Bone impact microindentation for preoperative *in vivo* assessment of bone strength in orthopedic surgery: a case report

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ABSTRACT

Portable bone impact microindentation devices are a novel generation of diagnostic instruments allowing direct in vivo assessment of cortical bone strength. The assessment involves application of a single impact cycle on the bone and measurement of tissue response to the applied force in relation to a reference value adjusted for age and sex.

Here, we report the case of a male patient, aged 66 years, who underwent a cementless right total hip replacement for the treatment of monolateral osteoarthritis, during which an incomplete spiral fracture of the proximal metaphysis of the femur occurred.

The patient had no history of bone fragility, and preoperative evaluation by radiofrequency echographic multi spectrometry showed mild osteopenia at both the lumbar spine and the femoral neck, suggesting he had a relatively low risk of fragility fracture.

Conversely, preoperative impact microindentation analysis, performed using the OsteoProbe device on the left tibia, showed extremely low bone resistance (average bone score of 58.4, versus the adult male normal value of 84.4 ± 7.0). Our case report suggests that bone strength evaluation by bone impact microindentation may potentially predict individual fracture risk not shown by bone mineral density assessment alone.

KEYWORDS

Bone strength, bone impact microindentation, individual fragility fracture risk, diagnosis of bone fragility.

Introduction

Individual fracture risk assessment remains a significant challenge in clinical practice. Bone strength is the key parameter defining bone tissue resistance to fracture. It is a complex feature that is determined by a variable combination of bone geometry, cortical thickness and porosity, trabecular bone morphology, and intrinsic properties of bone tissue. Pathological and aging-related reduction of bone strength makes bones more prone to fragility fracture resulting from low-energy trauma (a mechanical force that would not ordinarily cause a bone fracture). Assessment of bone strength reduction is therefore fundamental to identify people at at high risk of fragility fracture.

Bone mineral density (BMD) measurement by dual-energy X-ray absorptiometry (DXA) is currently the most commonly employed imaging technique for assessing bone health and individual fracture risk. However, this diagnostic approach, failing to capture bone geometry and trabecular microarchitecture, accounts for only 60–70% of the variation in bone strength [1], and is therefore not completely effective in correctly identifying bone resistance and the individual's real risk of fracture. Indeed, bone strength depends not only on BMD, but also on additional factors such as bone tissue architecture, microstructure, and material composition [2].

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Other imaging techniques, such as high-resolution peripheral quantitative computed tomography and radiofrequency echographic multi spectrometry (REMS), allow evaluation of bone structure and 3D microarchitecture.

In addition to these diagnostic techniques, bone impact microindentation (IMI) has recently become available. This is a minimally invasive technique which allows direct *in vivo* evaluation of the mechanical resistance of cortical bone in humans, a parameter difficult to evaluate until now.

The OsteoProbe device is a handheld impact microindenter based on Reference Point Indentation technology that evaluates individual bone quality, in skeletally mature adults, by calculating the "Bone Material Strength Index" (BMSi), or alternatively the Bone Score™, on the mid-shaft of the tibia. The OsteoProbe evaluation is performed under local anesthesia using a single-use disposable microtip that is repeatedly inserted (at least 8 times) into the external soft tissue, crossing the periosteum to reach and penetrate the cortical bone matrix of the distal left or right tibia, to a maximum depth of just one thousandth of a millimeter (1 micron). The depth (indentation distance) to which the tip cuts into the cortical bone of the patient is measured and compared with the indentation distance of a reference material (poly methyl methacrylate); the ratio of these two distances is expressed as a unitless value, the Bone Score™ [3]. The value of this score provides an index of bone resistance [4]. Analyses performed with the OsteoProbe have shown lower Bone Score™ values in patients with low-energy trauma fractures compared both with individuals with high-energy trauma fracture and with fracture-free subjects [5,6].

In this setting, preoperative application of bone IMI can help the orthopedic surgeon to select the most suitable osteosynthesis or prosthetic surgical procedure for the individual patient, based on the evaluation of their bone resistance.

Case report

We report the case of a male patient referred to our clinical center at the age of 66 years with suspected osteoarthritis. In the preoperative evaluation, X-ray screening of the pelvis showed severe right coxarthrosis for which a right total hip arthroplasty (THA) was scheduled. The patient's relatively young age, the absence of a personal or family history of fragility fracture, and the finding of a canal bone ratio (the ratio between the endosteal and outer diameters of the proximal femur at 10 cm below the lesser trochanter), assessed by plain radiograph of the proximal femur, of 0.36 (a value less than 0.49 is indicative of non-osteoporotic bone) [7] led to the preoperative planning decision to perform a cementless stem THA, as shown in Figure 1.

Ultrasound bone densitometry evaluation with REMS, performed at the lumbar spine (L1-L4) and left femoral neck, showed osteopenia at both bone sites (T-score -1.3 and -1.4 respectively), corresponding to a five-year risk of generic osteoporotic fracture of 10–20% and a five-year risk of osteoporotic femoral fracture of 4–8%. It thus reinforced the decision to perform a cementless stem THA.

The OsteoProbe evaluation, performed following administration of local anesthetic, involved eight microindentations on the left tibia, which showed extremely low bone resistance, assessed in relation to the load, with an average Bone Score™ of 58.4 (normal value for adult men 84.4 ± 7.0).

The day after bone IMI evaluation, the patient underwent arthroplasty surgery on the right hip. During the preparation of the femoral canal using rasps of increasing size, an incomplete spiral fracture of the proximal metaphysis of the femur occurred, with a rim that involved the upper third of the diaphysis (Figure 2). This complication made it necessary to perform an osteosynthesis with three cerclages at the metaphyseal level, which allowed the definitive uncemented stem to be introduced in line with the preoperative planning strategy. The complication delayed the postoperative recovery, with the patient requiring approximately 30 days of partial weight bearing on the operated side. At 30 days, radiographic follow-up showed consolidation of the fracture and complete recovery of function and total weight bearing (Figure 3).

Conclusions

Our case report suggests that evaluation of bone strength with bone IMI may potentially predict individual fracture risk not shown by BMD assessment alone.

In our male patient, who had no personal or family history of fragility fracture, the finding, through IMI analysis, of a significantly reduced Bone Score™ with respect to the expected normal value for his age and sex, was presumably indicative of reduced cortical bone resistance, despite the radiographically "normal" appearance of the bone tissue, which showed no signs of weakness. This finding was associated with the occurrence of an intraoperative fracture during THA. The routine use of IMI evaluation in the preoperative phase, and the resulting Bone Score™ , could therefore represent an additional element

Figure 1 Plain radiograph image of the right distal femur, showing the preoperative planning of cementless right THA in our patient. D = dysmetria -7 mm; G7 = type of Zimmer-Biomet acetabular cup; 50 = measure of the acetabular cup in mm; I 32 poly ER vitE = polyethylene ER (elevated rim) with vitamin E liner; TC = femoral neck osteotomy (16.5 mm); PC = distance between the lesser trochanter and the center of rotation (48 mm); CLS = type of Zimmer stem; T32 cerD = ceramic femoral head (32 mm).

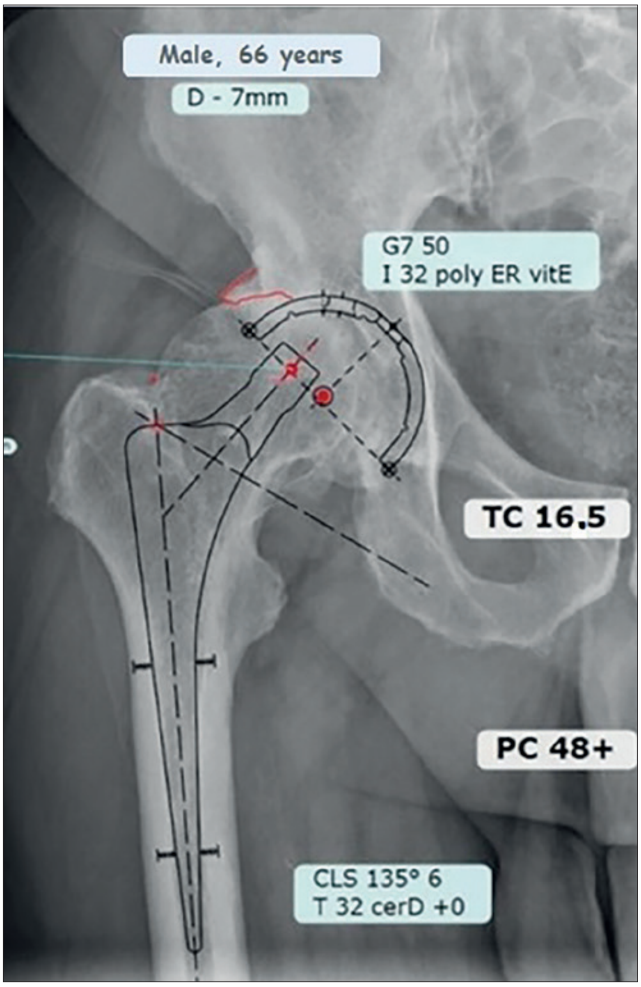

Figure 2 Intraoperative X-ray examination showing (red arrow) the occurrence of an incomplete spiral fracture of the femoral proximal metaphysis.

Figure 3 Postoperative X-ray of the operated right femur one month after the orthopedic surgery, showing complete consolidation of the fracture and complete recovery of limb function and load-bearing capacity.

to consider during preoperative planning to guide the choice of implant type (cemented vs. uncemented) in prosthetic hip surgery and reduce the occurrence of intraoperative and post-operative periprosthetic fractures.

Evaluations in larger numbers of patients are necessary to confirm the findings in this clinical case. In particular, prospective multicenter trials using a standard operating procedure are fundamental to assess the true effectiveness of the IMI technique in predicting future fracture risk, before it can be routinely integrated into preoperative orthopedic practice.

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