# PRECISION BONE STRUCTURAL MEASUREMENTS BY ADVANCED MULTIPLE PROJECTION DUAL ENERGY X-RAY ABSORPTIOMETRY (AMPDXA) TECHNIQUES FOR SPACEFLIGHT APPLICATIONS*

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*Funded by the National Space Biomedical Research Institute under Cooperative Agreement NCC 9-58 with NASA

## INTRODUCTION

An Advanced Multiple Projection Dual Energy X-ray Absorptiometry (AMPDXA) Scanning System is being developed to monitor the deleterious effects of weightlessness on the human musculoskeletal system during prolonged spaceflight. The AMPDXA is designed to measure bone mineral density (BMD), decompose soft tissue into fat and muscle, and derive structural properties (cross-sections, moments of inertia). Such data permits assessment of microgravity effects on bone and muscle and the associated fracture risk upon returning to planetary gravity levels. The protoflight scanner will be designed to minimize volume and mass (46 kg goal), while maintaining the required mechanical stability for high-precision measurement. The AMPDXA can detect 1% changes in bone mass and geometry and 5% changes in muscle mass.

## RESEARCH STATUS

It is known that the elimination of gravitational effects on the human body produces an adaptation response resulting in the wasting of body skeletal muscle and bone mass. The stimuli for maintaining homeostasis of muscle and bone appear to be different; moreover, there also appear to be differences between losses in weight bearing and non-weight bearing body regions. Bone mass lost from the vertebrae, pelvis, and proximal femurs of astronauts average between 1 and 1.6% per month. This compares to the loss of about 0.8 to 1.3% per year in postmenopausal women. The ultimate concern is that the loss of mass will lead to degradation in mechanical competence and possible failure. During prolonged space travel, bone fracture may prove to be catastrophic, especially since healing in the absence of mechanical stimulus (load) is believed to be degraded. Clearly, effective countermeasures to stem the loss as well as some method for dynamically monitoring countermeasure effectiveness are required. On earth, skeletal load causes mechanical strains within the bone, which tend to be greatest on the subperiosteal surface. Normal bone turnover accompanying the aging process causes a net loss of bone from endocortical and internal surfaces. This loss causes skeletal strains to increase, but in long bones the increase is greater on the subperiosteal surface, not at the internal surfaces where the mass loss occurred. New bone forms on the subperiosteal surface sufficiently fast to maintain the section modulus. Since it takes less new bone on the subperiosteal surface to compensate for bone loss from internal surfaces, strength can be maintained in the presence of net bone loss. This mechanism requires skeletal loading, which is absent on the lower skeleton during spaceflight. Bone loss accelerates under diminishing loading and evidence from Cosmonaut data on Mir suggest that no compensatory changes take place. This means that astronauts may be at a greater risk of fracture for the same loss of bone mass. Hence, it is important to determine the geometrical configuration of the bone structure.

### Methods

The AMPDXA development is being carried out in three stages: (1) Laboratory Test Bed for instrument development, (2) Clinical Test System for ground-based human testing and (3) a protoflight design for space applications.

### Results

The full-sized Laboratory Test Bed (1 meter source to detector distance) was constructed to verify principles and theoretical predictions. Scanning is provided by high-precision rotating and translating stages. The test bed, in conjunction with a high-resolution detector and our analysis software, has produced some exciting preliminary results. Figure 1(a) is a BMD image of a human femur immersed in a cylinder of water (simulates fatty tissue). The same bone was imaged on a new commercial DXA scanner located at the Johns Hopkins Hospital as shown in Figure 1(b). The improvement in spatial and contrast resolution with our scanner is quite evident by comparing the two figures. This improvement is further elucidated by the graph in Figure 1(c). The curves are measured bone projected thicknesses on a slice through the femoral shaft. The fine variations on the AMPDXA profile are not noise, but reflect small changes in the actual bone thickness. Using multiple projections, as shown in Figure 2, about the bone axis allows structural properties (e.g., bending strength) to be obtained independent of patient position. To do this at least three arbitrary projections over 90 degrees (two of which are orthogonal) must be obtained. Such analysis can provide maximum and minimum moments of inertia for bending or torsion in any plane. Our experiments to date with different sets of three projections show that the principal moments of inertia can be determined within 3 to 4%. Additional projections (above 3) reduce this number further. Our experimental systems also have some known non-linearities which when removed will drop the error in the three projection estimation of moments to less than 1%.

## CONCLUSION

An Advanced Multiple Projection Dual Energy X-ray absorptiometry (AMPDXA) System has been designed and two ground-based test systems developed. Results from these systems indicate that an AMPDXA system would provide the accuracy and repeatability necessary to monitor bone (muscle) loss in space as well as to develop and monitor the efficacy of countermeasures. The availability of an AMPDXA offers significant potential for fostering future musculoskeletal research in a number of disciplines.

## FUTURE PLANS

The AMPDXA is capable of real-time monitoring of bone and muscle loss at extremely high precision. Since the results are patient-specific and not tied to volumetric averages and statistical norms, the AMPDXA is a very useful tool for monitoring the effectiveness of countermeasures as well as determining risk of fracture under various loading conditions and activity scenarios. To bring the AMPDXA to its full potential, the following specific research problems must be addressed: (1) Human testing to develop the final instrument parameters, (2) refinement of soft tissue extraction algorithms (3) solution to the 2-D vs. 3-D reconstruction problem, (4) refinement of bone strength vs. risk of fracture algorithms, (5) develop lightweight power supply, and (6) software refinements to allow radiograph collection for the diagnosis of injury and disease.

## INDEX TERMS

dual energy x-ray absorptiometry (DXA), bone mineral density (BMD), bone loss, muscle loss, osteoporosis, microgravity effects, advanced multiple projection DXA (AMPDXA)

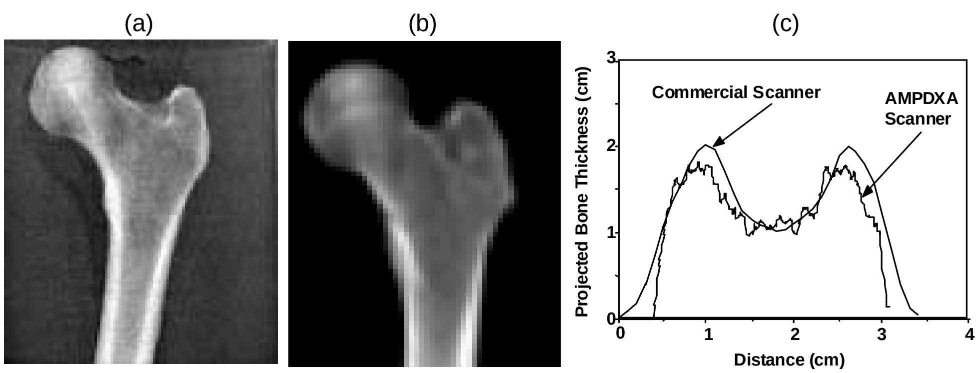


Figure 1. Comparison AMPDXA vs. conventional DXA. (a) AMPDXA BMD image. (b) Commercial DXA BMD image (same bone as (a)). (c) Bone mass profiles with distance across a given bone section.

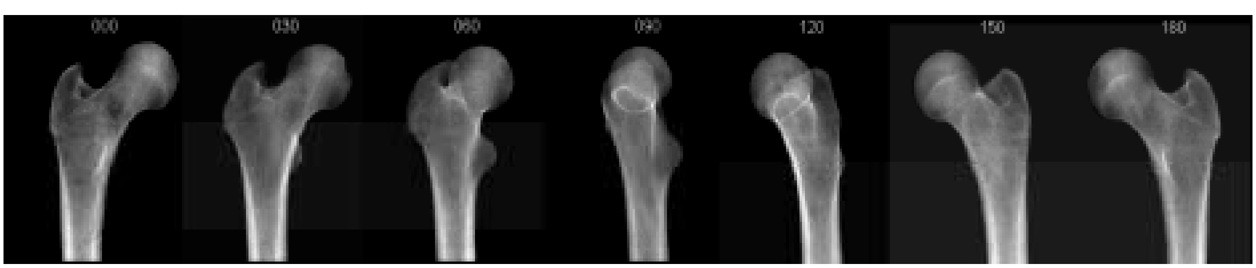


Figure 2. Multiple DXA projections using rotational stage.