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Review Article **Open Access**

Serial or compare bone mineral densitometry: how to do it step by step

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Bone mineral densitometry (BMD) is the most valuable method for assessing bone and calculating fracture risk. Serial or comparative bone densitometry is important in rheumatologists' work on osteoporosis management. The response or lack of response to osteoporosis treatment based on densitometry scans is crucial. This paper examines the timing of scan requests concerning the history of glucocorticoid use, renal or other solid organ transplantation, malignancy, and other situations discussed. We encountered four types of compared scans based on the centers where BMD was performed and the precision of the devices used for this survey: Same Center, Same Device (SSSD), Same Center Different Devices (SCDD), Different Centers Same Devices (DCSD), and Different Centers Different Devices (DCDD). We discussed the principles of comparison and the key indicators.

***Keywords*:** Bone densitometry; Bone density; Serial BMD; Compared BMD; Center; Device

Principles and methods

Definitely the most important role of bone mineral densitometry (BMD) is to compare with multiple results from similar patients for changes in bone density over time. Frequency and correct time of repeat of BMD based on risk factors showed in two Figures (Figures 1, 2) [1-8]. There are four types of compared BMD: (1) Same Center & Same Device (SCSD), (2) Same Center & Different Devices (SCDD), (3) Different Centers & Same Device (DCSD), (4) Different Centers & Different Devices (DCDD). In this article we discussed the principles of SCSD.

Same Center & Same Device (SCSD)

It is the best type and recommended form of BMD. Serial or compared BMD indications are (1) to monitor response to therapy, (2) to assess non-response by bone densitometry as one source of responsiveness, (3) to follow up patients who are not on treatment and are at risk of bone loss (such as steroid users, hyperparathyroidism). Same as other BMD reading and interpretation, SCSD have 5 steps.

Step I: ID Characters control

In this step we control the name, surnames, age, sex, height, weight and ultimately reference population (ethnicity) shown in Figures 3, 4. It should be remembered that any problems in above data, can be solved if both scans be available. About reference population, the International Society of Clinical Densitometry (ISCD) recommendation is selection of specific population such as White, Black, Hispanic, Asian, if patient is not in any of above population better

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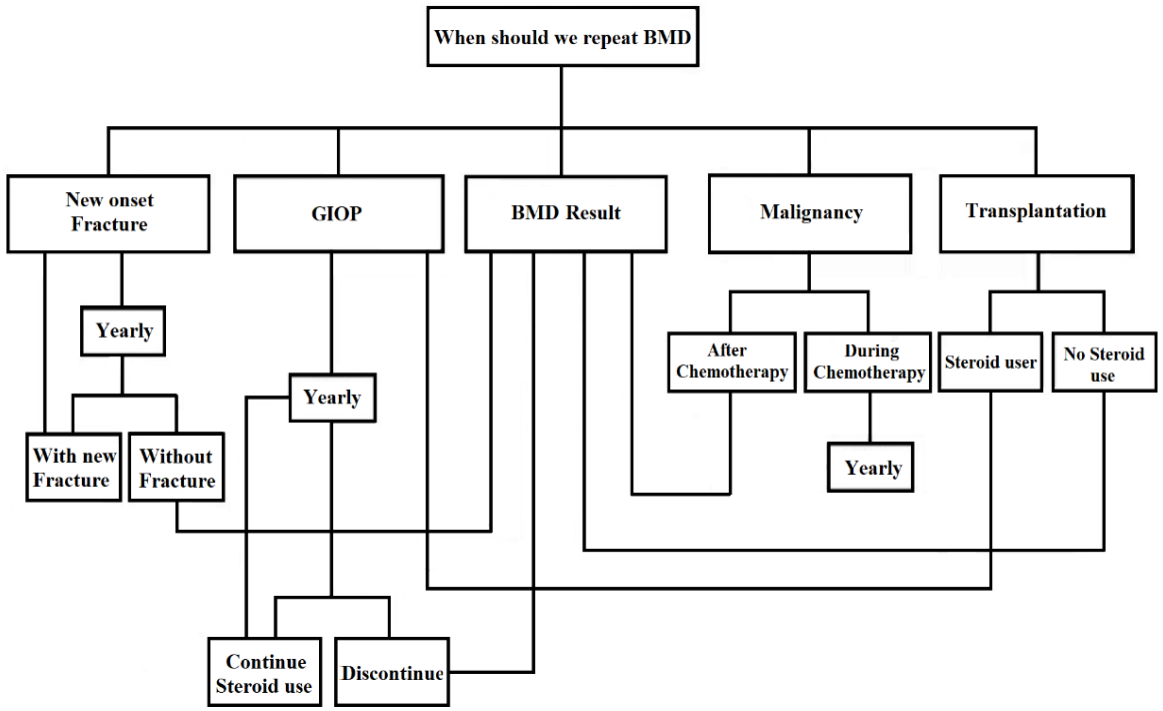


Figure 1. Algorithm for repeat BMD in some conditions

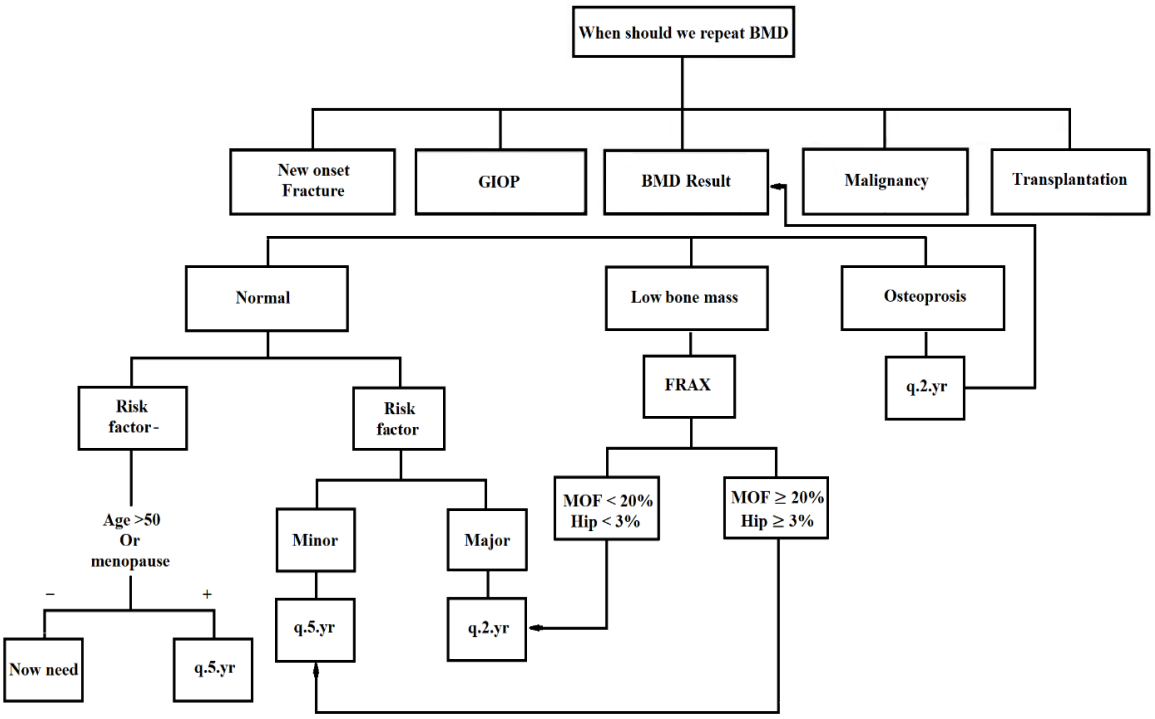


Figure 2. Algorithm for serial BMD based of BMD result

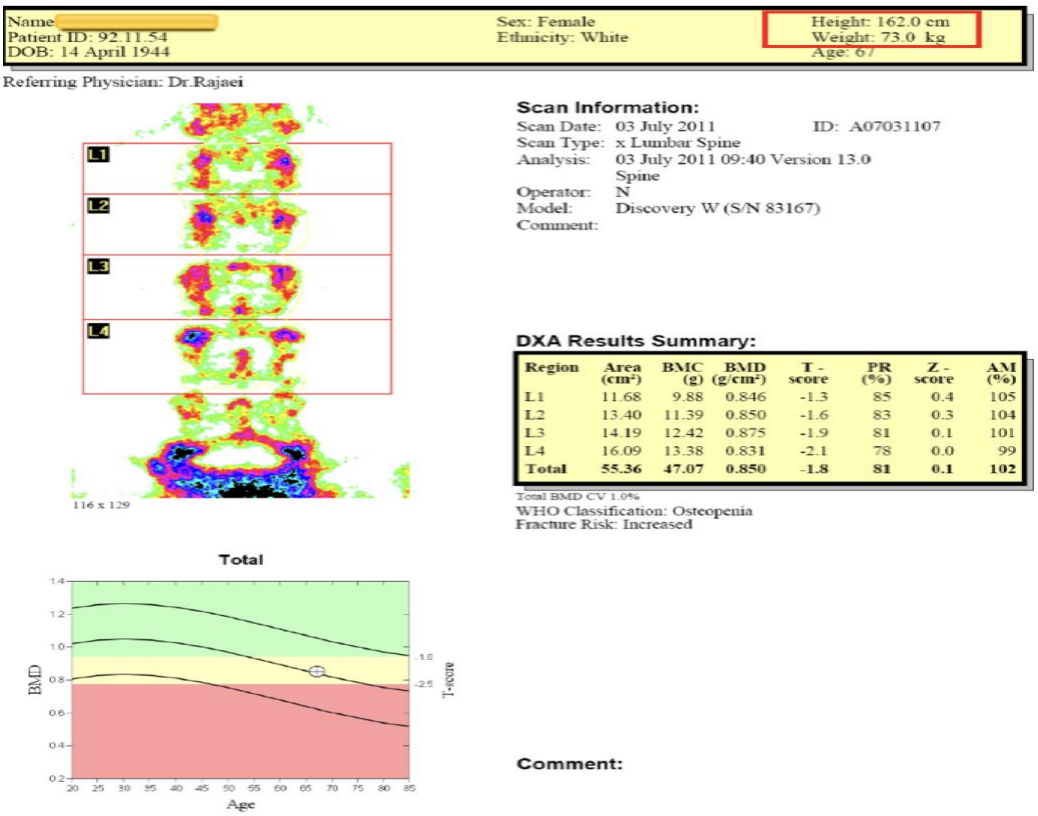


Figure 3. Attention to ID characters in the first scan

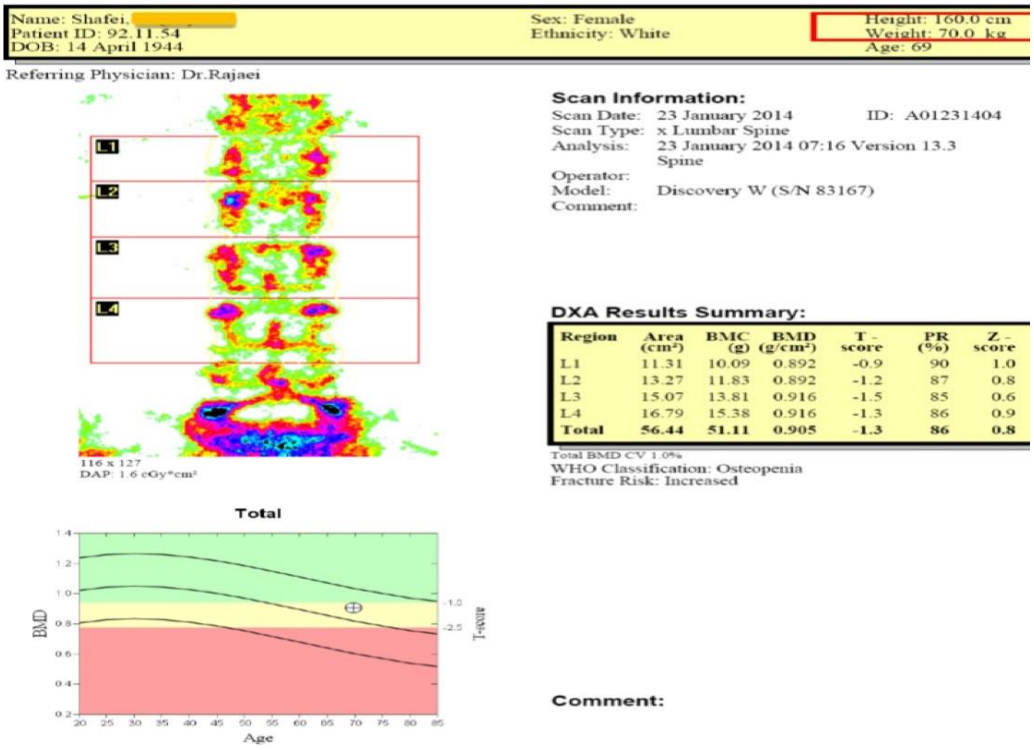


Figure 4. Attention to ID characters in the second scan

to use Caucasian.

Step II: Control of good scan criteria

This step has 2 phases:

I. Checking the similarity of scan image (straightness, top, bottom, both sides)

II. Checking the good scan criteria in each scan

It's very important that takes the new scan looks as similar as possible to the previous scan (except artifacts). The straightness of limbs (for example spine or hip) is very important at this step (Figures 5, 6). Since the first (old) scan is the basis for the second (last) scan, it is important to teach the technician the criteria for a good scan as shown in Figures 7 and 8 [9-13].

Spine good scan criteria (Figure 7) are:

1- Lack of artifact
2- Spine should be straight (S)
3- Upper border: at least ½ of T12 (A)
4- Lower border: at least ½ of L5 (B)
5- Each side: at least 2 cm at each side of spine (C)

Hip good scan criteria (Figure 8) are:

1. Lack of artifact
2. Hip should be straight (S)
3. Upper border: at least 2 cm above greater trochanter (A)
4. Lower border: at least 1.5 cm below ramus of pubis (B)
5. Inner border:
   a. no or small size of lesser trochanter (E)
   b. visibility of a part of obturator foramen (D)
   c. distance between ramus and neck 1cm(C)
6. Outer border: at least 1 cm soft tissue (OB)

When this step successfully passed (similarity of each scan in previous and recent results such as Figure 4 for spine scans and Figure 5 for hip region), we can go to step III. In should be emphasized that the technician must be seen the previous scan and take the new one with maximum similarity to earlier scan [14-26].

Step III: Unification of Region of Interest (ROI) insertion

During this step, the ROI or area of both scans should be the same. In spine region it's necessary to uniform labeling of vertebrate in scans. For this purpose, the vertebrates should be labeled or numbered. Technically two ways for labeling exist:

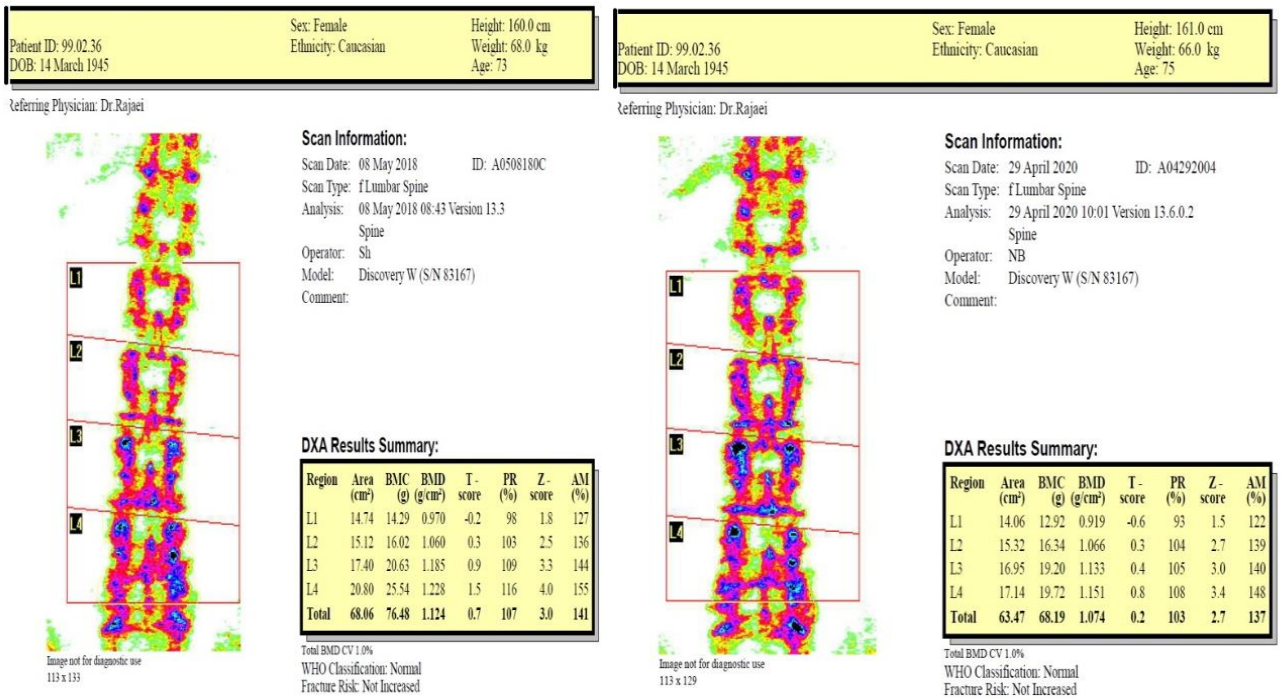


Figure 5. Special attention to spine image for similarity of straightness, above, below & sides of both scan

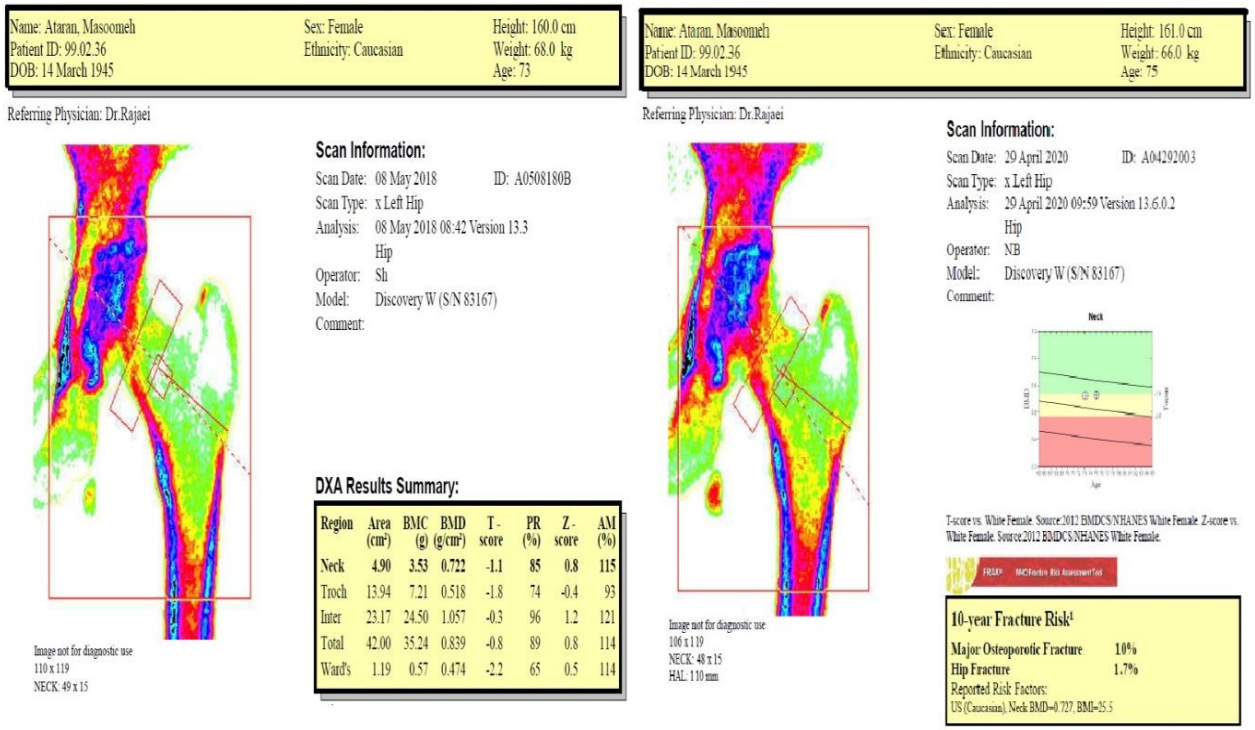


Figure 6. Compare the both hip image for mentioned items (straightness, above, below & sides)

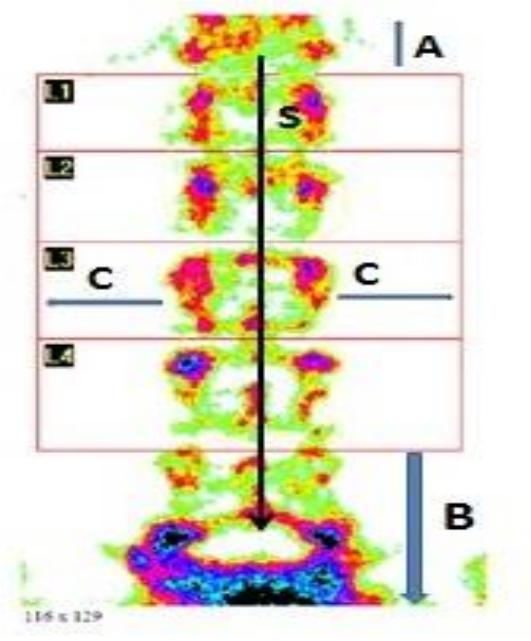


Figure 7. Spine good scan criteria

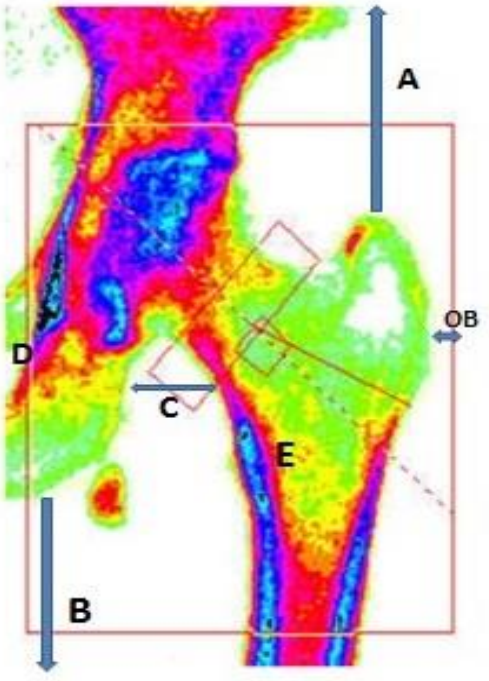


Figure 8. Hip good scan criteria (the bone (OC) below the ramus is osteochondroma not artifact

1. Shape of vertebrae: as a rule, vertebrae of L1, L2 and L3 are U shape and L4 is "X" or "H" shape. L5 has "wm" so the above border of L5 is same "w" and below borders as "m" (Figures 9, 10).

2. Landmark use: iliac crest bone is parallel of L5 and rib connects to T12 and the third landmark is long transverse process that see on L3 (Figures 11 and 12).

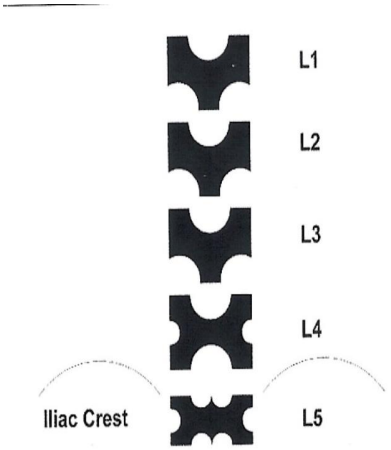


Figure 9. Schematic scan labeling [12]

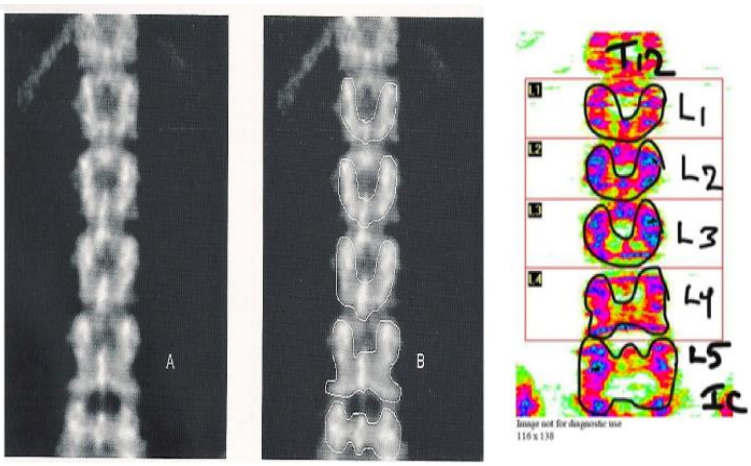


Figure 10. Real scan [12]

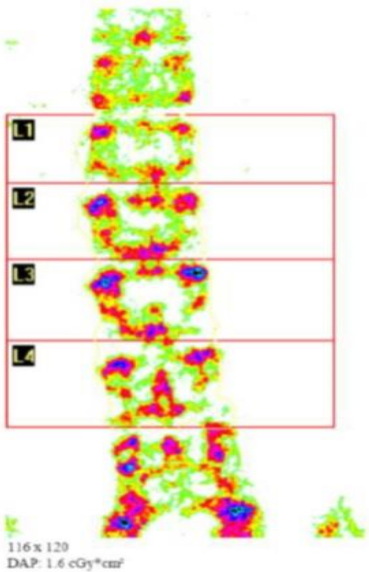


Figure 11. labeling of vertebrae based of landmarks

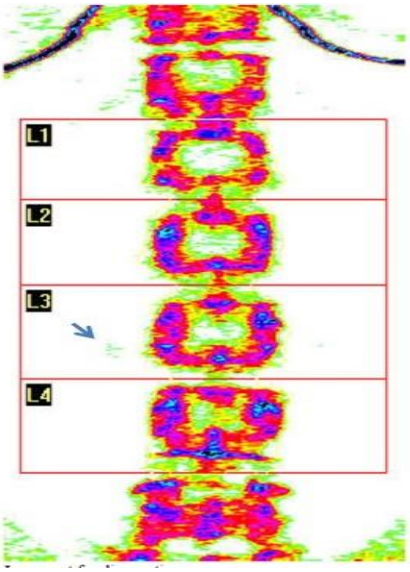


Figure 12. Long transverse process at L3

In compared BMD, unifying of both spine scan is very important and need to use of similar labeling of vertebrae correct passing of this step is obligatory for going to next step.

In the pelvic area, it is important to have the neck box (rectangular box) in the same location in both scans (Figure 13).For this purpose, four characters should be assessed:

1. Neck box should not be entered to head or greater trochanter region (H/GT at Figure 14)
2. The inner line of the neck box should cross the ramus pubis if it continues (NBIB at Figure 15).
3. The outer line of neck box should not enter the greater trochanter region if it continues (NBOL at Figure 16).
4. The ward triangle (the square box) should be near or attached to neck box (WBNB at Figure 17) and should not be separated (Figure 18).

If all the characters in the two images are similar, you can go to the next step. It should be mentioned again, we or technician can correct this step without repeating of scan [27-29].

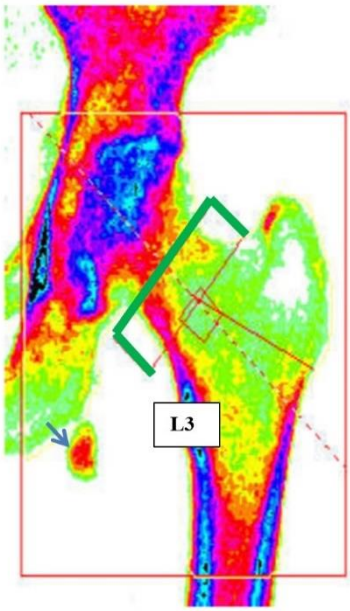


Figure 13. Neck box (green box)

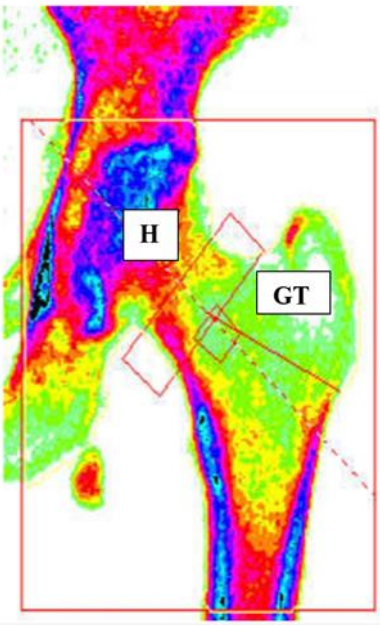


Figure 14. Neck box between head (H) and greater trochanter (GT)

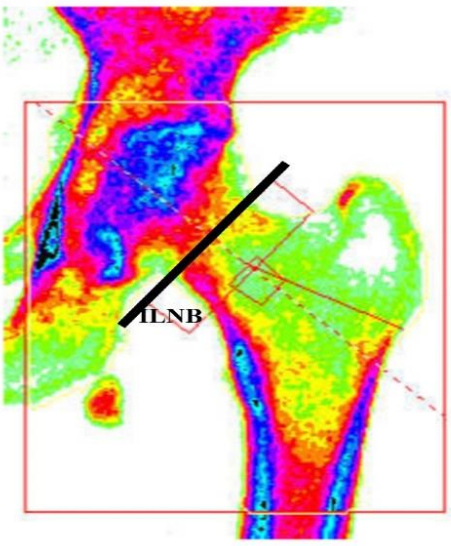


Figure 15. Inner line of neck box should be near or cross the ramus of pubis or ILNB (black line)

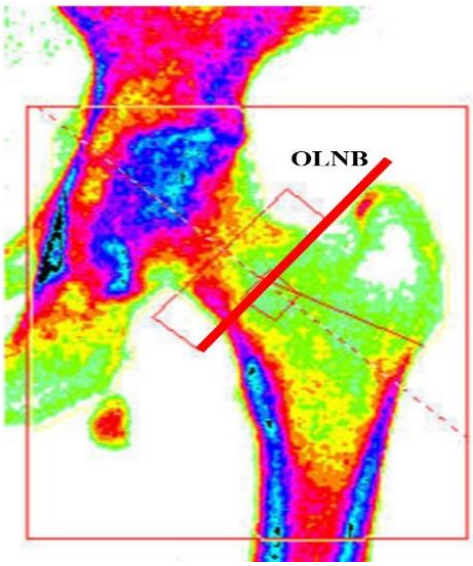


Figure 16. outer line of neck box should not be enter the greater trochanter or OLNB (red line)

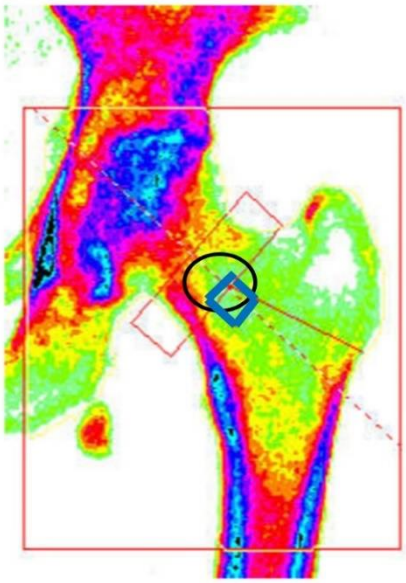


Figure 17. ward box (blue) should be near of neck box or WBNB (black circle)

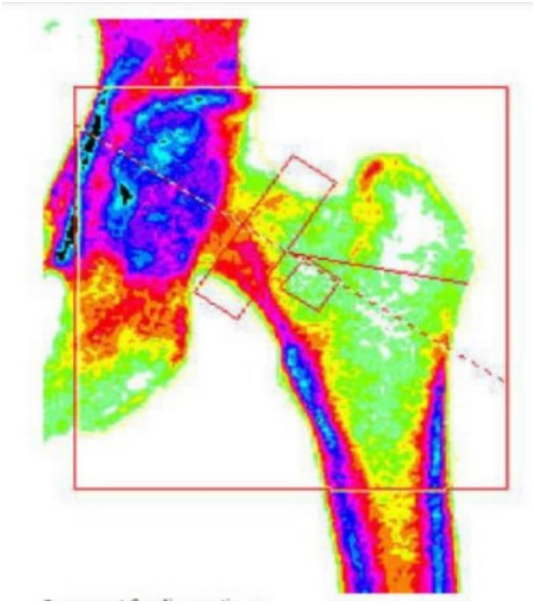


Figure 18: ward box not near the neck box

If all the characters in the two images are similar, you can go to the next step. It should be mentioned again, we or technician can correct this step without repeating of scan [27-29].

Step IV: Control of area & BMD in both scan

This step has 3 phases for spine region and two steps for hip and forearm regions. In *the spine scan* 3 phases should be considered:

Phase 1: selection of best region

For selection of best region, area and BMD rules should be considered. According to the area rule, the lumbar spine area gradually increases from L1 to L4 (L1 < L2 < L3 < L4) (Figure 19). The border of the vertebral region is determined by the technician, so it requires great care to clarify the top, bottom and both sides. On the other hand, the area rules are the most important duty of the technician, and compliance with the rules of the area in each scan (spine, hip, forearm and whole) is the main duty of the technician to reduce reporting errors.

According to the BMD rule, the lumbar spine BMD gradually increases from L1 to L3 and the decrease to L4 (L1 < L2 < L3 > L4) (Figure 19). Thus, if both rules (area & BMD) are kept, L1-4 selected and based on the rules three or two consecutive vertebrae should be elected (Figure 20 area error & Figure 21 BMD error). The best region to scan the spine for a patient is shown in Figure 22.

Phase 2: selection of the common best region for both scan

If two scans have the same best region based of area and bone density, the same region is selected as the common best region. But if in the first scan L1- 3 is suitable and in the second L2-4 is suitable, then L2-3 is the common best region (Figure 23).

Phase 3: Controlling the area difference between two scans

At this phase, it is necessary to compare the common best region between the two scans and this difference should not be more than 2 square centimeters (Figure 24). It should be noted that if there is no problem in performing & analysis the scans, the device itself compares the L1-4 region (Figure 25).

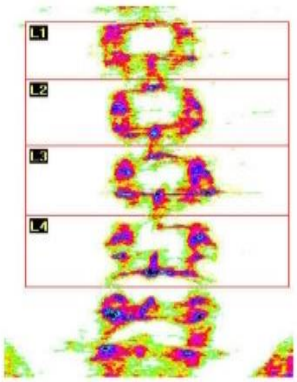
In the hip scan 2 phases should be considered:

Phase 1: Choosing the total area as the common best region

For comparison in hip scan, we should be used total region. If the total region cannot be used in decreasing frequency greater trochanter, inter trochanter, and finally neck regions may be used.

Phase 2: Controlling the area difference between two scans

In hip scan, the difference area should not be above 2 cm^2 (Figure 26). If the difference in the total area of two scans is more than 2 square centimeters, then it is necessary to correct this



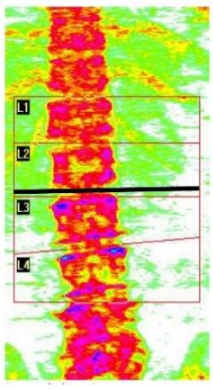
Scan Information:

Scan Date: 07 April 2021 ID: A0407210K
Scan Type: f Lumbar Spine
Analysis: 07 April 2021 11:45 Version 13.6.0.2 Spine
Operator: NB
Model: Discovery W (S/N 83167)
Comment:

DXA Results Summary:

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	13.63	9.88	0.725	-3.2	68	-3.2	68
L2	14.41	11.02	0.765	-3.0	70	-3.0	70
L3	16.03	12.98	0.810	-2.7	73	-2.7	73
L4	16.17	12.65	0.782	-2.8	72	-2.8	72
L1-L2	28.04	20.90	0.746	-2.8	71	-2.8	71
L1.L3	29.66	22.86	0.771	-2.6	73	-2.6	73
L1.L4	29.80	22.53	0.756	-3.0	70	-3.0	70
L2-L3	30.44	24.00	0.789	-2.8	72	-2.8	72
L2.L4	30.58	23.67	0.774	-3.2	69	-3.2	69
L3-L4	32.20	25.63	0.796	-3.0	71	-3.0	71
L1-L3	44.07	33.89	0.769	-2.7	72	-2.7	72
L1-L2.L4	44.21	33.56	0.759	-3.0	70	-3.0	70
L1.L3-L4	45.83	35.52	0.775	-2.9	71	-2.9	71
L2-L4	46.61	36.65	0.786	-3.0	71	-3.0	71
L1-L4	**60.24**	**46.54**	**0.773**	**-2.9**	**71**	**-2.9**	**71**

Figure 19: keeping of rules in area and BMD in all vertebrae from L1 to L4 and election of L1-4 for report



Scan Information:

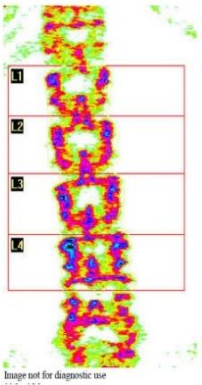
Scan Date: 26 October 2022 ID: A10262209
Scan Type: f Lumbar Spine
Analysis: 26 October 2022 09:19 Version 13.6.1.2 Spine
Operator: A
Model: Horizon Wi (S/N 304687M)
Comment:

You should be know the area can be changed by alter the above, below or sides of vertebrae, therefore except during fracture correction of area is possible, such as this case with change of above line of L3 the area of L3 increase and L2 decrease (black line)

DXA Results Summary:

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	10.70	6.98	0.652	-3.1	66	-0.8	88
L2	11.20	7.35	0.657	-3.4	64	-0.9	87
L3	11.14	8.56	0.768	-2.9	71	-0.3	96
L4	11.74	8.05	0.685	-3.4	65	-0.7	90
L1-L2	21.89	14.33	0.655	-2.9	67	-0.6	91
L1.L3	21.84	15.54	0.711	-2.7	70	-0.3	96
L1.L4	22.44	15.03	0.670	-3.3	65	-0.8	88
L2-L3	22.34	15.91	0.712	-3.1	67	-0.6	92
L2.L4	22.94	15.40	0.672	-3.7	62	-1.1	85
L3-L4	22.89	16.61	0.726	-3.4	66	-0.8	90
L1-L3	33.04	22.89	0.693	-3.0	68	-0.5	93
L1-L2.L4	33.64	22.38	0.665	-3.4	64	-0.9	88
L1.L3-L4	33.59	23.59	0.702	-3.2	67	-0.6	91
L2-L4	34.08	23.96	0.703	-3.4	65	-0.8	89
L1-L4	**44.78**	**30.94**	**0.691**	**-3.2**	**66**	**-0.7**	**90**

Figure 20. Area error in spine region and choosing of kept area rules



Scan Information:

Scan Date: 12 July 2023 ID: A0712230T
Scan Type: f Lumbar Spine
Analysis: 12 July 2023 12:14 Version 13.6.0.5 Spine
Operator: NB
Model: Horizon Wi (S/N 304687M)
Comment:

Area rules are correct but BMD in L3-L4 increases instead of decreasing, so the best region is L1-3

DXA Results Summary:

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	PR (%)	Z - score	AM (%)
L1	11.64	10.06	0.864	-1.1	87	0.4	105
L2	14.23	13.07	0.919	-1.0	89	0.7	109
L3	14.93	14.58	0.976	-1.0	90	0.8	110
L4	15.10	15.72	1.041	-0.2	98	1.6	121
L1-L2	25.87	23.14	0.894	-0.8	91	0.8	111
L1.L3	26.57	24.64	0.927	-0.8	92	0.9	112
L1.L4	26.74	25.78	0.964	-0.7	93	1.0	113
L2-L3	29.16	27.65	0.948	-1.0	90	0.7	109
L2.L4	29.33	28.79	0.982	-0.9	91	0.9	111
L3-L4	30.03	30.30	1.009	-0.8	92	1.0	112
L1-L3	40.80	37.71	0.924	-0.9	91	0.8	111
L1-L2.L4	40.98	38.86	0.948	-0.8	92	0.9	112
L1.L3-L4	41.67	40.36	0.969	-0.8	92	1.0	112
L2-L4	44.27	43.37	0.980	-0.9	91	0.9	111
L1-L4	**55.91**	**53.44**	**0.956**	**-0.8**	**91**	**0.9**	**111**

Figure 21. Failure of BMD rule and selection of areas that have complied the rule

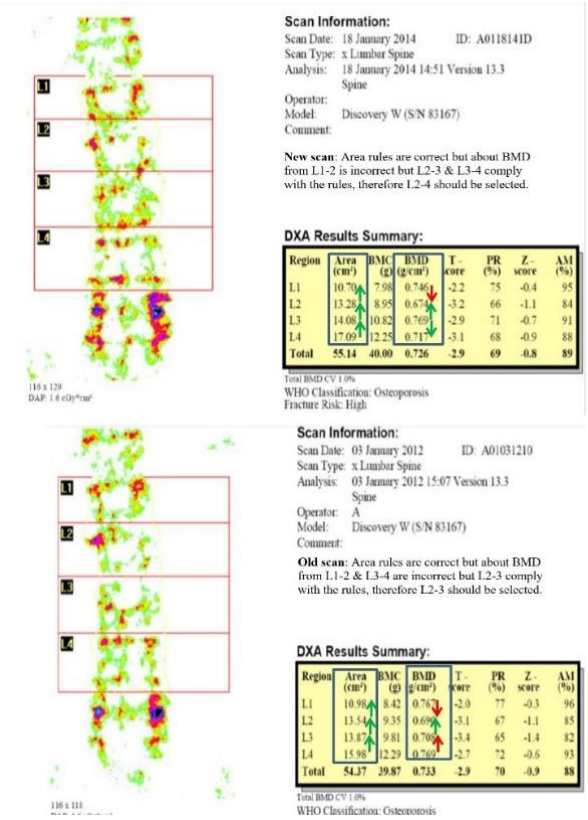


Figure 22. Selected best region for old & new spine scan

Figure 24. The difference between the two area in the selected common region, should not be more than 2 cm²

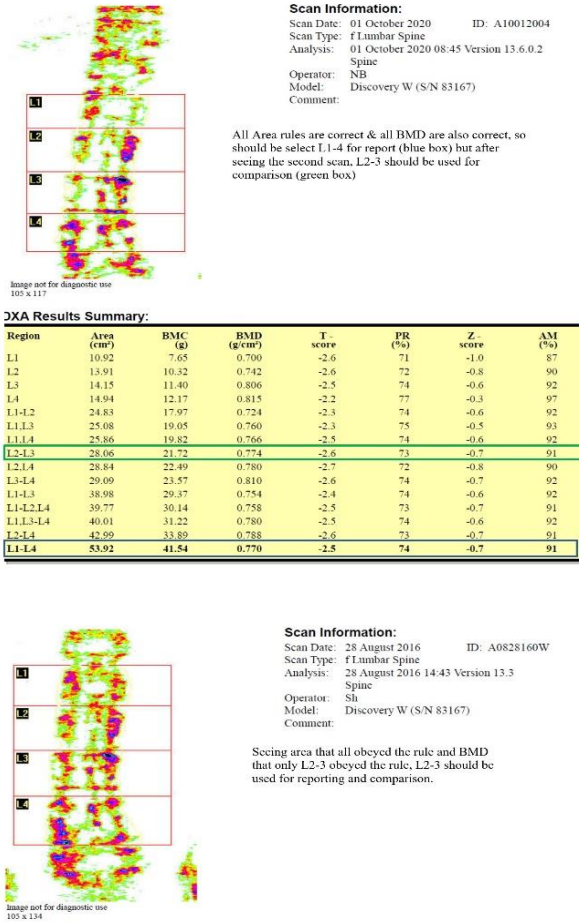


Figure 23. Common best region selection

difference by increasing or decreasing the area. Figure 27 shows the compared scan in hip region with high area difference and how to correct this problem [30,31].

Step V: interpretation

This step has 3 phases:

Phase 1: reporteach scan separately

In this phase based on the results (best selected region in step IV for spine, lower result between total and neck in hip scan and 1/3 of radius for forearm) of bone density are reported (Figure 28). It should be mentioned here that the final conclusionis the lowest result between spine, total and neck in hip, so that if, for example the spine is osteoporotic and the neck is normal, the final conclusion is osteoporosis (Figure 29).

Phase 2: determine percentage change between two scans:

In spine, after finding of best region or best vertebrae in previous step we can take percentage change between scans based this formula:

Cbmd= new the common selected region bmd - previous same the common selected region bmd/ previous same the common selected region bmd ×

100. For example, for case of Figure 22 after use of formula we reached to these results:
Cbmd (L2-3) = bmd (L2-3: 2020) – bmd (L2-3: 2016)/ bmd (L2-3: 2016) × 100
Cbmd (L2-3) = 0.774 - 0.813/0.813 × 100 Cbmd (L2-3) = - 4,8% ~ - 5%

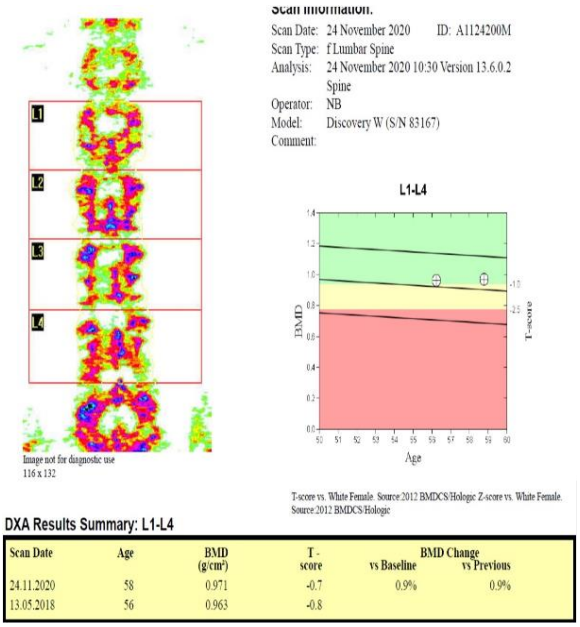


Figure 25. Usual device comparison

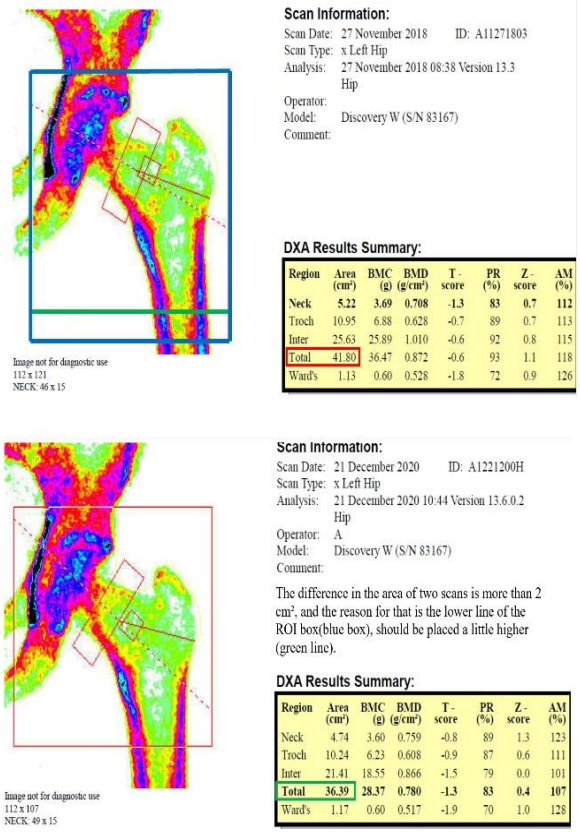


Figure 27. The area difference of two scans is more than the rule

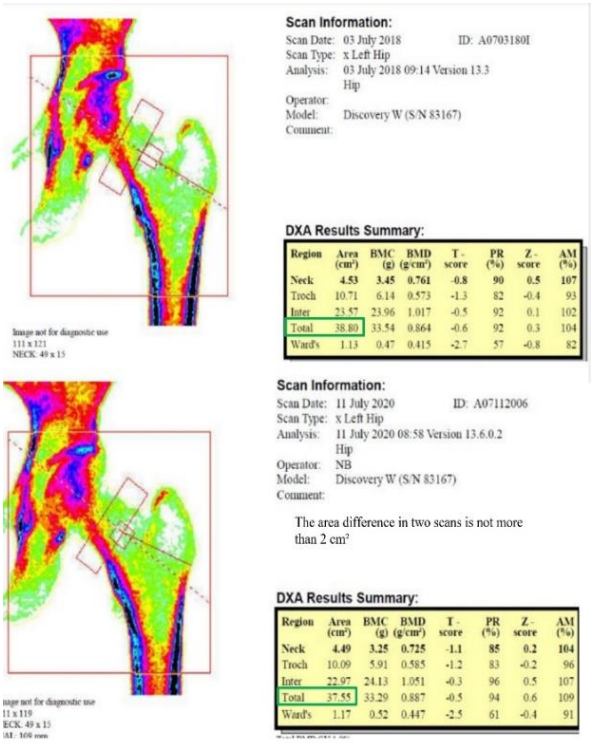


Figure 26. The difference in the appropriate area in the hip scan

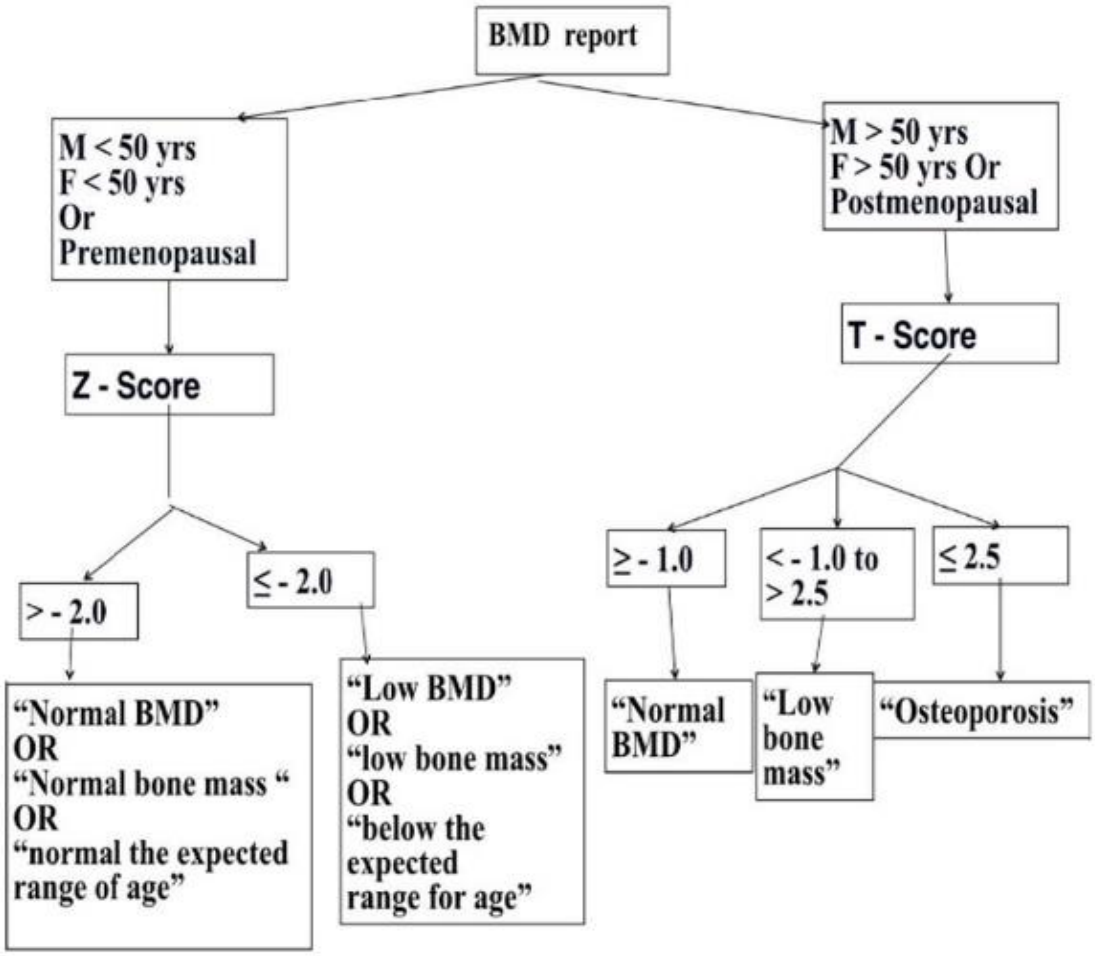


Figure 28. Algorithm of BMD report based the results of best region of spine and hip(total or neck), forearm(1/3 or 33%) & whole body (subtotal or TBLH)

Indication for densitometry:

Age>65 yrs

History of fragility fracture(s):

None

Bone mineral density results:

	BMD	*T- score*	*Z- score*	*Result*
Spine (L1-L4)[1]	0.809	**- 2.2**	0.3	*Low Bone Mass*
L-Hip (Total)[1]	0.549	**- 3.2**	- 1.4	*Osteoporosis*

Diagnosis by WHO criteria[2]:

According T-Score criteria this study indicates Osteoporosis.

Figure 29. Conclusion of BMD report as lowest result

Another way to measure Cbmd is to use standardized bmd or sBMD calculator. To interpret densitometry with two devices, it is necessary to first convert BMD into sBMD (Figure 30) which shows how to convert in three different devices used (we will fully discuss the use of SBMD and its value later in DCDD, SCDD, DCSD topics). When the information is put in the standardized BMD calculator, the result of the Figure 31 is obtained. In hip region, the best region for comparison is total hip and we can take percentage change between scans based on this formula:

Calculation of compared hip scan (based formula) = total hip bmd (new) - total hip bmd (previous) / total hip bmd (previous) × 100

For example, the calculation of compared scan in the hip scan based on the standardized BMD calculator for case Figure 32 is as follows:

= total hip (2020) – total hip (2018) / total hip (2018) × 100

= 0.887 - 0.864 / 0.864 × 100

= 2.7% ~ 3%

The bone density change percentage in the hip scan is often presented as a graph (Figure 33). Phase 3: Review of response to treatment: To check the response to treatment, we need at least two information:

1. Precision of the device
2. The Least Significance change (LSC) of the

It should be noted that the precision of the device is constant, but the LSC of the center is often variable, because the technicians and their ability can change over time.

How to calculate the summary LSC (sLSC) is as follows:

sLSC = (LSC C1 + LSC C2) × (precision C1 + precision C2)

Based on this, LSC C1 is the LSC of the first center, LSC C2 is the LSC of the second center, and precision C1 & C2 is the precision of the first and second centers. For example, with the following information, the result of the sLSC for hip & spine region is as follows:

Spine: LSC C1=1.8%, LSC C2= 2%, precision C1= 1%, precision C2= 1.2%

sLSC = (LSC C1 + LSC C2) × (precision C1 + precision C2)

= (1.8 + 2) × (1 + 1.2) = 8.36 ~ 8%

For SCSD, the precision of the device should be considered constant, and often LSC is often constant, so the formula changes as follows:

sLSC= LSC × precision (if LSC of first & second is constant)

sLSC= (LSC first/ old scan + LSC second/new scan) × precision (if LSC of first & second scans changes)

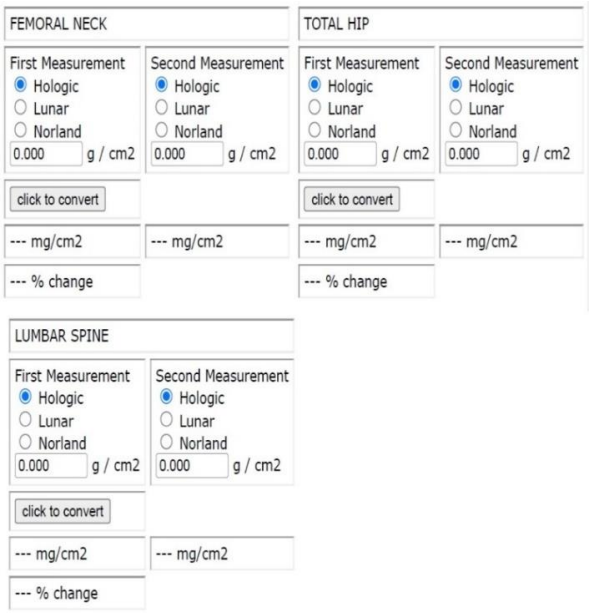


Figure 30: Standardized BMD

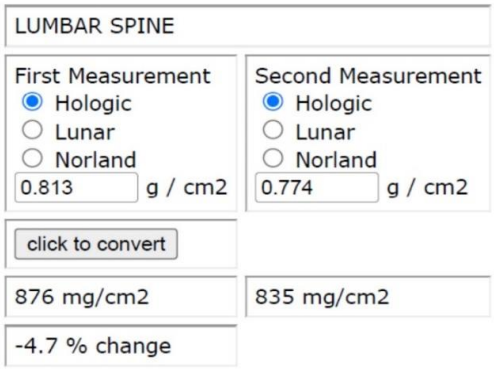


Figure 31. Use of standardized BMD for case of Figure 22

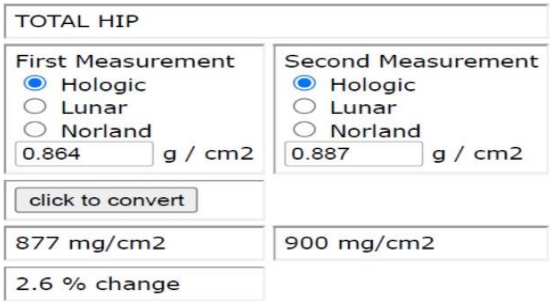


Figure 32. Hip scan compared BMD calculator

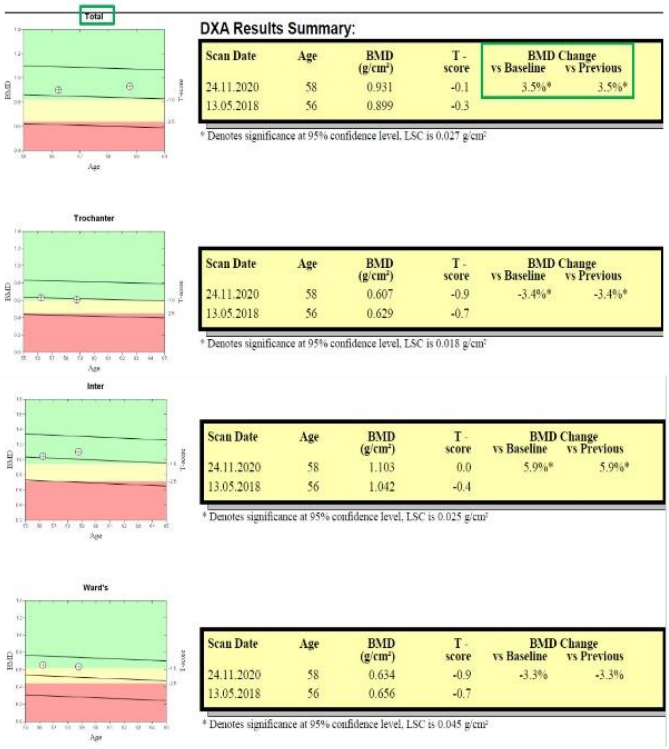


Figure 33. Usual device comparison in hip scan

Evaluation of treatment response is defined in three ways:

I. Complete response: when it increases more than the sLSC, but if there is no information, the value of 7% is the criterion, which indicates a greater increase.

II. Failure to response OR no response: when the reduction is more than sLSC or 7% in cases where we do not have the device & center information, it indicates a lack of response.

III. Partial response: which is when neither the increase nor the decrease is greater than sLSC, and in cases where we do not have device & center information, it is between +7% and -7%.

Of course, it should be known that the definition of lack of treatment response or refractory osteoporosis treatment is different, and based on this; the definition is one of the following three situations:

- Occurrence of two fragile (low trauma) vertebral fractures after 1 year of correct treatment or one vertebra & one another regions (forearm, rib, humerus, tibia, pelvis)
- Occurrence of fragility hip fracture after 1 year of correct treatment.
- Occurrence of one fragile vertebra fracture and decrease of above 7% BMD (with this sequence: spine, then hip (total, troch, intertrochanter/body) & forearm total) on SCSD after 1 year of correct treatment.

Treatment outcome	Description
Response	Stability or significant increase of BMD with appropriate change of bone turnover marker level
Success	BMD increase to T-score > −2.0 when treatment is started because of T-score ≤ −2.5, or T-score increase of at least 1.0 units when treatment is started with T-score > −2.5, and no recent fracture (e.g., within 3 years)
Failure	Two or more incident fractures; or one incident fracture with significant decrease in BMD and/or lack of appropriate change of bone turnover marker level; or significant decrease in BMD and lack of appropriate change of bone turnover marker level

Figure 34. Consequences of osteoporosis treatment [33]

There are other definitions for examining response to treatment, an example of which can be seen in Figure 34. Based on the mentioned rules, for the case, the spine changes -5% and hip +3% were calculated. The final response is “partial response”, which means that is not necessary to change the treatment [31-36].

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Conflict of Interests

The author declares no conflict of interest.

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