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Law of dynamic deformation of bone

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Human bones change dynamically. For a human, bones usually start to form at the 7th week of the embryonic period and continue to develop until the human has reached skeletal maturity. During this stage of development, the mass, density, morphology, hardness and strength of human bones are constantly changing. There are studies that describe the dynamic changes in bone morphology in each part of the human body from the embryonic period to puberty. For example, the femoral neck torsion angle (FNTA) is approximately 30 to 40 degrees at birth, and the angle gradually recedes to 10 to 15 degrees by early adolescence. Infants have a large femoral neck-shaft angle (NSA), and this angle decreases gradually to an angle common in adults. Recent studies have focused on the physiological and molecular mechanisms by which bones sense, transduce, and respond to mechanical loads and have investigated the effects of aging processes on the relationship between cortical bone properties (such as cross-sectional geometry and bone mineral density) and mechanical function.[1,2]

Do the density and strength of human bones continue to change after skeletal maturity? The answer is YES. According to Wolff's law, bones in the living body will adapt to mechanical loads under which they are placed.[1] If loads on a particular bone increase, the bone will remodel to become thicker and stronger to resist the loads. The inverse is also true; if loads on a bone decrease, the bone will become thinner and weaker. Then, does the morphology of human bones continue to change under long-term strains after skeletal maturity? The answer is also YES. Based on clinical observations and a series of scientific studies, the dynamic deformation of human bones continues under long-term strains even after skeletal maturity.[3-8] This kind of change in bone morphology is lifelong and has a certain regularity, which is named Zhang's law of dynamic deformation of bone based on the pioneering and fruitful studies conducted by Zhang's team.[3-10] Zhang's law of dynamic deformation of bone is a supplement to Wolff's law.

According to Zhang's law of dynamic deformation of bone, the morphology of bone in a living body, including the shape, diameter, length, curve and alignment of the bone, adapt to long-term loads both before and after skeletal maturity. According to the magnitude of strain, the mode of action, the location site, and the quality of bone, the resulting deformations and rates are different. The dynamic deformations of bones are more obvious in elderly populations than in middle-aged populations. Senile osteoporosis is one of the main causes of the dynamic deformation of human bones. During the development of osteoporosis, microfractures have been found to occur in cancellous bones (such as the hip, spinal vertebra, and proximal tibia) during daily activities. The number of microfractures has been found to increase exponentially with age. Microfractures can induce bone remodeling. It has been reported that at least 10% of bone is renewed per year by this physiological process.[1] Microfractures, bone absorption and bone regeneration can lead to changes in skeletal morphology.

Dynamic deformation of human bone morphology will ultimately result in changes in the physical posture of elderly individuals. Our team has systematically measured the dynamic deformation of bones of four extremities, the spine, the pelvis and the acetabulum.[3-8] The physical posture of elderly individuals has changed substantially compared to that of young individuals; for example, elderly individuals exhibit stature shrinking, spinal kyphosis, and lower extremity extorsion.[4] It is well known that a vertebral wedge deformity is a major cause of height loss. Our team retrospectively analyzed computed tomography (CT) images of thoracolumbar segments of the spine in adults with and without osteoporosis. Statistical analyses revealed that there is a significant relationship between vertebral wedge deformity and aging and that the vertebral wedge deformity in patients with osteoporosis is more severe than that in patients without

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osteoporosis.[6] In addition, the angle of the pedicle of the vertebral arch has also been found to decrease with aging.

Another change in the posture of elderly individuals is in the extorsion of the lower extremities. We proposed a novel method to measure the FNTA with the use of reconstructed femoral neck oblique-axial CT images.[3] A retrospective study was then conducted to measure the FNTA, NSA and acetabular anteversion angle (AVA) of 140 Asian patients aged 18 to 88 years using this method.[4] It was found that the NSA and FNTA obviously decreased with age and that the AVA increased with age, which reveals the reason elderly individuals demonstrate extorsion of the lower extremities. These changes in bone morphology ultimately result in changes in physical posture.

The settlement of the proximal tibia plateau is a kind of dynamic deformation. In radiographic and clinical studies of medial compartment knee osteoarthritis (KOA), we found that the height of the medial tibial platform was lower than that of the lateral side and this height difference is defined as the settlement of the proximal tibia.[5,7,8,11] The proximal tibia mainly comprises cancellous bone, and the medial plateau bears larger loads than the lateral tibia. Patients with medial compartment KOA are generally elderly individuals with osteoporosis. It is very difficult for osteoporotic tibia to bear large pressures; therefore, large pressures result in microfractures of bone trabecula, absorption, regeneration and the subsequent occurrence of settlement, which is more obvious in the medial compartment than in the lateral compartment. The phenomenon of obvious settlement on the medial side with unapparent settlement on the lateral side is defined as nonuniform settlement of the proximal tibia.[5] The obvious settlement of the medial platform can lead to the loss of support and function for the medial femoral condyle, which can result in a sliding movement and varus alignment of the knee joint; in turn, these effects can aggravate the severity of KOA. The settlement value of the medial tibial plateau has been measured in patients with KOA. A large settlement value is associated with a large Kellgren-Lawrence (K-L) grade, and the settlement value is also significantly correlated with changes in the hip-knee-ankle angle, the minimum medial joint space width, the proximal fibular curvature and the condylar plateau angle.[5] These findings suggest that the settlement of the tibial plateau could be used in the early diagnosis of medial compartment knee OA and could act as an evaluation indicator for the progression of OA.

Zhang's law of dynamic deformation of bone plays an important role in both clinical practice and related researches. Degenerative diseases of the musculoskeletal system in middle-aged and elderly individuals are highly related to the dynamic deformation of bones. The dynamic deformation of bone is an important indicator for both the onset and the progression of degenerative diseases. For instance, a nonuniform settlement of the medial tibial plateau plays an initial role in the occurrence of medial compartment KOA.[5,11] A progressive settlement indicates the aggression of medial compartment KOA. Zhang's law of dynamic deformation of bone can be used in the selection of suitable treatment algorithms. For example, proximal fibular osteotomy is a choice of surgical option for patients with medial compartment KOA of K-L grades II and III and a curved proximal fibula,[7] in addition to proximal tibial osteotomy proposed by Coventry MB in 1965. Zhang's law of dynamic deformation of bone can also be used in the assessment of fracture reduction as well as the placement of implants in a fracture fixation. For example, the FNTAs and NSAs vary among males and females as well as middle-aged and elderly individuals.[4] The different FNTAs should be taken into consideration when assessing the quality of fracture reduction under a true anteroposterior radiograph of the femoral neck or when inserting the lag screw or cannulated screws into the femoral neck during a hip-related surgery. When inserting screws into the pedicle of the vertebral arch, attention should also be paid to the altered angle of the pedicle in elderly patients, especially those with osteoporosis.[6]

Conflicts of interest

None.

References

1. Pearson OM, Lieberman DE. The aging of Wolff's "law": ontogeny and responses to mechanical loading in cortical bone. Am J Phys Anthropol 2004;Suppl 39:63–99. doi: 10.1002/ajpa.20155.
2. Bailey S, Karsenty G, Gundberg C, Vashishth D. Osteocalcin and osteopontin influence bone morphology and mechanical properties. Ann N Y Acad Sci 2017;1409:79–84. doi: 10.1111/nyas.13470.
3. Yin Y, Zhang L, Hou Z, Yang Z, Zhang R, Chen W, *et al*. Measuring femoral neck torsion angle using femoral neck oblique axial computed tomography reconstruction. Int Orthop 2016;40:371–376. doi: 10.1007/s00264-015-2922-4.
4. Yin Y, Zhang R, Jin L, Li S, Hou Z, Zhang Y. The hip morphology changes with ageing in Asian population. Biomed Res Int 2018;2018:1507979. doi: 10.1155/2018/1507979.
5. Dong T, Chen W, Zhang F, Yin B, Tian Y, Zhang Y. Radiographic measures of settlement phenomenon in patients with medial compartment knee osteoarthritis. Clin Rheumatol 2015;35:1573–1578. doi: 10.1007/s10067-015-3146-0.
6. Wei J, Chen W, Wang H, Wang J, Cheng L, Zhang Y. Application of non-uniform settlement theory in spine degenerative kyphosis (in Chinese). J Hebei Med Univ 2019;40:54–57. doi: 10.3969/j.issn.1007-3205.2019.01.012.
7. Liu B, Chen W, Zhang Q, Yan X, Zhang F, Dong T, *et al*. Proximal fibular osteotomy to treat medial compartment knee osteoarthritis: Preoperational factors for short-term prognosis. PLoS One 2018;13:e0197980. doi: 10.1371/journal.pone.0197980.
8. Wang J, Lv HZ, Chen W, Fan MK, Li M, Zhang YZ. Anatomical adaptation of fibula and its mechanism of proximal partial fibulectomy associatedwith medial compartment knee osteoarthritis. Orthop Surg 2019;11:204–211. doi: 10.1111/os.12437.
9. Hu ZS, Liu XL, Zhang YZ. Comparison of proximal femoral geometry and risk factors between femoral neck fractures and femoral intertrochanteric fractures in an elderly chinese population. Chin Med J 2018;131:2524–2530. doi: 10.4103/0366-6999.244118.
10. Zhang YZ. Brave to Advance the Theoretical and Technological Innovation on the Basis of Orthopedic Practice. Chin Med J 2018;131:2521–2523. doi: 10.4103/0366-6999.244123.
11. Lv H, Chen W, Yuwen P, Yang N, Yan X, Zhang Y. Multivariate analysis of factors related to radiographic knee osteoarthritis based on the comparison between football players and matched nonsportsmen. Int Orthop 2018;42:519–527. doi: 10.1007/s00264-018-3797-y.

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