Technical note:

Small changes in the load directions may cause bone failure – the need for realistic load cases.

S. Dendorfer, Ph.D.

As most biological tissues, bone has a pronounced structural anisotropy. Fig. 1 shows a cancellous bone sample and Fig. 2 displays cortical bone tissue. Obviously, both bone types are non-uniform in their structural composition. Cancellous bone is built from a spongy network of rods and plates. Cortical bone is mainly formed with column like structures, Osteons. This anisotropy is also mirrored in the mechanical properties. The load bearing capacity is larger along the main material axis, which is, due to remodelling processes, also the main loading direction.

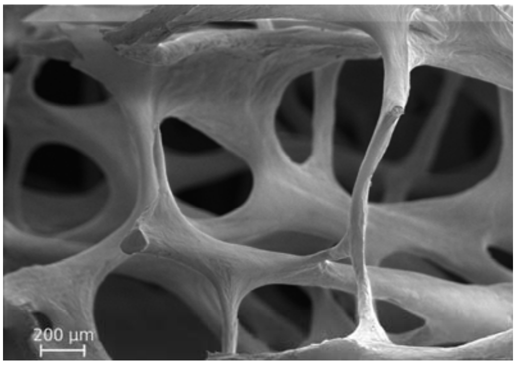

Fig. 1: Scanning electron microscopy of a human vertebral cancellous bone specimen (80 y). The main structural axis is in vertical direction [3].

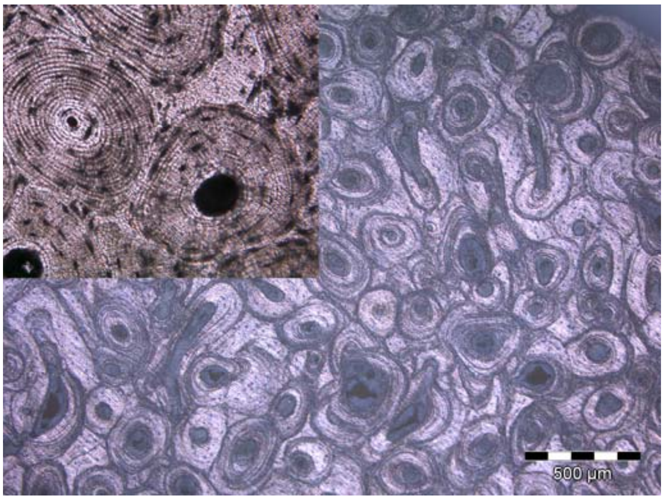

Fig. 2: Microstructural composition of cortical bone. Osteons in a transverse section through human femoral cortical bone [1].

Fig. 3 shows a modified S-N curve for vertebral cancellous bone specimens. Basically it states the number of cycles certain specimen groups can withstand an applied stress. The groups differ in their orientation with respect to the main physiological axis. It can be shown that already small deviations from the main load axis may cause a dramatic decrease in time to failure, i.e. bone fracture. For instance bone tissue perfectly aligned with the main (loading and structural) axis of the vertebral body (0 degrees) can be loaded 10 cycles with 3.25MPa, whereas a specimen misaligned 22 degrees can only withstand 1.7MPa in order to reach 10 cycles.

This effect is of increased importance when implants are designed for elderly people. It is a well established fact that bone mass decreases with age, but not only the overall amount of bone decreases, also the structural anisotropy gets more pronounced [5], [6]. In cancellous bone mainly struts oriented transversely to the main loading direction are removed.

Therefore, the difference in the mechanical properties between the different structural axes gets more pronounced with increasing age [3].

AnyBody Technology A/S · Niels Jernes Vej 10 · DK-9220 Aalborg East · Denmark · Phone +45 9635 4286 · Fax +45 9635 4599
www.anybodytech.com · anybody@anybodytech.com · CVR no. 26367042

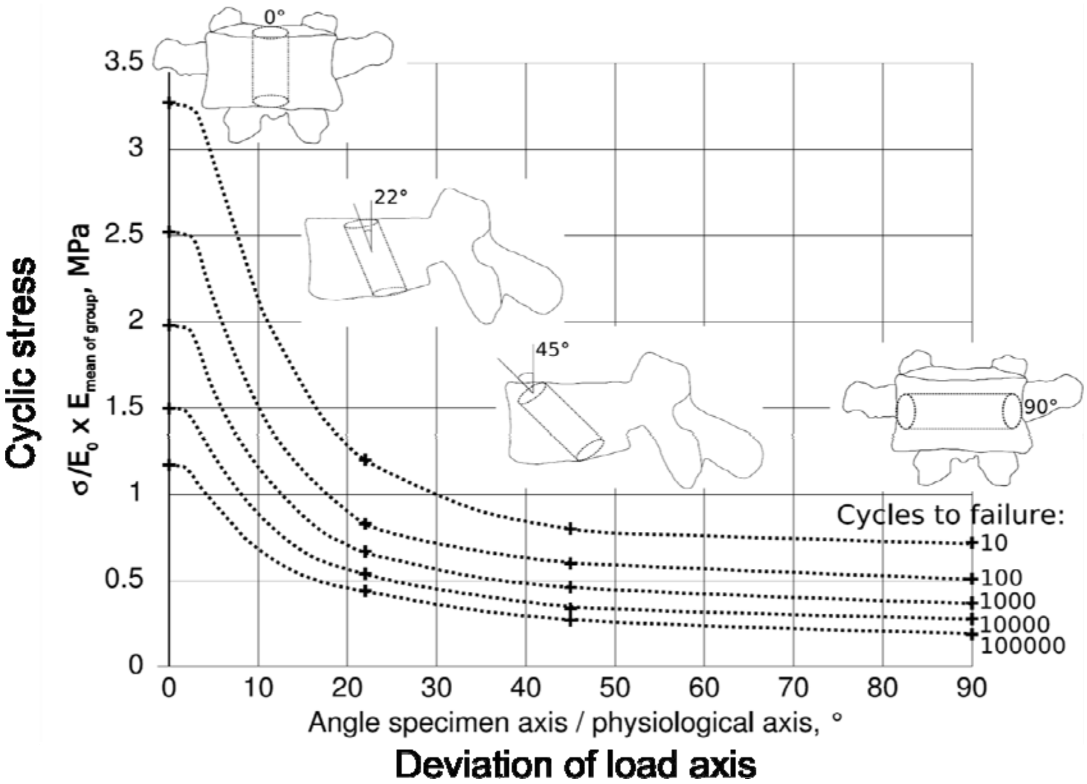

Fig. 3: Modified S-N curves for various specimen groups of human vertebral cancellous bone. The groups were cored in different orientations with respect to the main axis of the vertebral body. The curves represent the mean cycles a specimen of a certain orientation can withstand an applied cyclic stress value. [2]

These findings also imply that all loads contributing to the acting in-vivo stress must be considered for a realistic biomechanical evaluation. Especially muscle forces are mostly neglected in structural analysis of implant-bone compounds and mostly highly simplified models are used. The effect of muscle forces on the resulting force vector is illustrated in Fig. 4 and 5. A musculoskeletal model of the human body is analyzed in the AnyBody Modeling System™. A full body model, equipped with more than 1,000 individual muscle branches and a detailed description of the lumbar spine is used [4]. The orientation of the resulting force vector with respect to the main bone axis is computed in the L1-L2 joint of the spine. The applied motion is a pure spine flexion from a 0 degree (upright standing) to a 45 degree angle between Thorax and Pelvis. Both arms are held in 80 degree glenohumeral flexion. Even for this simple load case, the angle of the force vector increases up to 16 degrees. Also if the direct application of the data from Fig. 3 is not valid in a strict manner, the results underline the importance of inclusion of the muscle forces to get realistic boundary conditions for biomechanical analysis.

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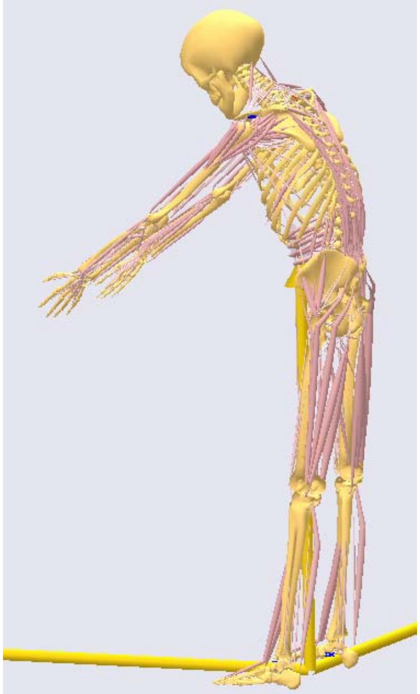

Fig. 4: Musculoskeletal model taken from the AnyBody Repository [7].

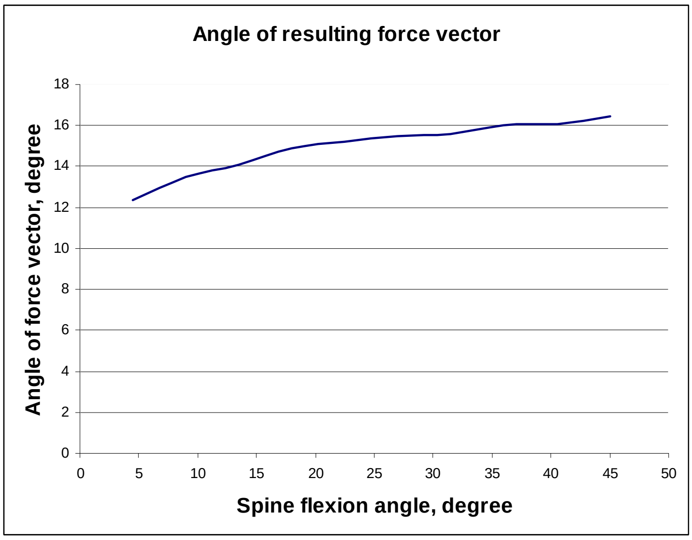

Fig. 5: Angle of resulting force vector in L1-L2 joint as a result of an increasing spine flexion angle. The angle is given with respect to the main bone axis.

References:

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[7] AnyBody Managed Model Repository www.anyscript.org

AnyBody Technology A/S · Niels Jernes Vej 10 · DK-9220 Aalborg East · Denmark · Phone +45 9635 4286 · Fax +45 9635 4599
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