 15 mm	Frozen	Not reported in paper	Not reported in paper	0.15 mm/s D to 2 mm displacement	Preload to 5 N at 0.5% strain, repeated until 5 N position was reproducible
Lambers et al[104] (2014)	The effects of tensile-compressive loading mode and microarchitecture on microdamage in human vertebral cancellous bone	Cancellous vertebras	Materials testing device	Not reported in paper	Cylinder 8 mm diameter, 25 mm to 30 mm height	Stained with xylenol orange in PBS for 2 hrs	Not reported in paper	Brass fixtures and bone cement	0.5%/s D up to 0.8% strain	Not reported in paper
Leichter et al[105] (1990)	Acoustic emission from trabecular bone during mechanical testing: the effect of osteoporosis and osteoarthritis	Cancellous femur	Materials testing machine (J. J. Lloyd)	Not reported in paper	Cylinder 10 mm diameter, 10 mm height	Frozen at -18°C, thawed at RT	Not reported in paper	Not reported in paper	0.1/min D	Not reported in paper
Díaz León et al[106] (2016)	Mechanical characterization of bone allografts, enriched with mesenchymal cells	Cancellous, cortical or mixed long bones	Testing machine (Instron)	Not reported in paper	Cubic 5 mm × 5 mm × 5 mm	Added mesenchymal stem cells	Not reported in paper	Rotating lower platen	1 mm/min Not reported in paper	Not reported in paper
Li et al[107] (2012)	Difference in subchondral cancellous bone between postmenopausal women with hip osteoarthritis and osteoporotic fracture: Implication for fatigue microdamage, bone microarchitecture, and biomechanical properties	Cancellous femur	Servohydraulic machine (Instron)	Not reported in paper	Parallelepiped 15 mm × 15 mm × 10 mm	Frozen in saline -20°C, thawed at RT	Not reported in paper	N	2 mm/min D	Not reported in paper
Linde et al[108] (1990)	Three-axial strain controlled testing applied to bone specimens from the proximal tibial epiphysis	Cancellous tibia	Material testing machine (Instron)	Not reported in paper	Cubic 7 mm	Not reported in paper	Not reported in paper	Not reported in paper	0.1/s ND test between 5 N and 0.5%	5 to 10 cycles until steady state
Linde et al[109] (1985)	Material properties of cancellous bone in repetitive axial loading	Cancellous tibia	Universal testing machine (Instron)	Not reported in paper	Cylinder 8 mm diameter, 8 mm height	Frozen, thawed before testing	Not reported in paper	Not reported in paper	0.01/s 10 cycles Up to 50% of ultimate strength	Not reported in paper
Linde et al[110] (1988)	Mechanical properties of trabecular bone by a non-destructive compression testing approach	Cancellous tibia	Screwdriven machine (Instron)	Not reported in paper	Cylinder 7.5 mm diameter, 7.5 mm height	Not reported in paper	Not reported in paper	Not reported in paper	0.01/s	~10 cycles 0.2 Hz up to 5 N
Liu et al[111] (2013)	Quasi-static compressive and tensile tests on cancellous bone in human cervical spine	Cancellous vertebras	Microtester machine (Instron)	Not reported in paper	Parallelepiped mean 5.36 mm × 6.29 mm × 9.81 mm	Not reported in paper 0.001/s	Not reported in paper	Lubrication on contact surfaces, ball joint anvil	0.001/s D	19 cycles up to 0.3% strain, 0.001/s
Lv et al[112] (2015)	Comparison of microstructural and mechanical properties of trabeculae in femoral head from osteoporosis patients with and without cartilage lesions: a case-control study	Cancellous femur	Dual column testing system (Instron), 10 kN load cell	Not reported in paper	Cylinder 12 mm diameter, height 20% of head height	Dry frozen at -80°C	Not reported in paper	Not reported in paper	1%/min D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Martin et al[113] (1998)	Noninvasive assessment of stiffness and failure load of human vertebras from CT-data	Cancellous vertebras	Material testing apparatus (Shimadzu), 5 kN load cell	Not reported in paper	Cubic 10 mm	Frozen or stored in buffered formalin, stored at 100% relative humidity	Not reported in paper	Not reported in paper	0.1/mm D	Not reported in paper
Mosekilde et al[114] (1987)	Biomechanical competence of vertebral trabecular bone in relation to ash density and age in normal individuals	Cancellous vertebras	Testing machine (Alwetron)	Not reported in paper	Cylinder 7 mm diameter, 5 mm height	Frozen at -20°C, thawed at 20°C in Ringer's solution for 30 mins	Not reported in paper	Platen mounted on steel ball bearing	2 mm/min D	N
Nazarian et al[115] (2007)	Densitometric, morphometric and mechanical distributions in the human proximal femur	Cancellous femur	Custom build screwdriven machine (Nazarian and Muller)	Not reported in paper	Cylinder 2:1 ratio, (5 mm diameter, 10 mm height)	Not reported in paper	Not reported in paper	Brass endcaps with cyanoacrylate glue	0.01/s D	0.005/s strain for 7 cycles
Nicholson et al[116] (1997)	Structural and material mechanical properties of human vertebral cancellous bone	Cancellous vertebras	Materials testing machine (J.J. Lloyd)	Not reported in paper	Cubic 20 mm	Defatted by cold water jet, immersed in excess trichloroethylene for 12 hrs, re-rinsed in methanol, air dried for 6 hrs, frozen at -20°C	Not reported in paper	Ball bearing loading system	1 mm/min ND	3 cycles of increasing load and return to preload of 30 N
Nicholson and Strelitzki[117] (1999)	On the prediction of Young's modulus in calcaneal cancellous bone by ultrasonic bulk and bar velocity measurements	Cancellous calcaneus	Materials testing machine (J.J. Lloyd)	Not reported in paper	Cubic 20 mm	Defatted using water jet and trichloroethylene	Not reported in paper	Not reported in paper	Not reported in paper	3 cycles to 0.6% strain
Njeh et al[118] (1997)	Prediction of human femoral bone strength using ultrasound velocity and BMD: an in vitro study	Cancellous femur	Testing machine (Instron), load cell 20 N to 10 kN, test at RT	Not reported in paper	Cubic 20 mm	Fixed in formalin, Frozen at -80°C for ⩾ 3 mths	Not reported in paper	Not reported in paper	0.5 mm/min D	Not reported in paper
Ozan et al[119] (2017)	Micro-CT and mechanical evaluation of trabecular bone structure in osteopenic and osteoporotic fractures	Cancellous femur	100 kN test machine (Shimadzu)	Not reported in paper	Rectangular, prism-shaped 3 cm × 2 cm × 2 cm	Frozen at -18°C, defrosted 24 hrs before testing	Not reported in paper	Not reported in paper	0.04 mm/s until 4 mm displacement	Not reported in paper
Portero-Muzy et al[120] (2007)	Eulerstrut.cavity, a new histomorphometric parameter of connectivity reflects bone strength and speed of sound in trabecular bone from human os calcis	Cancellous os calcis	Universal screwdriven machine (Schenck), 5 kN load cell, tested in saline 37°C	Not reported in paper	Cylinder 14 mm diameter, 9 mm height	Frozen at -20°C	Not reported in paper	Free rotating bottom platen	0.5 mm/min D	10 cycles of preloading to steady state
Pothuaud et al[121] (2002)	Combination of topological parameters and bone volume fraction better predicts the mechanical properties of trabecular bone	Cancellous vertebras	Materials testing machine (Alwetron)	Not reported in paper	Cylinder 7 mm diameter, 5 mm height	Dried specimens	Not reported in paper	Steel ball bearing on endplates	2 mm/min D	Not reported in paper
Poukalova et al[122] (2010)	Pullout strength of suture anchors: effect of mechanical properties of trabecular bone	Cancellous humerus	Universal testing machine (Instron)	Not reported in paper	Cylinder 8 mm diameter, 12 mm height	Frozen at -20°C, thawed at RT for 24 hrs	Not reported in paper	Not reported in paper	0.1%/s up to 60% strain	Not reported in paper
Poumarat et al[123] (1993)	Comparison of mechanical properties of human, bovine bone and a new processed bone xenograft	Cancellous femur	Materials testing machine (Hounsfield), test at RT	Not reported in paper	Parallelepiped 15 mm × 12.5 mm × 8 mm	Washed in saline, then in gentamycin-supplemented saline, wet frozen at -30°C, thawed	Not reported in paper	Not reported in paper	0.025 mm/min D	Not reported in paper

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Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Rauh et al[124] (2014)	Comparative biomechanical and microstructural analysis of native versus peracetic acid-ethanol treated cancellous bone graft	Cancellous tibia	Materials testing machine (Instron), test at RT	Not reported in paper	Cylinder 12 mm diameter, 15 mm height	Fat removed (high pressure sterile water for 30 mins, chloroform-methanol incubation for 2 hrs, methanol for 15 mins to remove chloroform, sterile deionized water to remove methanol, frozen at -20°C, thawed for 24 hrs in saline at RT	Not reported in paper	Not reported in paper	0.07 mm/s D, maximum load 10 kN	Not reported in paper
Rho et al[125] (1997)	The characterization of broadband ultrasound attenuation and fractal analysis by biomechanical properties	Cancellous tibia	Not reported in paper	Not reported in paper	Cubic 15 mm	Stored in normal saline at 4°C	Not reported in paper	Not reported in paper	0.01%/s ND up to 0.35% strain	Not reported in paper
Rodrigues et al[126] (2012)	Low osteocalcin/collagen type I bone gene expression ratio is associated with hip fragility fractures	Cancellous femur	Universal testing machine (Instron), load cell 10 kN	Not reported in paper	Cylinder 15 mm diameter, height dependent on epiphysis size	Defatted for 3 hrs in chloroform and methanol, hydrated overnight in saline, frozen at -80°C, thawed at RT	Not reported in paper	Not reported in paper	0.1 mm/s D	Not reported in paper
Seo et al[127] (2014)	Efficacy of dual energy X-ray absorptiometry for evaluation of biomechanical properties: bone mineral density and actual bone strength	Cancellous vertebras	Compression testing machine (Texture Technologies)	Not reported in paper	Parallelepiped ~15 mm × 10 mm × 15 mm	Embedded in 10% formalin solution for 24 hrs	Not reported in paper	Not reported in paper	0.2 mm/s D	Not reported in paper
Shim et al[128] (2006)	Characterisation of the dynamic compressive mechanical properties of cancellous bone from the human cervical spine	Cancellous vertebras	Universal testing machine (Instron)	Not reported in paper	Parallelepiped 5 mm × 5 mm × 8 mm	Not reported in paper	Not reported in paper	Not reported in paper	0.001/s D	Not reported in paper
Sierpowska, et al[129] (2005)	Prediction of mechanical properties of human trabecular bone by electrical measurements	Cancellous femur, tibia	Not reported in paper	Not reported in paper	Cylinder 16 mm diameter, 8 mm height	Sprayed with PBS to hydrate, frozen at -20°C for 12 mths	Not reported in paper	Not reported in paper	0.0045/s D up to 5% strain	5 cycles to 0.5% strain, pre-stress of 100 kPa for 2 mins
Steinhauser et al[130] (2006)	Biomechanical investigation of the effect of high hydrostatic pressure treatment on the mechanical properties of human bone	Cancellous femur	Universal testing machine (Zwick), 2 kN load cell	Not reported in paper	Cylinder 7.2 mm diameter, 14.4 mm height	Frozen at -20°C	Not reported in paper	Not reported in paper	5 mm/min D: until load decrease of > 10% of maximum	Preload 2 N at 10 mm/min
Stoppie et al[131] (2006)	Structural and radiological parameters for the characterization of jawbone	Cancellous mandible	Not reported in paper	Not reported in paper	Cylinder 6 mm diameter, 8 mm height	Formalin embalmed, frozen with nitrogen into cupper rod to remove cortex, frozen at -20°C in saline	Not reported in paper	Brass end caps with glue	0.2 mm/min D	Preload 3 N, 10 to 15 cycles at 0.2 mm/min up to 0.6% strain

(*continued*)

Table i. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / preconditioning
Sun et al[132] (2008)	Difference in femoral head and neck material properties between osteoarthritis and osteoporosis	Cancellous femur	Materials testing machine (MTS)	Not reported in paper	Cubic 1cm	Frozen at -10°C, defrosted for 24 hrs	Not reported in paper	Not reported in paper	0.04 mm/s D	Not reported in paper
Thurner et al[133] (2009)	The effect of NaF in vitro on the mechanical and material properties of trabecular and cortical bone	Cancellous vertebras	Custom testing device, immersed in Na-buffer during testing	Not reported in paper	Parallelepiped 4 mm × 4.9 mm × 4.9 mm	Frozen at -20°C, then in Na-buffer (control) or saturated Na-buffer for 20 hrs, thawed in NaCL and Hepes solution at pH 7.0 at RT, marrow removed with water jet	Not reported in paper	Not reported in paper	50%/s up to 50% D	Preload of 0.5 N
Vale et al[134] (2013)	At the moment of occurrence of a fragility hip fracture, men have higher mechanical properties values in comparison with women	Cancellous femur	Universal testing machine (Instron), 10 kN load cell	Not reported in paper	Cylinder 15 mm diameter, 30 mm height	Defatted for 3 hrs in chloroform and methanol solution, hydrated overnight in PBS solution, frozen at -80°C, thawed at RT	Not reported in paper	Not reported in paper	0.1 mm/s D	Not reported in paper
Vale et al[135] (2013)	Micro-CT and compressive characterization of trabecular bone	Cancellous femur	Universal testing machine (Instron), 10 kN load cell	Not reported in paper	Cylinder 5 mm diameter, 15 mm height, or 15 mm diameter, 30 mm height	Defatted for 3 hrs in chloroform and methanol solution, hydrated overnight in PBS solution. Frozen at -80°C, thawed at RT	Not reported in paper	Not reported in paper	0.1 mm/s D	Not reported in paper
Vastel et al[136] (2004)	Effect of different sterilization processing methods on the mechanical properties of human cancellous bone allografts	Cancellous femur	Screw-filled tensile-compression machine (Wolpert)	Not reported in paper	Cubic 9 mm	Frozen in saline at -80°C, thawed at RT	Not reported in paper	Not reported in paper	2 mm/min D	Not reported in paper
Wells and Rawlings[137] (1985)	Acoustic emission and mechanical properties of trabecular bone	Cancellous tibia, femur	Screwdriven testing machine	Not reported in paper	Cubic 15 mm	Frozen at -18°C	Not reported in paper	Series 1: mounted in steel pot; series 2: contained in PTFE tape with holes	Range of 0.1 mm/min to 5.0 mm/min; not reported in paper	Not reported in paper
Zhang et al[138] (2010)	Micro-CT and mechanical evaluation of subchondral trabecular bone structure between postmenopausal women with osteoarthritis and osteoporosis	Cancellous femur	Mechanical testing machine (Critm Co.)	Not reported in paper	Cylinder, 5 mm diameter, 10 mm height	Not reported in paper	Not reported in paper	Not reported in paper	2 mm/min D	Not reported in paper
Zhu et al[139] (1994)	Effects of specimen load-bearing and free surface layers on the compressive mechanical properties of cellular materials	Cancellous vertebras	Materials test system (MTS), irrigated with saline	Not reported in paper	Parallelepiped 9 mm × 9mm × 5 mm, 9 mm, or 16 mm height	Frozen at -30°C, thawed at RT for 2 hrs	Yes (~1.5×10^{-5} mm/N)	Lubricated platens, platen annulus to centre specimens	1%/s ND but D for short specimens	Not reported in paper

D/ND, destructive/non-destructive; MTS, materials testing machine; RT, room temperature; PMMA, polymethyl methacrylate; Gd-DTPA, gadopentetic acid; HBSS, Hank's Balanced Salt Solution; μFE, micro finite element; DIC, Digital Image Correlation; CCD, charge-coupled device; LVDT, linear variable differential transformer; PBS, phosphate-buffered saline; PTFE, polytetrafluoroethylene

Table ii. Papers included in qualitative synthesis – studies using both cancellous and cortical bone specimens or mixed specimens; articles are ordered according to method of strain measurement and secondly according to author (alphabetical order); where "Not reported in paper" is written, no information has been provided regarding that subject

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / precondi-tioning
Bayraktar et al[140] (2004)	Comparison of the elastic and yield properties of human femoral trabecular and cortical bone tissue	Cancellous and cortical, femur	Servohydraulic machine (MTS)	Extensometer (5 mm)	Cancellous: Cylinder 8 mm diameter, 32 mm height Cortical: parallel piped 2.5 mm × 30 mm × 11 mm	Frozen hydrated and air-tight at -20°C	Not reported in paper	End caps, cortical specimens embedded in PMMA	Cancellous: 0.5%/s, ND (0.2% yield); cortical: 0.2%/s	Not reported in paper
Samuel et al[141] (2016)	Effect of water on nanomechanics of bone is different between tension and compression	Not reported in paper, femur	Servohydraulic machine (MTS), PBS continuously dripped onto control specimens	Extensometer on gauge region	Cylinder 3 mm diameter, 5 mm height	Dry group: dehydrated at 70°C and 25 in. Hg vacuum for 8 hrs; control: PBS soaked gauze frozen at -20°C	No	Strip of absorbent paper wrapped on specimen during test	Multiple loading cycles with incremental strains, 150 s relax period between cycles, unload to baseline of 5 N, further 150 s relax period D	Not reported in paper
McElhaney et al[142] (1970)	Mechanical properties of cranial bone	Mixed cranium	Electromatic testing machine (Tinius Olsen)	Stiff strain gauge load ring, compliant strain gauge cantilever contact arm	Cube machined from 20 mm cylindrical core	Embalmed and fresh specimens, stored in isotonic saline buffered with calcium	Not reported in paper	Not reported in paper	0.01 inch/min D in a third of samples	Not reported in paper
Reilly et al[143] (1974)	The elastic modulus for bone	Not reported in paper, femur	Testing machine with loading pendulum	Strain gauge extensometer	Parallelepiped 5 mm × 5 mm × 15 mm (2 mm × 6 mm central diameter)	Frozen in saline at -20°C	Not reported in paper	Not reported in paper	0.05/s; not reported in paper	Not reported in paper
El Masri et al[144] (2012)	Apparent Young's modulus of vertebral cortico-cancellous bone specimens	Mixed vertebras	Universal testing machine (Instron), 5 kN load cell, test at RT	LVDT sensor	Pseudo-parallelepiped 12 mm × 10 mm × 3 mm	Frozen at -20°C, thawed at 20°C for ⩾2 hrs	Not reported in paper	Not reported in paper	1 mm/min D	Preload 10 N, 10 cycles between 0.1% to 03% strain
Li et al[145] (2017)	Biomechanical analysis of the posterior bony column of the lumbar spine	Mixed vertebras	Universal testing machine	Machine crosshead displacement	Irregular geometry; unable to process standard pieces	Wrapped in saline soaked gauze, frozen -20°C, thawed at RT	Not reported in paper	Embedded on both ends in denture powder and resin	0.01 mm/s D	Preload 5 N
Balsly et al[146] 2008)	Effect of low dose and moderate dose gamma irradiation on the mechanical properties of bone and soft tissue allografts	Mixed femur	Mechanical testing machine (Instron), 30 kN load cell, grooved platen, test at RT	Not reported in paper	Cylinder 14 mm diameter, varied height (Cloward dowel)	Disinfected and defatted in Allowash, freeze dried, rehydrated in saline at RT for ⩾60 mins	Not reported in paper	Not reported in paper	35 mm/min D	Not reported in paper
Bosisio et al[147] (2007)	Apparent Young's modulus of human radius using inverse finite-element method	Mixed radius	Test machine (Instron), 100 kN load cell	Not reported in paper	20 mm thick slices	Frozen at -20°C	Not reported in paper	Custom rotating platen	0.07%/sec; not reported in paper	Preload 10 N, 10 cycles 8 mm/min to 0.3% strain
Finlay and Repo[148] (1978)	Cartilage impact in vitro: Effect of bone and cement	Mixed tibia	Custom made drop tower	Not reported in paper	Cylinder 9 mm diameter, 1.4 mm to 2.2 mm height	Bone surface prepared with emery cloth and diamond grit paper	Not reported in paper	Stainless-steel holder and bone cement	1000/s D up to 20% strain	Not reported in paper
Jankowska-Kuchta et al[149] (1994)	Comparison of mechanical properties of the bone investigated by compression test and holographic interferometry	Not reported in paper, tibia	Test machine (Instron)	Not reported in paper	Cylinder diameter not reported in paper, 25.2 mm height	Not reported in paper	Not reported in paper	Not reported in paper	0.2 mm/min D	Not reported in paper

(*continued*)

Table ii. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / precondi-tioning
Keller[150] (1994)	Predicting the compressive mechanical behaviour of bone	Mixed vertebras, femur	Servohydraulic machine (MTS)	Not reported in paper	Cubic 8 mm and 10 mm	Frozen at -30 °C, irrigated with 0.9% saline	Yes, 10^{-5} mmN^{1}	Oiled stainless-steel platens	0.01 s^{-1} D	Preload 0.1 N, no preconditioning
MacNeil and Boyd[151] (2008)	Bone strength at the distal radius can be estimated from high-resolution peripheral quantitative computed tomography and the finite element method	Mixed radius	Testing machine (MTS), 10 kN load cell	Not reported in paper	9.1 mm thick sections	Frozen, thawed at RT	Not reported in paper	N due to specimen height restrictions	3%/s D	Preload of 100 N
Misch et al[152] (1999)	Mechanical properties of trabecular bone in the human mandible: Implications for dental implant treatment planning and surgical placement	Cancellous and cortical, mandible	Servohydraulic machine (Instron)	Not reported in paper	Cylinder 5 mm diameter 5 mm height	Frozen at -20°C	Not reported in paper	Tested side-constrained and free	0.01/s D	Not reported in paper
Nazarian et al[153] (2008)	Bone volume fraction explains the variation in strength and stiffness of cancellous bone affected by metastatic cancer and osteoporosis	Bone type not reported in paper, vertebras, femur	Screwdriven testing system	Not reported in paper	Cylinder 2:1 ratio (~5.5 mm diameter, ~10 mm height)	Not reported in paper	Not reported in paper	Brass endcaps with cyanoacrylate glue	0.01% up to 20% strain	0.005/s strain for 7 cycles
Parsch et al[154] (2008)	Mechanical stability of structured bone grafts from the anterior iliac crest	Cancellous and cortical Ilium	Universal testing machine (Frank Prufmaschinen), 10 kN force plotter	Not reported in paper	Cylinder 6.4 mm diameter, 30 mm height or 8.5 mm diameter, 40 mm height	Not reported in paper	Not reported in paper	Not reported in paper	15 mm/min ND to decrease in force of 5 N	Not reported in paper
Rao et al[155] (1993)	Biomechanical comparison of bone graft used in anterior spinal reconstruction: Freeze-dried demineralized femoral segments versus fresh fibular segments and tri-cortical iliac blocks in autopsy specimens	Mixed Iliac crest, fibula, femur	Hydraulic machine (MTS)	Not reported in paper	Not reported in paper	Water jet, 95% ethanol, ethyl ether, air dried, surface demineralized in 0.5-N hydrochloric acid for 24 hrs at 4°C	Not reported in paper	Not reported in paper	0.5 mm/min D	Not reported in paper
Speirs et al[156] (1999)	Biomechanical properties of sterilized human auditory ossicles.	Mixed ossicle	Biaxial testing machine (MTS)	Not reported in paper	Cylinder 1.5 mm diameter, 4 mm height	Frozen at -20°C	Repeatability tests on synthetic bone samples	Low viscosity glue on lower platen	0.05 mm/s Not reported in paper	Not reported in paper
Stein and Granik[157] (1980)	Human vertebral bone: relation of strength, porosity, and mineralization to fluoride content	Bone type not reported in paper vertebras	Static tester (Instron)	Not reported in paper	Cylinder 1.25 cm diameter, 2.5 cm height	Not reported in paper	Not reported in paper	Not reported in paper	2.54 mm/minD	Not reported in paper

D/ND, destructive/non-destructive; MTS, materials testing machine; PMMA, polymethyl methacrylate; PBS, phosphate-buffered saline; LVDT, linear variable differential transformer; RT, room temperature

Table iii. Papers included in qualitative synthesis – studies using cortical bone specimens; articles are ordered according to method of strain measurement and secondly according to author (alphabetical order); where "Not reported in paper" is written, no information has been provided regarding that subject

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / precondi-tioning
Caler and Carter[158] (1989)	Bone creep-fatigue damage accumulation	Cortical femur	Electrohydraulic system (MTS), Wood's metal grips, tested at 37°C	Extensometer (8 mm)	Cylinder 3 mm diameter, 8 mm height	Frozen airtight at -20°C	Not reported in paper	Not reported in paper	0.002/s to 0.009/s D	Not reported in paper
Cotton et al[159] (2005)	Damage rate is a predictor of fatigue life and creep strain rate in tensile fatigue of human cortical bone samples	Cortical femur	Universal testing machine (Dartec), test at 37°C in Ringer's solution	Extensometer (12 mm)	Parallelepiped 8 mm × 8 mm × 20 mm	Not reported in paper	Yes for grip compliance	Not reported in paper	20 cycles 2 Hz to 100 N D	Not reported in paper
Dong et al[160] (2012)	Orientation dependence of progressive post-yield behavior of human cortical bone in compression	Cortical femur	Mechanical testing machine (MTS)	Extensometer (3 mm)	Cylinder 3 mm diameter, 5 mm height	Stored in PBS solution, frozen at -20°C	Not reported in paper	Not reported in paper	0.001/s 11 cycles incremental compressive load and unloading D	Preload 20 N
Hansen et al[161] (2008)	The effect of strain rate on the mechanical properties of human cortical bone	Cortical femur	Servohydraulic testing machine (Zwick), 5 kN load cell, Ringer's solution bath, test at 37°C	Extensometer (7 mm)	Dog-bone-shaped, 3 mm to 2.4 mm	Frozen in Ringer's at -20°C, thawed before testing	Not reported in paper	Not reported in paper	Varied strain rates in range 0.14/s to 29/s D	Not reported in paper
Imbert et al[162] (2015)	Microstructure and compressive mechanical properties of cortical bone in children with osteogenesis imperfecta treated with bisphosphonates compared with healthy children	Cortical femur	Custom compression machine, 2.5 kN load cell	Extensometer	Parallelepiped 3 mm × 1.6 mm × 1.6 mm	Immersed in saline for scanning, frozen at -20°C	Not reported in paper	Not reported in paper	0.7 µm/s, loaded until 100 N, then unloaded and loaded again to failure D	10 N preload
Mirzaali et al[163] (2015)	Mechanical properties of cortical bone and their relationships with age, gender, composition and microindentation properties in the elderly	Cortical femur	Biaxial servohydraulic testing machine (MTS), soaked in HBSS during testing, test at 23°C and 44% relative humidity	Bi-axial extensometer (Epsilon)	Dumb-bell shaped 3 mm diameter, 6.5 mm height, 30 mm total height	Frozen at -20°C, lubricated with ethylenglycol during lathing, rehydrated in HBSS for 12 hrs at 4°C, then RT for > 2 hrs	Not reported in paper	Not reported in paper	~ 2.5^{10-4} s^{-1} D	3 load cycles up to 0.2% strain
Öhman et al[164] (2008)	The effects of embalming using a 4% formalin solution on the compressive mechanical properties of human cortical bone	Cortical femur	Materials testing machine (MTS)	Extensometer (4.6 mm, MTS) fixed with acrylic resin	Cylinder 3 mm diameter, 20 mm height	Control group: Ringer's solution at RT for 24 hrs; group 2 to 4: 4% formalin for 48 hrs, 4 wks, or 8 wks then stored in Ringer's for 24 hrs, frozen between -19°C and 21°C	Not reported in paper	Not reported in paper	1.2 mm/s D	Not reported in paper
Öhman et al[165] (2011)	Compressive behaviour of child and adult cortical bone	Cortical femur, tibia	Materials testing machine (MTS)	Extensometer (4.6 mm, MTS)	Cylinder diameter 3 mm, 18 mm height, or 2 mm diameter, 14 mm height	70% ethanol for at least 4 wks, rehydrated in Ringer's solution for 24hrs	Not reported in paper	PMMA and endcaps	0.1/s D until 5% reduction in free height	Not reported in paper
Wachter et al[166] (2001)	Prediction of strength of cortical bone in vitro by microcomputed tomography	Cortical femur	Uniaxial materials testing machine (Zwick), test at RT, samples periodically moistened	Extensometer (Zwick)	Cylinder 3.6 mm diameter, 4.126 mm average height	Frozen at -20°C	Not reported in paper	Lubrication on specimen ends	0.6 mm/min ND	Preconditioning 3 cycles at 0.6 mm/min up to 50 N

(*continued*)

Table iii. (Continued)

Author (year)	Title	Bone type/ origin	Machine setup	Strain measurement method	Sample dimensions	Sample preparation / storage	Compliance correction	Surface / boundary conditions	Strain or displacement rate / D/ND test	Preload / precondi-tioning
Wachter et al[167] (2002)	Correlation of bone mineral density with strength and microstructural parameters of cortical bone in vitro	Cortical femur	Materials testing machine (Zwick), test at RT, samples periodically moistened	Extensometer (Zwick)	Cylinder 3.6 mm diameter, 4.1 mm mean height	Frozen at -20°C	Not reported in paper	Lubricated contact areas	0.6 mm/min D	Preconditioning 3 cycles at 0.6 mm/min up to 50 N
Bargren et al[168] (1974)	Mechanical properties of hydrated cortical bone	Cortical femur	Ebonite clamps, 100lb load cell (Tyco), test at 70°F	Strain gauges (0.05 x 0.08 inch)	Parallelepiped 1.5 mm × 1.5 mm × 20 mm	Air-dried < 5 mins during strain gauge application, rehydrated and stored in saline at 4°C, test repeated after air-drying	Not reported in paper	Not reported in paper	Cyclic up to 0.052/s ND (up to 0.002 or 20% strain of failure)	Not reported in paper
Reilly and Burstein[169] (1975)	The elastic and ultimate properties of compact bone tissue	Cortical femur	Testing machine with loading pendulum, displacement cam	Strain gauge extensometer (2000Ω)	Unclear	Frozen	Not reported in paper	Not reported in paper	0.02/s to 0.05/s not reported in paper	Not reported in paper
Vardakastani et al[170] (2014)	Increased intra-cortical porosity reduces bone stiffness and strength in pediatric patients with osteogenesis imperfecta	Cortical femur, tibia	Uniaxial device (Raith), 1 kN load cell	DIC (Canon, custom DIC software)	Varied (1.3 mm to 4.3 mm diameter, 5.0 mm to 6.9 mm in height)	Frozen in saline at -18°C	Not reported in paper	Not reported in paper	0.001/s D	Preload 3 cycles to 20 N
Duchemin et al[171] (2008)	Prediction of mechanical properties of cortical bone by quantitative computed tomography	Cortical femur	Universal tension-compression system (Instron), dehydrated for 5 mins at RT	Optical CCD camera (Pulnix)	Parallelepiped 3 mm × 3 mm × 5 mm	Frozen at -20°C, thawed at 4°C in water for 1 hr to 3 hrs	Not reported in paper	Not reported in paper	0.04/min D	Preload of 12 N, 3 cycles to max. load 50 N
Bourgnon et al[172] (2014)	Impact of microscale properties measured by 50-MHz acoustic microscopy on mesoscale elastic and ultimate mechanical cortical bone properties	Cortical tibia	Materials testing machine, 10 kN load cell	Not reported in paper	Parallelepiped 4 mm × 3 mm × 2 mm	Frozen at -20°C, embedded in cryo-embedding material (removed and thawed before testing in saline)	Not reported in paper	Pivoting upper platen, microscopy cameras for alignment	0.05/min or 0.02/s D	3 cycles between 0.12 MPA and 1.2 MPA
Cezayirlioglu et al[173] (1985)	Anisotropic yield behavior of bone under combined axial force and torque	Cortical femur, tibia	Dynamic testing machine (Instron)	Not reported in paper	Cylinder 2.5 mm diameter, 16 mm height	Frozen	Not reported in paper	Not reported in paper	0.01-0.06/s	Not reported in paper
Evans and Wood[174] (1976)	Mechanical properties and density of bone in a case of severe endemic fluorosis	Cortical radius	Testing machine (Instron), 22.68 kg load cell	Not reported in paper	Cylinder 3 mm diameter, 5 mm height	Not reported in paper	Not reported in paper	Not reported in paper	1.27 mm/min D	Not reported in paper
Jones et al[175] (1993)	Iliac crest bone graft. Osteotome versus saw	Cortical Iliac crest	Testing machine (Instron)	Not reported in paper	Horseshoe-shaped, 6 mm height, 12 mm depth	Frozen, thawed at RT	Not reported in paper	Not reported in paper	Not reported in paper D	Not reported in paper
Murdoch et al[176] (2004)	Investigation into the material properties of beech wood and cortical bone	Cortical tibia	Servohydraulic machine, custom built test ring (Instron), irrigated with saline	Not reported in paper	Cylinder 4 mm diameter, 20 mm height	Frozen at -40°C, thawed at RT	Not reported in paper	Not reported in paper	0.5 mm/min D	Not reported in paper
Pattin et al[177] (1996)	Cyclic mechanical property degradation during fatigue loading of cortical bone	Cortical femur	Servohydraulic machine (MTS), tested at 37°C	Not reported in paper	Cylinder 4 mm diameter, 3 mm height	Frozen at -20°C in wet paper towels	Not reported in paper	Not reported in paper	Not reported in paper; cyclic, 100 N ramp at 2 Hz	Not reported in paper

D/ND, destructive/non-destructive; MTS, materials testing machine; PBS, phosphate-buffered saline; HBSS, Hank's Balanced Salt Solution; DIC, Digital Image Correlation; CCD, charge-coupled device; PMMA, polymethyl methacrylate; RT, room temperature

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