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THE MOST COMMON MISTAKES IN BONE MINERAL DENSITY TESTING WITH DXA METHOD

NAJČEŠĆE GREŠKE PRILIKOM MERENJA MINERALNE KOŠTANE GUSTINE DXA METODOM

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Ključne reči
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Abstract

Osteoporosis is systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture. In comparison with other techniques of bone mineral testing, central DXA has many advantages: short time of scanning, low radiation dose, easy patient preparing and good accuracy. Its purpose is as follows: making diagnosis, fracture risks assessing, making decision in treatment initiation and therapy effects monitoring. Measurement accuracy depends on: technical validity of the device (fan beam technology, proper calibration, regular quality control, and regular service), human factors (comprehensive history, data input, positioning, and scan analysis) and local structural changes on bone tissue or its environs. Osteoporosis can be diagnosed by WHO criteria (T-score ≤ - 2, 5) or if there is a presence of low energetic fracture. Patient classification according T-score only misses near half of patients with clinical diagnosis of osteoporosis. New series of DXA devices have possibility to perform, during the same visit to DXA Center, lateral scan (VFA) and with using Genant Scale to determine changes in vertical height and vertebral body shape. In that way, diagnosing is easier and timely treatment initiation is more useful. Genant's method is semi-quantitative and it is based on change of vertebral body vertical height and on identification of radiologic characteristics of fracture according to position and shape of vertebral bodies cover plate. Assessment of change in vertical height is standardized and vertebral fracture is determined as a reduction in vertebral body height for more than 20%. Fractures are categorized in three grades according the reduction in vertebral body height. However, Genant's method is subjective which can lead to mistakes in analyses, especially in grade I deformities. Disadvantage of this method is also poor visualization of vertebral bodies Th4-Th6 and the inability to determine etiology of changes (metastases, myeloma, Shmorl's hernia, degenerative disease). It can lead to wrong conclusion. Possibility of fracture risk assessment is easier with improvement of central DXA device technological characteristics. Health assessment depends on quality and validity of DXA report on which further clinical decisions and treatment will be made. Clinicians in DXA Centers must be educated and trained in bone densitometry and update their skills on regular basis.

OSTEOPOROSIS

Osteoporosis is a disease connected with increased fracture risk, morbidity and mortality rates, as well as treatment costs (1). Osteoporosis is characterized by low bone mass and micro-architectural deterioration of bone tissue, which leads to bone fragility and increased susceptibility to fracture of bones (2).

BONE MINERAL DENSITY TESTING WITH DXA METHOD

In everyday work, the golden standard for assessment of bone mineral density (BMD) is Dual Energy X-ray Absorptiometry (DXA). Bone mineral density (BMD) testing represents the key factor in diagnosing of osteoporosis.

It is recognized as a reference method with acceptable accuracy error, good precision and reproducibility [3]. World Health organization (WHO) officially announced DXA as the best technique for BMD assessment in postmenopausal women and it based definition of osteopenia and osteoporosis on achieved results and interpreted it based on T-score (the number of standard deviations-SD of patient's BMD above or below average BMD observed in young, healthy person, a member of reference population (Table 1) [4].

***Tabela 1**. WHO classification of osteoporosis according to osteodensitometry result*

Diagnosis	T-score
Normal result	≥ -1,0
Reduced (Low)bone mineral density (Osteopenia)	- 2,5 < T-score > -1,0
Osteoporosis	≤ -2,5
Severe osteoporosis	≤ -2,5 plus fracture on a small trauma

Technologies used in devises for bone mineral density testing include dual energy x-ray absorptiometry (DXA), quantitative ultrasound (QUS) and quantitative CT (QCT). Compared to other bone mineral density measurement techniques, central DXA has many advantages, as follows: short scanning time, low radiation dosage, easy patient preparation, and good accuracy. Central DXA is used for the following:

-making diagnosis of osteoporosis
-fracture risk assessing
-bringing the decision to initiate the treatment of the patient and
-therapy effects monitoring/follow up

Traditionally, BMD is considered as main bone strength and fracture risk determinant [5,6]. Out of all localizations, BMD measurements on femur and spine are the best to predict possibility of fractures on stated location. Bone mineral density measurement, identification of risk for osteoporotic fracture and decision on who needs to be treated are optimal goals in evaluation process of the patient with osteoporosis. Osteoporotic fractures prevention is primary goal in treatment of osteoporosis[7]. Bone mineral density measurement, helps us in our daily work, in identification of patients who are at high risk, before the moment of first fracture appearance. It enables us better selection of patients, who will benefit from the treatment. Indications for DXA testing are presented in Table 2.

MISTAKES IN DAILY WORK

Inadequate usage of DXA device and BMD testing can lead to incorrect clinical assessment, inadequate patient treatment, unnecessary costs and it can be harmful to the patient (Table 3). Examples concerning the quality are, as follows :

-Selection of patients for bone mineral density testing, where it is highly unlikely that the result will influence the decision on the treatment.

- The failure to direct patients to bone mineral density testing , where it is highly likely that finding will influence the decision on the treatment.

- Incorrect use of WHO criteria for diagnose making (for the example: in population groups like children, premenopausal women and men younger than 50 years, than usage of wrong testing location, as Ward's triangle, or testing on inadequate devices).

- Incorrect serial DXA measurement comparison.

***Table 2.** : Indications for BMD testing [8]*

Women above 65 years old
Postmenopausal women below age 65 with present clinical risk factors
Men above 70 years old
Adults with minimal trauma fracture
Adults with associated disease or status which is connected to low bone mass and bone loss
Adults using medicaments which are known for being associated with low bone mass or bone loss
Persons who are planned for therapy initiation
Persons undergoing the therapy, in the purpose of effect monitoring/follow up
Persons who do not receive therapy but to whom the therapy would be initiated in case of bone loss confirmation.
Women interrupting estrogen therapy should be considered for testing purposes, according to previously stated factors

In order to make obtained data accurate and applicable in clinical practice, bone mineral density testing with DXA method on axial skeleton must be done according to ISCD principals (International Society for Clinical Densitometry). This means that diagnosis of osteoporosis is based on the lowest values of T-score obtained either on spine or on hip , both regions must be tested (whenever it is possible), and forearm region is being tested only if testing on axial skeleton is not possible, in cases of extreme obesity and in cases of hyperparathyroidism [8].

Measurement accuracy depends on the following:

- Technical validity of the device (fan beam technology, proper calibration, regular quality control, regular service)
- Human factor (comprehensive history, positioning, scan analysis)
- Local structural changes on bone tissue and its surroundings

Technical requirements give advantage to FAN beam technology (it assumes beam of x-rays in the form of a fan) over Pencil beam technology, with regular calibration and quality control.

Nowadays there is a proliferation of devices which are used for DXA measurements. Different devices which are used for BMD measuring, as well as results obtained are such, that, although the used technology is the same, it is impossible to compare findings obtained from different devices without previous existence of cross –calibration [9]. Cross-calibration is mathematical model and it represents correlation of BMD findings after repeated phantom measuring and certain number of patients, in two, different systems. The phantom is an object used for testing of DXA device medical operation and/or calibration or any other change or movement in respect to measured BMD values. In order to compare serial results on the same device, accuracy assessment is very important, and it should be conducted according to well accepted standards. It is necessary to know

accuracy mistake and the least significant change (LSC) for each device [10]. Accuracy represents the reproducibility of BMD measurement and it is typically calculated through measuring of 15 patients 3 times or 30 patients 2 times, scanned with repositioning, within the same day. LSC is a measure obtained from calculation of accuracy mistake and it represents the lowest statistically significant change with 95% CI. Without such results, it is not possible to monitor the effect of therapeutic response through control/follow up measurement.

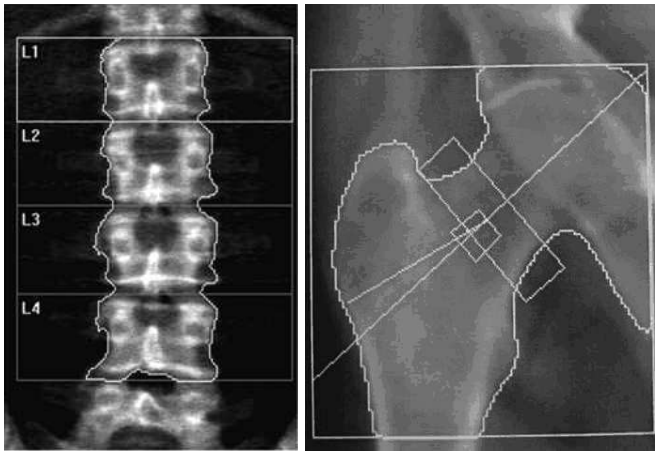
Human factor is very important and it affects detailed anamnesis taking, in the purpose of identifying risk factors and selection for DXA measurement. Also, it is necessary for correct data entry into the system, correct patient positioning, properly done scan analysis and subsequent description.

Technically correct scan includes first four lumbar vertebrae, which represent our region of interest (ROI), centrally positioned with equal quantity of soft tissue from both sides, with visible lower body half Th 12 and upper vertebral body half L5 (picture 1 a). An anatomic variation, which often appears as a problem, is present in approximately 15% of population members, and this variation it is the presence of 4 and/or 6 lumbar vertebrae, as well as last rib series on TH11 or L1. In case the wrong segment is selected for analysis, the whole vertebra series moves and such a result is not accurate, due to the fact that BMD is software calculated for each vertebra separately, depending on localization (example 2). Correct hip scan assumes that shown femur axis is vertical to the end of the scan, that great trochanter is centered vertically, that the whole femur head is visible, as well as, 25 º internal hip rotation (picture 1 b). In hip scan, the

Table 3. *The most common mistakes during BMD measuring by central DXA method [11]*

The most common mistakes during DXA measuring		
Category	**Mistake**	**Example/Comment**
Scanning indications	The scan in highly risked patent is not done	Healthy woman, 67 years old
	The scan is done in patient, where the result will highly unlikely affect subsequent treatment	Testing of healthy, young woman, who is 35 years old, with regular period
Quality control	Non-conducting of manufacturer's instructions in reference with maintenance of the device and phantom scanning	No phantom scanning
	Failure to identify and correct significant change in calibration	Results of phantom scanning are not considered or device servicing is not done when calibration was changed
	Failure to calculate accuracy error and to calculate LSC (the least significant change)	It is not possible to quantitatively measure results of serial BMD testing, in case LSC is not known
Acquisition	Inadequate patient positioning	Spine scan is not parallel with table edges or internal hip rotation is not sufficient
	Improper scanning mode	Scanning mode can change BMD value and it is selected manually or automatically, depending on the device
	Improper scanning location	Scanning of the hip on which a total endoprosthesis is implemented
	Artifacts on scanning location	Scan with visible bra wires, metal belt, buttons and safety pins
	Incorrect demographic marking	A mail patient entered as a female patient , or entered wrong patient's data in respect to age or body weight , all of that changes the result …
Analysis	Failure to mark ROI adequately and exclude bone appositions.	Computer also calculates big osteophytes in the region which is being analyzed
	Wrong marking of vertebral bodies	Auxiliary orientation is iliac christ which is situated between L4 and L5, last ribs most frequently on Th12.
Interpretation	Incorrect use of WHO criteria for the purpose of making the diagnosis and ISCD propositions	Usage of T-score in young, healthy pre menopausal women, as well as usage of WHO diagnostic criteria will lead to wrong comprehension of fracture risk
	Wrong BMD comparison	Unknown LSC, use of different devices, scanned different bone regions, comparison of incorrectly marked levels, comparison of results on left hip with the right hip, comparison of T-score instead of BMD, different scanning mode
	A claim that bone loss occurred, based on one scan only..	It can be asserted only based on serial BMD measurement and known LSC
	Inadequately presented fracture risk	Expression of fracture risk as relative would lead to incorrect fracture risk assessment , in case that comparative population has low fracture risk

before mentioned internal hip rotation is often neglected (it is good if trochanter minor cannot be seen), as well as existence of large adduction, abduction and different soft tissue presence on the scan, which makes monitoring more difficult (pictures 2 and 3). Each movement of correct positioning, even the movement of only 5º, can affect measuring results.



Pictures 1 a and b: *A proper DXA scans.*

Local, structural changes on vertebral bodies or the environment (osteoarthrosis, compressive fracture, laminectomy, hemangiomata, metal implants, grafts, abdominal aorta calcification) can change T-score of each vertebra, and, therefore, they should be excluded from analysis. According to ISCD recommendations, the T-score difference between two, vicinal vertebrae must not be higher than 1SD (example 1). The most common artifacts in interpretation of hip result are: degenerative joint change or luxated joint, presence of previous fractures, cysts and presence of metal. Therefore, such scans should not be interpreted.

The mode, in which the scan is made, is also significant, because the mistake which is obtained, especially in obese patients, in two different modes, with the same positioning, can sometimes be larger than LSC (example 3).

Table 4. Results of the study which analyzed clinical DXA scans made on a sample that included 400 patients. Even 22% of obtained scans on lumbar spine were inadequate for analysis, due to artifact.

Most frequently present artifacts were as follows: aortal calcification, osteophytes, myeloma, non diagnosed Paget's disease or ankylosing spondylitis [12]. Presence of osteophytes on vertebral bodies is common finding in elderly patients and it can have the biggest effect on results, especially on AP DXA of spine [13].

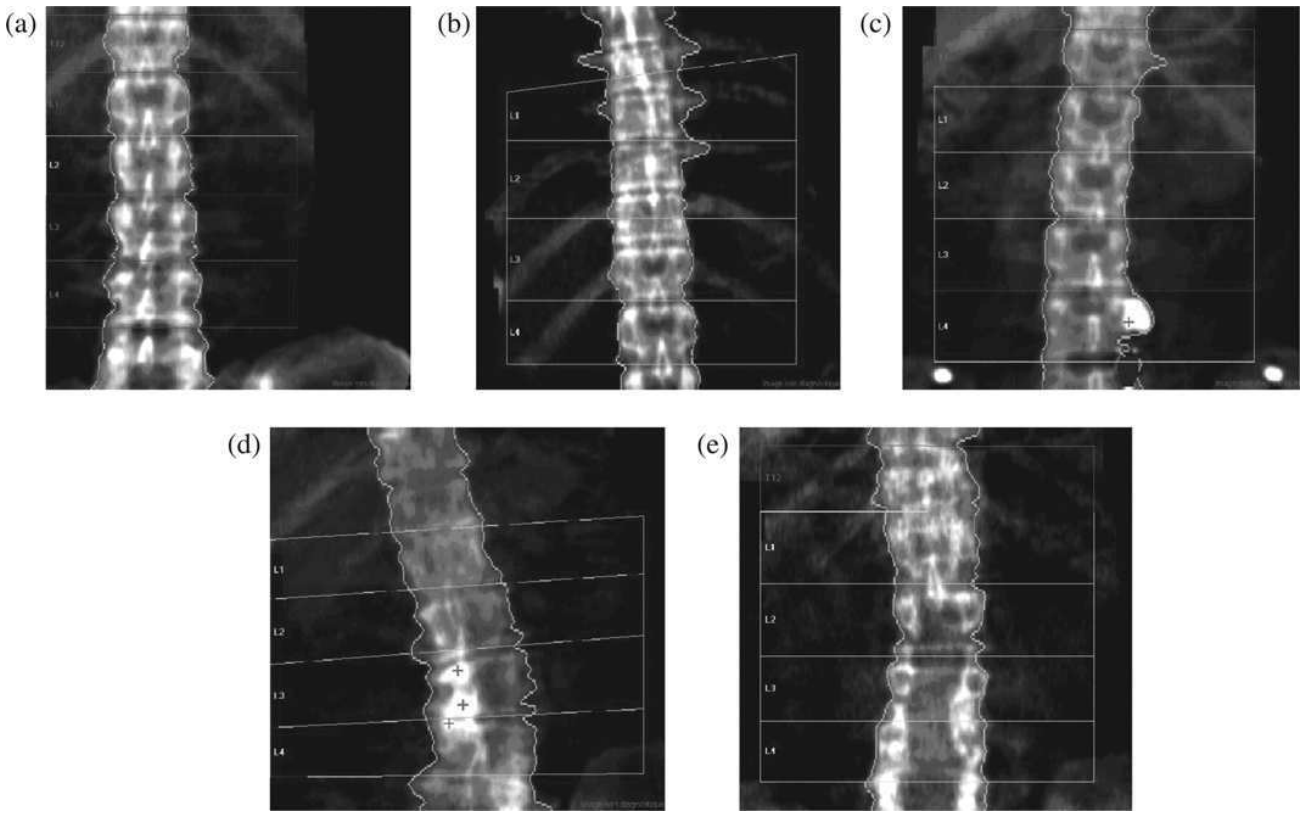
Table 4. *Most frequently artifacts.*

Status	**Effect on the scan**	**Activity**
Aortal calcification	Gives greater BMD value on lumbar spine than real value	Perform lateral radiography and exclude vertebral bodies in superposition with calcificates in aortal wall from the analysis
Osteophytes	Gives greater BMD values on certain vertebrae or the whole lumbar spine, then it is realistic	Exclude vertebral bodies from analysis or perform lateral DXA scan
Myeloma	Increased BMD on one vertebra	Perform RTG in order to confirm.
Paget's disease	High BMD values	Check vertebral area which is of increased value.
Ankylosing spondylitis	Joint vertebra of high BMD value.	Lateral DXA scan, exclude procesus spinozus
Dermatomyositis	Calcium deposits in soft tissue around bones	If both scans are not for analysis, perform the scan of forearm
Osteoarthritis	Increased BMD values on spine or hip	Exclude certain vertebrae from analysis of the whole region scan
Fracture	Increased BMD, reduced vertebral area	Exclude certain vertebrae from analysis or the whole scan of the spine

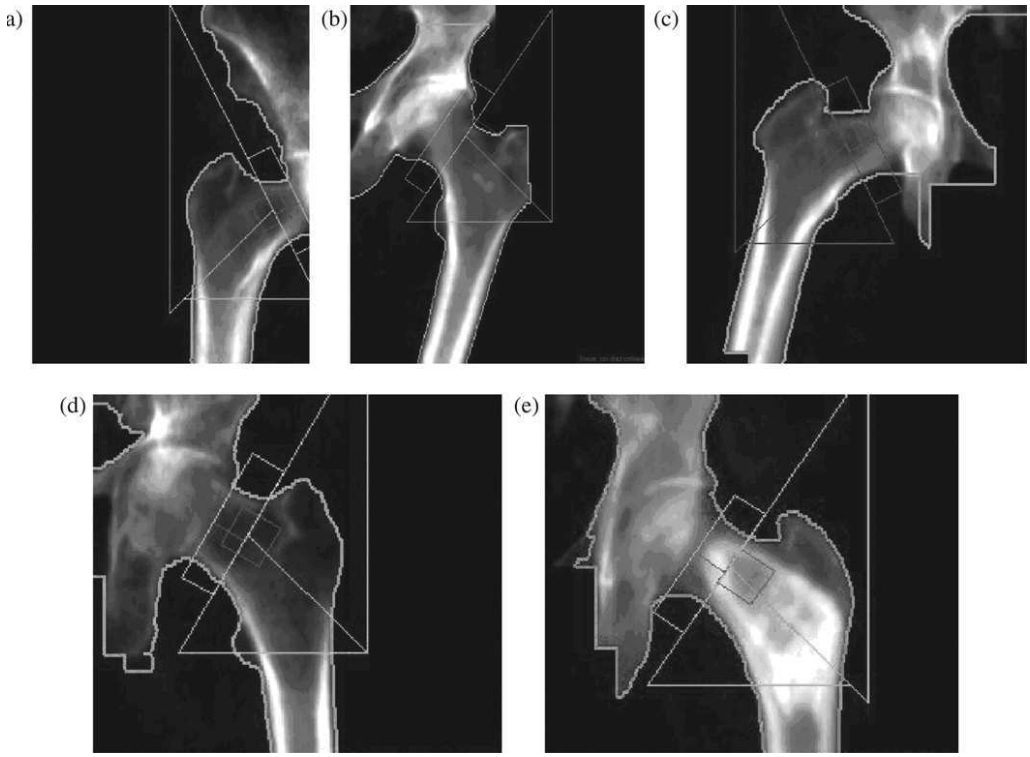
The study on the quality of DXA reports between 6.000 ISCD members included 743 clinicians and 754 technicians. Majority of clinicians (71%) and large number of technicians (45%) reported that they saw, at least one, incorrect scan a week. Even 98% of clinicians state that incorrectly made and interpreted scans harm the further decision about therapy [16].

SEMIQUANTITATIVE VERTEBRAL MORPHOMETRY

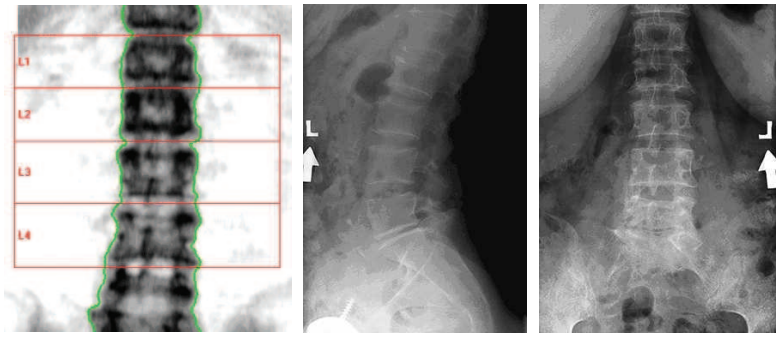
Osteoporosis can be diagnosed according to WHO criteria (T-score ≤-2,5) and based on existence of previous small trauma fracture. However, classification of patients only according to T-score misses almost half of the patients with clinical diagnosis of osteoporosis, which were the results of OFELY study. This study was conducted with participation of 671 postmenopausal women and it showed that 44% of vertebral fractures happen with T-score ≤ -2,5, 48% in osteopenia and 8% with normal BMD result (17.) Fracture risk increases with the number of vertebral fractures (SOF study), (18) as well as with grading of previous fractures (MORE study) [19]. The existence of previous fracture predicts future fracture independently from BMD. Integration of BMD result and identification of fractures, improves comprehension of future fracture risk.



Picture 2. *Examples of most common technical problems during scanning of the spine (14):*
a) Scan of the spine is excesivelly moved to one side with different soft tissue quantity on the left and on the right side , which will give inccorect result b) Wrongly marked vertebral bodies c) Metal button in superposition with L4 d) Scoliosis and existance of osteofits on L3 and L4 e) Laminectomy

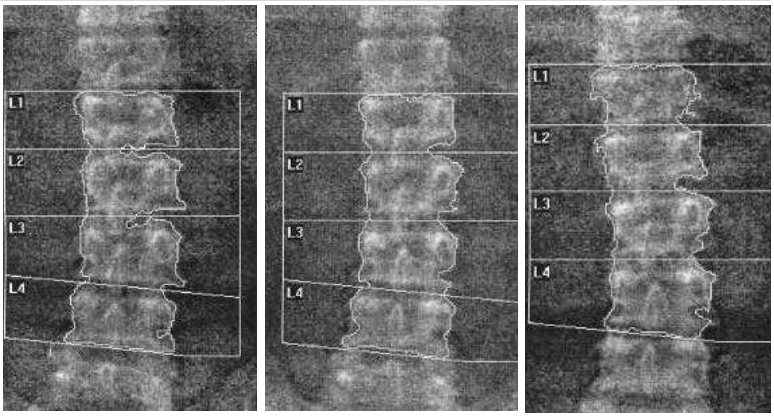


Picture 3.*: Examples of most common technical problems in hip scanning (14):*
a) Inadequate scan because a part of ROI (Region of Interest) is missing b) Femur positioned in too large abduction c) Insufficient internal hip rotation (trochanter minor can be seen) d) Disrupted bone structure due to previous fracture and osteosynthesis is not ROI for analysis



Example 1: There is a difference, which is greater than 1SD, between T-score value on certain vertebral bodies (L1 and L2 have significantly greater values). RTG lateral spine scan shows presence of osteophytes and compressive fracture on L1 and L2, which explains such result (15). Vertebrae L1 and L2 should be excluded from analysis.

Example 2: A woman of 65 years, is on the treatment for osteoporosis (L1-L4 T-score:-3,3). Treatment started by oral bisphosphonates which caused significant improvement of BMD, which is established during control densitometry after a period of one year, but on the next control examination, after 2 years of treatment, a decrease in BMD is recorded.



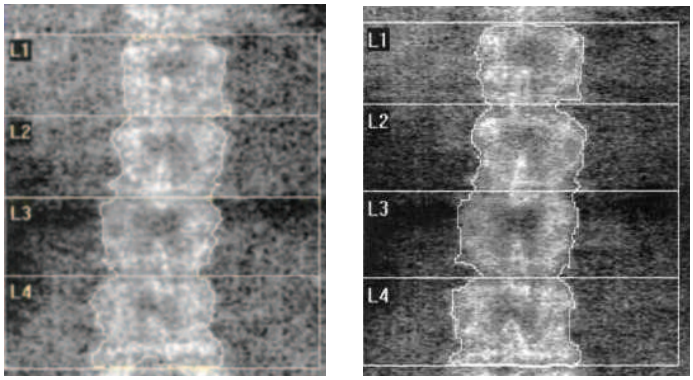
Baseline scan BMD=0,729g/cm^2

Follow-up scan #1 BMD=+0,039g/cm^2 (+3,5%) Improved result.

Follow-up scan #2 BMD= -0,037g/cm^2 (-5,1%) Decrease in BMD when compared to the previous scan.

On the last scan, vertebral bodies are incorrectly marked, because the whole segment is lifted up for one vertebra. Re-analysis of the last scan with correctly marked vertebral bodies shows stable BMD compared to previous scan, showing good response to Th (Archives of Vasic J, MD).

Example 3*:* Scans of the same, obese patient which are done in different scanning mode, made during the same visit, without repeated positioning. Obtained values show the difference that is greater than LSC, which is very significant for the diagnosis, as well as for the follow up of treatment effects (Archives of Vasic J, MD).



Fast Array Mode-exposition lasts 30 seconds. L1L4 BMD=0,833g/cm^2

Array Mode-exposition lasts 60 seconds. L1L4 BMD greater for 0,035g/cm^2 (>LSC)

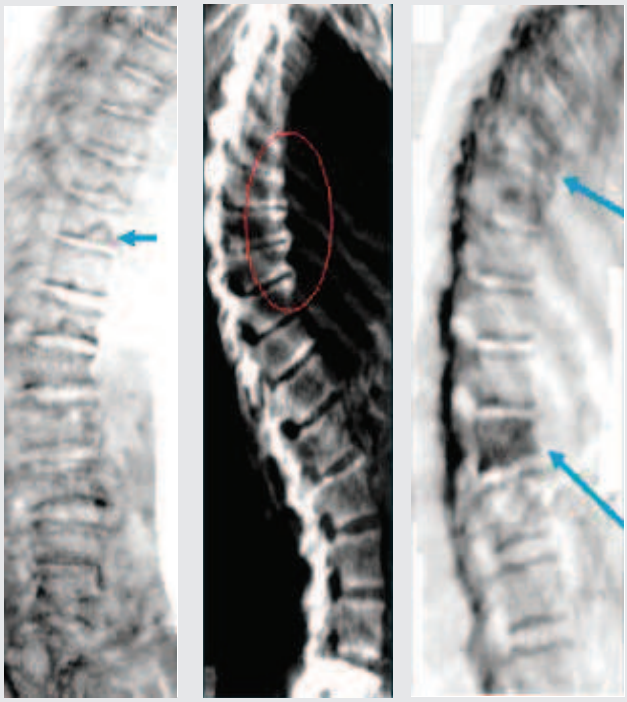
As new series of DXA devices have possibility to perform lateral scan (VFA), during the same visit to DXA Center and, supported by Genant Scale, it is possible to determine changes in vertical height and vertebral body shape, making the diagnosis is easier, thus, a timely initiation of treatment is more useful. VFA should be done routinely, in the following cases:- if BMD result is in osteopenia: in women who are older then 70 and men older than 80; in case the data on body height decrease compared to their youth are ≥ 4cm in women and ≥ 6cm in man; if height decrease in last year is ≥ 2cm in women and ≥ 3cm in men, if the patient reports previous spinal fracture without supporting medical documents; if 2 or more data are present- for women 60-69 years old or men 70-79 years old: presence of non vertebral fracture, chronic systematic disease, therapy with androgens , the decrease in height in women is 2 -4 cm and in men it is 3 to 6 cm. Also, VFA should be done always when we think that obtained result could influence the decision on further treatment or therapy change [8].

Genant's method is semiquantitative and based on determination of the extent of vertebral body height reduction and on identification of radiological fracture characteristics, according to position and shape of vertebral bodies cover plate [20]. The very assessment of vertical diameter decrease is standardized, so vertebral fracture is defined as a decrease in vertebral body height for more than 20%. Fractures are categorized in three grades: grade I- mild, grade II-moderate and grade III- severe. Also, they are categorized according to percentage of body height decrease: a 20-25% decrease, 25-40% decreased and decrease for more than 40%.

According to position and shape of vertebral body cover plate, fractures are described as: wedge-shaped, biconcave and crash. Genant also designed a calculation of SDI-index spinal deformity, which is obtained by adding numbers 0, 1, 2 and 3 based on semiquantitative analysis of vertebral bodies from Th4 to L4. This is useful because the increase in SDI can, during control measurements, point out to occurrence of a new fracture or worsening of the old one. It can, also, predict appearance of new fractures [21].

Genant's method is subjective which can lead to mistakes during analysis, especially in grade I deformity, where specificity and sensitivity of this method amounts between 79-85% (22). SOF study has shown that frequency of grade I fracture identification is four times higher compared to other methods. In gr. II and gr.III, sensitivity and specificity are much greater (92% and 96%) (23). Disadvantage of this method is poor visualization of vertebral bodies Th4-Th6: from Th7 and lower, visualization is 97%, for Th6 it is 70%, for TH5 it is 60% and for Th4 it is 43%.

Another disadvantage of this method is inability to determine etiology of changes (metastasis, myeloma, Shmorl's hernia, degenerative disease) - pictures 4,5 and 6.



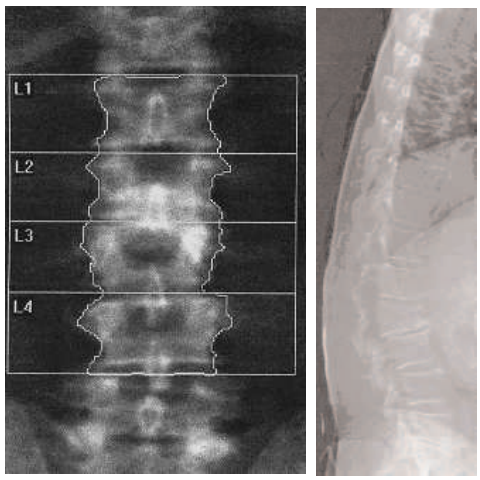
Picture 4: Changes which are not fracture - Shmorl's hernias associated with compressive fractures [24].

Picture 5: Degenerative changes and hypertrophy lead to elongation and vertebral bodies' wedge shape, which resembles to a fracture [24].

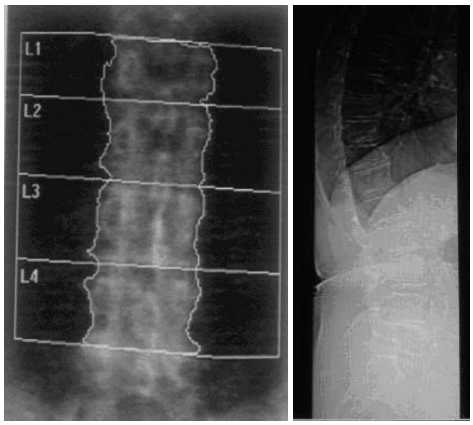
Picture 6: Some fractures are not caused by osteoporosis-metastasis of prostate carcinoma [24].

CONCLUSION

Health assessment depends on DXA report quality and validity, according to which, a subsequent decision on patient's treatment will be based. The imperative is that DXA devices enable consistent high quality data obtaining. Reports of poor quality can influence making of such clinical decisions which can produce unnecessary medical expenses and therapy options which can be harmful to the patient. Clinicians, who are working in DXA Centers, must be adequately trained for device operation and must improve and update their work on regular basis.



Example 4: A 70 years old, Caucasian male patient; body height 178 cm, body weight 71 kg, BMI 22,6 , without previous minimal trauma fracture, without other fractures. DXA result on L spine (T-score: L1 -0,9; L2 +1,8; L3 +0,8; L4 -0,9) shows a great BMD variation on certain vertebral bodies and higher T-score on L2 (almost 2 SD in respect to L1) and for almost 2SD higher T-score on L3, in respect to L4. VFA is done: increased density about i.v. L1, L2 with sclerotic edges which directs to degenerative disease of the discus. Also, there is a compressive deformity L2 with secondary anterior osteophytes, which explains increased BMD L2! If this is a compressive fracture, why can't we see reduced height of fractured vertebra on DXA scan? This is height diameter decrease in anterior aspect and, given the fact that posterior height is not disrupted, scan L1L4 will not show compression and deformity, but it will reflect to BMD of vertebral body. What is diagnosis? DXA diagnosis according to WHO criteria is normal bone mineral density. However, if atraumatic fracture is in question, then the diagnosis is osteoporosis. Is this a new or an old fracture? Presence of anterior osteophytes suggests that this is an old fracture [25].



Example 5: A77 years old, Caucasian female patient; menopause started at age 57; body height is 152 cm, body weight is 63 kg, BMI 27,3; she sustained radius fracture at age 57, it occurred due to a fall in the same level; she has been a smoker for 50 years. She states that her body height decreased for 5cm. DXA result on spine (T-score: L1- 1,4; L2 -1,4; L3 -0,2; L4 -0,3; L1L4 -0,8) : The difference larger than LSD on L3 and L4 is observed in relation to L1 and L2. DXA result on the hip: femoral neck T score-1,7 and total hip T-score -2,1. VFA is done according to ISCD recommendations and it shows preserved vertebral bodies height diameter, decreased i.v. L4 and L5 with signs of degenerative changes and abdominal aorta calcifications in front of L3 and L4, which gives falsely better result than the realistic one. L3 and L4 should be excluded from analysis (archives of Vasic J, MD).

Sažetak

Osteoporoza se karakteriše sniženom koštanom masom i narušenom mikroarhitekturom kosti što posledično vodi ka povećanom riziku za nastanak preloma. U poređenju sa ostalim tehnikama merenja gustine kosti, centralna DXA ima brojne prednosti kao što su: kratko vreme skeniranja, mala doza zračenja, laka priprema pacijenta, dobra preciznost. Ona nam služi za : postavljanje dijagnoze osteoporoze, procenu frakturnog rizika, odluku o otpočinjanju lečenja, praćenja efekata lečenja. Preciznost merenja zavisi od: tehničke ispravnosti aparata (fan beam tehnolgija, uredna kalibracija, redovna kontrola kvaliteta, redovan servis), ljudskog faktora (sveobuhvatna anamneza, unošenje podataka, pozicioniranje, analiza skena) i lokalnih strukturnih promena na koštanom tkivu koji se snima ili njegovoj okolini). Osteoporoza se može dijagnostikovati prema WHO kriterijmima (T-skor ≤-2,5) ili na osnovu postojanja prethodnog preloma na malu traumu. Klasifikacija pacijenata samo na osnovu T-skora propušta skoro polovinu pacijenata sa kliničkom dijagnozom osteoporoze. Kako nove serije DXA aparata imaju mogućnost da se prilikom iste posete DXA centru uradi i lateralni sken kičme (VFA) koji uz pomoć Genantove skale utvrđuje promene vertikalnog promera i oblika pršljenskh tela, postavljanje dijagnoze je time olakšano a samim tim i pravovremeno otpočinjanje terapije korisnije. Genantov metod je semikvantitativan i zasniva se na proceni smanjenja vertikalne visine pršljenskih tela i na identifikaciji radioloških osobina preloma na osnovu položaja i oblika pokrovnih ploča pršljenskih tela. Procena smanjenja vertikalnog promera je standardizovana, tako da se vertebralni prelom definiše kao smanjenje visine tela pršljena za više od 20%. Prelomi se kategorizuju na tri stepena i to prema procentu smanjenja visine pršljenskog tela. Medjutim, Genantova metoda je subjektivna što može da dovede do greški pri analizi, posebno kod gr. I deformiteta. Mana ove metode je i lošija vizuelizacija pršljenskih tela Th6-Th4 kao i nemogućnost utvrđivanja etiologije promena što takođe može dovesti do pogrešnog zaključivanja (metastaze, mijelom, Šmorlove hernije, degenerativna bolest...).

Mogućnosti sagledavanja frakturnog rizika su danas olakšane unapređenjem tehnoloških karakteristika centralnih DXA aparta. Zdravstvena procena zavisi od kvaliteta i validnosti DXA izveštaja na osnovu kojih će se i bazirati dalja odluka o tretmanu. Kliničari koji rade u DXA centrima moraju biti adekvatno obučeni radu na aparatima i redovno da svoje veštine unapređuju.

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