Facts and Artefacts in Bone Densitometry

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Abstract: Measurement of bone mineral density (BMD) with dual-energy X-ray absorptiometry (DXA) is widely used in clinical practice for the diagnosis of osteoporosis and assessment of fracture risk. However, variants and artefacts such as, osteophytes and metallic objects can affect the BMD results of the spine and hip. We demonstrate a spectrum of clinical examples that may impact on BMD evaluation. Recognition of such artefacts is important for the correct interpretation of these studies.

INTRODUCTION

Osteoporosis is a progressive skeletal disorder characterized by low bone mass, leading to increased bone fragility and risk of fracture. Although osteoporosis is common and predominantly affects elderly women it is increasingly being recognized in men and can affect all ages. Skeletal status can be measured by various methods such as single and dual X-ray absorptiometry, quantitative ultrasound and computed tomography. However, each technique has its own limitations related to the technique itself and the manner in which it is applied [1]. Currently, the best predictor of osteoporotic fracture risk is the level of bone mineral density (BMD) measured by dual X-ray absorptiometry (DXA) [2]. Bone densitometry is used to diagnose osteoporosis, assess fracture risk and is also useful for monitoring the response to therapeutic agents [3]. The results of spine and hip DXA scans are interpreted using the World Health Organisation (WHO) definition of osteoporosis as a T-score less than -2.5 [4,5]. The advantages of DXA include low radiation dose to patients, short scan times, high-resolution images, long-term stability of calibration and high precision [6]. For these reasons DXA scans are widely used in clinical practice to assist in making decisions regarding treatment, and to follow-up response to therapy. It is important that relevant clinical information is obtained to aid scan interpretation (Table **1**). Hospitals generally follow the international society for clinical densitometry (ISCD) guidelines [7].

Table 1. Relevant History with Relation to BMD Imaging and Interpretation

Patient identification
Sex
Age
Ethnicity
Height
Weight/ change of weight (±10kg)
Clinical details/history/indication
Medications/duration/dose
History of spine surgery/fracture/trauma
Artefacts
Recent contrast related imaging (barium/CT)

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Analysis of the data from DXA is computerised and almost completely automated, but operator input is required during the performance of several key steps, such as the size and placement of analysis regions [8] Fig. (**1**). The interpretation of the BMD result depends on several factors such as age, sex and ethnic origin. Factors such as patient positioning, scan acquisition mode and data analysis are important in obtaining an optimal study [8]. Operator errors may lead to errors in the interpretation of the results [9,10]. The most frequent operator errors are misplaced region of interest (ROI), misplaced intervertebral disk space markers, mislabeled vertebrae and oversized ROI's [8]. Reports suggest that operator-dependent errors due to the incorrect placement of a ROI or the presence of artefacts result in incorrect interpretation in 2% of the cases [9]. Operator-dependent analysis errors are potentially of greater magnitude than the machine's intrinsic precision errors for both the hip and the spine [8].

Artefacts are of various types. They can be found in the internal organs or structures or externally placed or worn by the patients. The DXA scan images should be assessed for visible artefacts such as overlying metal objects, and less frequently retained contrast after barium or CT scan [8-10] Figs. (**2-6**). Metallic implants after orthopedic surgery also artificially elevate the BMD scores Figs. (**7-9**).

Disease process such as degenerative changes, soft tissue calcification, severe scoliosis, osteophytes, and compression fracture can artefactually increase the values [8-10] Figs. (**10-14**). However, when gross sclerotic lesions are identified, conditions such as Paget's disease and bone metastases should also be excluded Figs. (**15**). Reports indicate that aortic calcifications superimposed over the spine cause only a minor increase in calculated bone mineral density [12-14] Fig. (**16**).

It is also important to note that artefacts and variants not only elevate the BMD values, but may also lower the BMD (absent bone after surgery/laminectomy) [8-11] Fig. (**17**) (Table **2**). In general if artefacts overlie part of a vertebra or adjacent soft tissue, one should exclude the entire vertebra from the analysis. A spine scan should include at least two evaluable vertebrae. In the hip, various conditions such as Paget's disease, vascular calcifications and osteoarthritis can increase and surgery may decrease the BMD values [9, 15]. In such cases the other hip or an alternative site such as the forearm should be used for analysis and interpretation Fig. (**18**).

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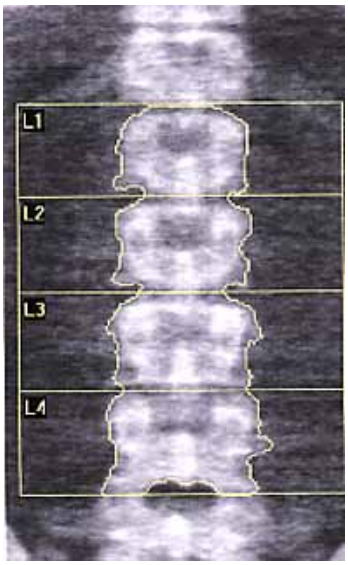
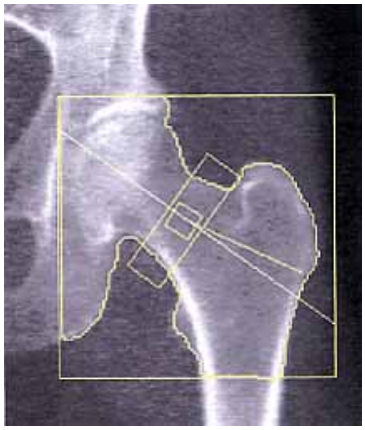


1a



1b

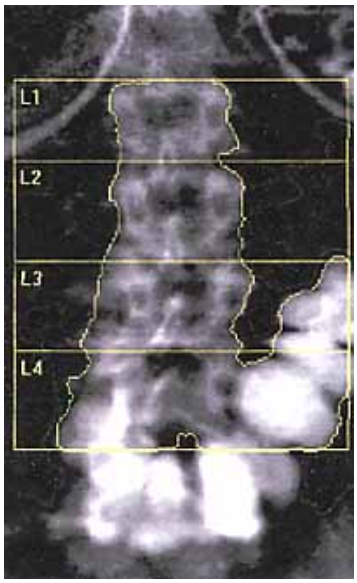
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	1.019	0.1	0.1
L2	1.079	-0.1	-0.1
L3	1.129	0.2	0.2
L4	1.074	-0.6	-0.6
Total	1.078	-0.1	-0.1

1c

Region	BMD (g/cm^2)	T-Score	Z-Score
Neck	0.958	0.2	0.6
Troch	0.889	0.9	1.1
Inter	1.297	0.6	0.6
Total	1.134	0.7	0.8
Ward's	0.860	0.5	1.2

1d

Fig. (1a,b). Normal DXA scans free of any artefacts showing the standard regions of interest (ROI). **1a**. DXA scan of spine showing outlining of vertebrae. 1b.DXA scan of hip showing ROI. Results are also provided for spine (Fig. **1c**) and hip regions (**1d**).



2a

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.793	-1.2	0.2
L2	0.942	-0.8	0.7
L3	1.133	0.4	2.0
L4	1.502	3.5	5.2
Total	1.197	1.4	2.9

2b

Fig. (2a,b). DXA spine scan of a 61-year-old lady. The patient recently had a CT scan of abdomen with contrast. The values at L3 and L4 are artificially elevated and the L1-L2 BMD values may be affected too. Patients should be rescanned in 3 months time to allow contrast to completely clear.

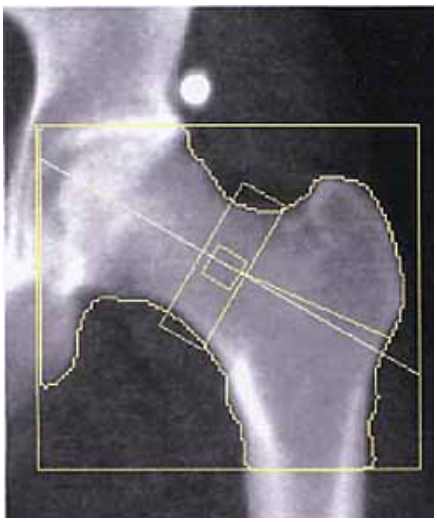
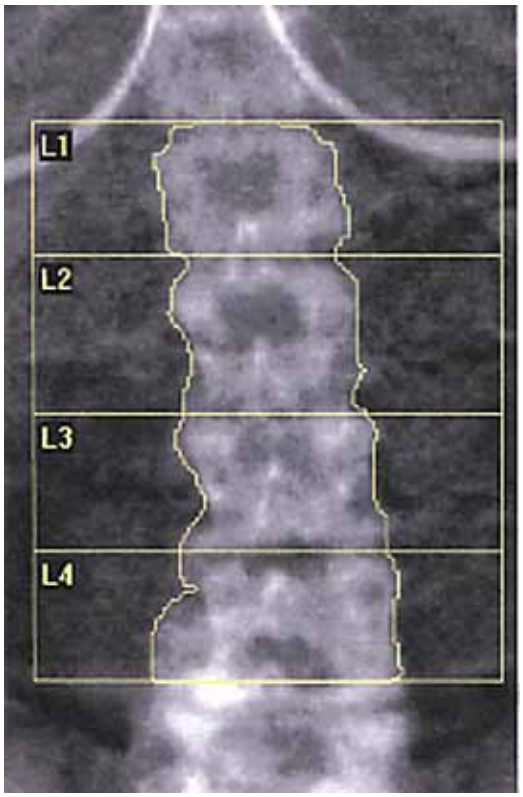
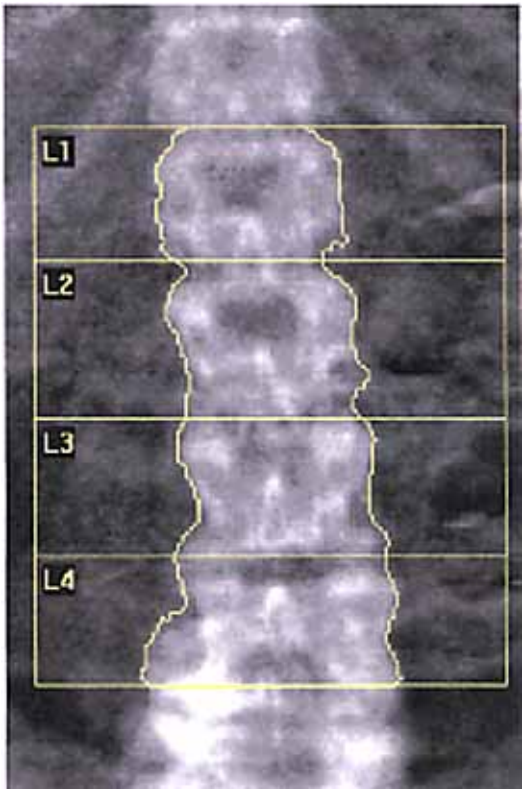


Fig. (3). DXA hip scan of a 27-year-old male. The scan shows a jeans stud in the rear pocket. There is no problem if the metal artefact is outside the rectangular ROI box. However, a metal artefact within the rectangular ROI box superimposed on bone will affect the BMD measurements directly. An artefact superimposed over soft tissue within the ROI box may indirectly affect the BMD measurements by altering the soft tissue reference baseline.

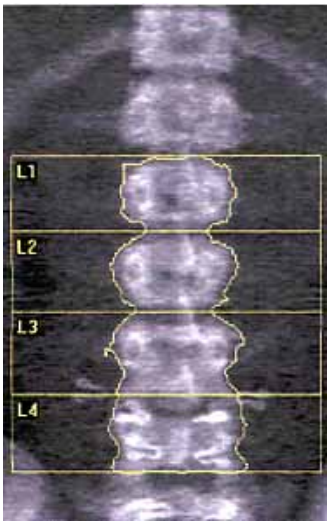


4a

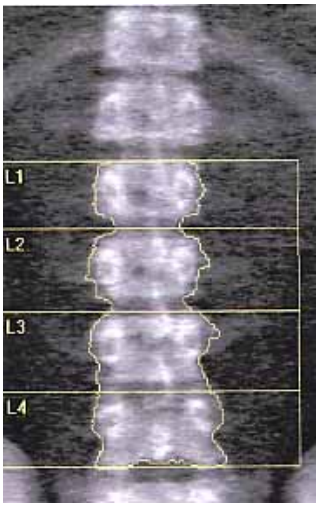


4b

Fig. (4a). 55-year-old lady with under wired garment (L1 region) affecting soft tissue. (**4b**) The DXA scan should be performed after removal of the artefact.



5a



5b

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.967	-0.4	-0.2
L2	0.989	-1.3	-1.0
L3	1.028	-1.5	-1.2
L4	1.088	-1.2	-1.0
Total	1.023	-1.2	-0.9

5c

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.990	-0.2	-0.0
L2	0.986	-1.3	-1.1
L3	1.026	- 1.5	-1.3
L4	0.991	-2.1	-1.9
Total	0.999	-1.4	-1.1

5d

Fig. (5). 25-year-old lady with suspender belt on (a) and suspender belt off (b). Fig. **5c**. The L4 vertebral values are artificially elevated by metal superimposed over the bone. Following removal of the belt, the result for L4 is significantly lower (Fig. **5d**) [Please note this case is difficult to analyse as the patient has six lumbar vertebrae and a decision has to be made as to where L1 is chosen].

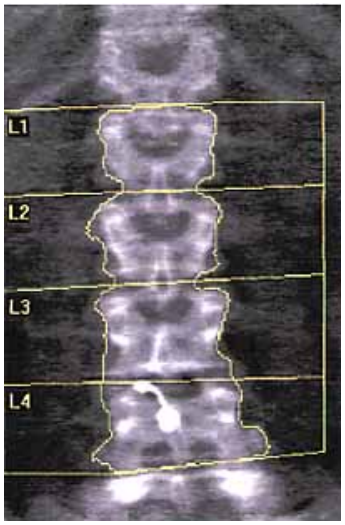
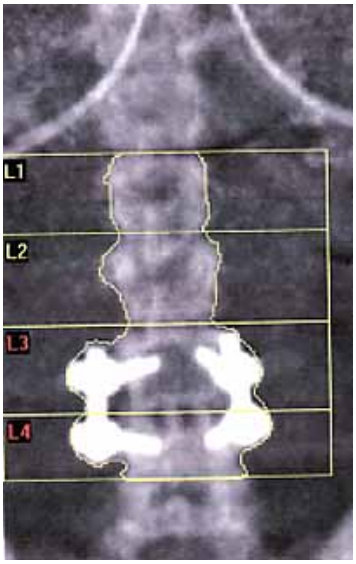


Fig. (6). DXA scan of a 49-year-old lady with a navel ring. In cases like these if the navel ring cannot be removed, it is essential to exclude region/vertebra with the metal artefact.



7a

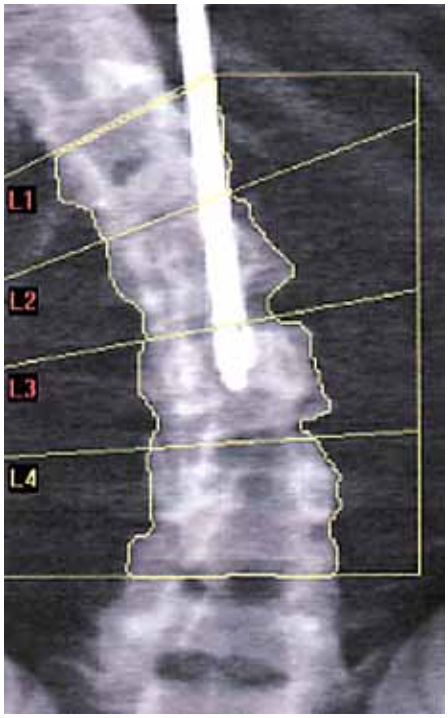
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.713	-1.9	-1.2
L2	0.801	-2.1	-1.3
L3	2.173	9.9	10.7
L4	2.357	11.3	12.1
Total	1.670	5.7	6.4

7b

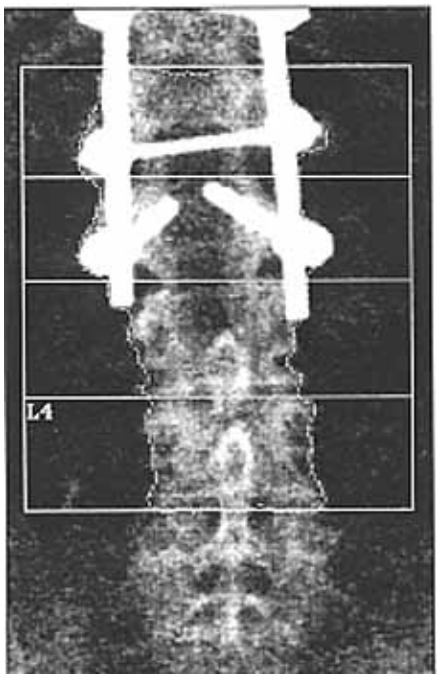
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.713	-1.9	-1.2
L2	0.801	-2.1	-1.3
Total	0.762	-2.0	-1.2

7c

Fig. (7a). 58-year-old lady with surgical prosthesis to the lower lumbar vertebrae. As the L3-4 BMD values were artificially elevated (Fig. **7b**) the scan was reported by taking only L1-2 values, which confirm osteopenia (Fig. **7c**).



8a

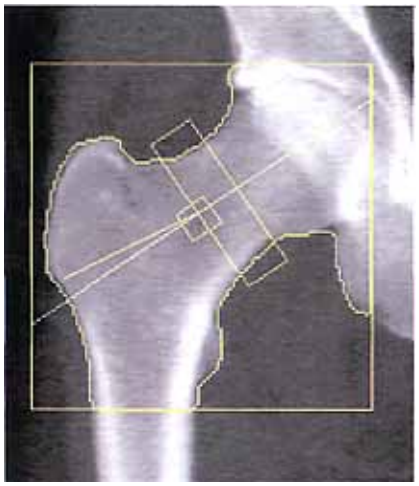


8b

Fig. (8a). DXA scan of a 46-year-old male with an orthopaedic fixation device, which gave artificial elevated BMD values. Fig. (**8b**). DXA scan of a 59-year-old lady with an orthopaedic fixation device, which gave artificial elevated BMD values.

It is essential to exclude region/vertebrae with artefacts. In both these cases only theL4 vertebra was evaluable.

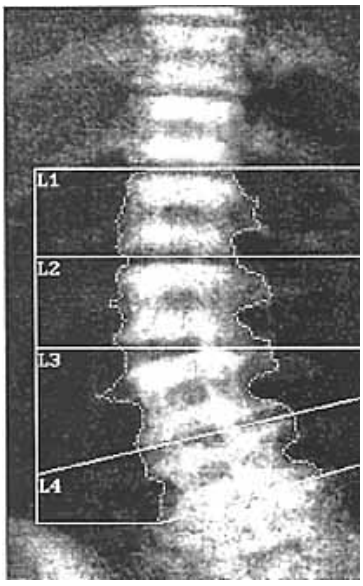
In general it is recommended that spine DXA interpretation should be based on at least two evaluable vertebrae. In cases like this BMD evaluation will depend upon measurements at other sites such as hip ± forearm.



9a

9b

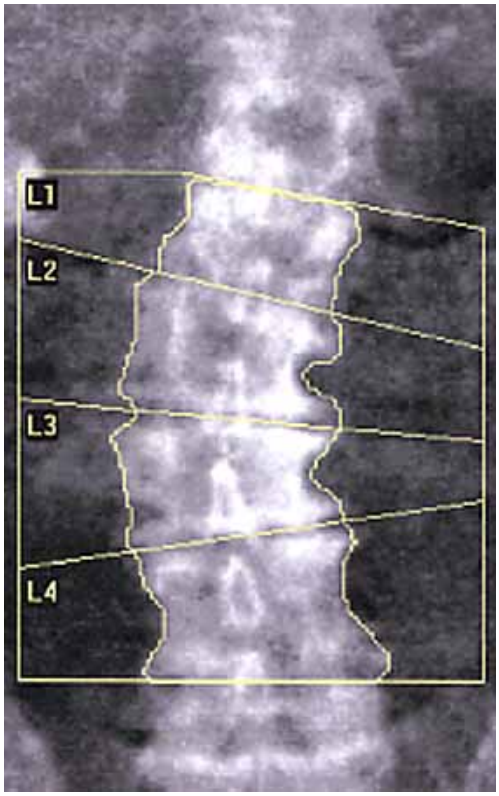
Fig. (9a,b). DXA scan of a 49-year-old male with previous history of metallic implant to the left hip (Fig. **9b**). There are subtle sclerotic changes in the left hip. It is therefore preferable to use the other hip (**9a**).



10a

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	1.896	8.8	10.8
L2	1.896	7.8	10
L3	2.117	9.4	11.7
L4	2.295	10.7	13.1
Total	2.048	9.1	11.3

Figs. (10a,b). DXA scan of a 72-year-old lady with low back pain. The spine scan shows sclerotic endplates consistent with osteopetrosis. BMD values in the spine are significantly elevated.

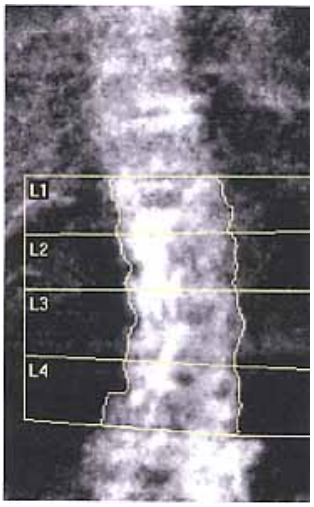


11a

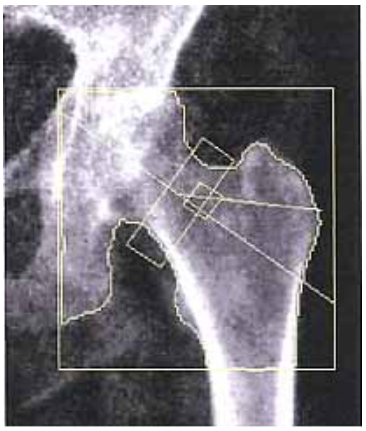
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	1.041	1.1	3.1
L2	1.087	0.5	2.8
L3	1.167	0.8	3.2
L4	1.112	-0.0	2.4
Total	1.106	0.5	2.8

11b

Fig. (11a). DXA scan of a 73-year-old lady with kypho-scoliosis in the lumbar vertebrae. The BMD results show elevated values due to degenerative changes (Fig. **11b**). This is a common problem in elderly patients. Affected vertebrae should be excluded from analysis and the spine may not be evaluable when there are extensive degenerative changes.



12a



12b

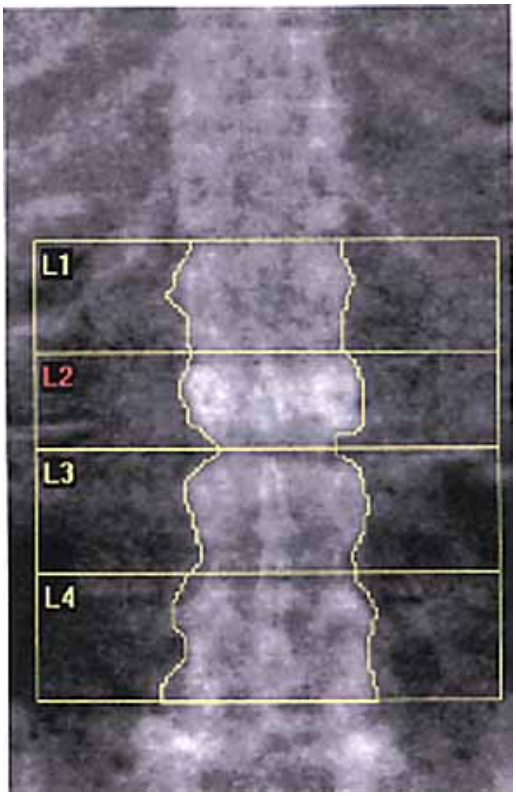
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	1.005	0.7	2.2
L2	1.028	-0.0	1.7
L3	0.932	-1.4	0.4
L4	1.1016	-0.9	0.9
Total	0-.993	-0.5	1.2

12c

Region	BMD (g/cm^2)	T-Score	Z-Score
Neck	0.464	-3.5	-2.0
Troch	0.491	-2.1	-1.1
Inter	0.617	-3.1	-2.2
Total	0.572	-3.0	-1.9
Ward's	0.274	-3.9	-1.7

12d

Fig. (12a). DXA scan of a 64-year-old lady with back pain. The scan shows degenerative changes/scoliosis in the spine with elevated BMD values (Fig. **12c**). However, the left hip values confirm osteoporosis (Fig. **12b&d**). As in Fig. (**11**), the spine values are not of diagnostic value in view of the extensive degenerative changes.



13a

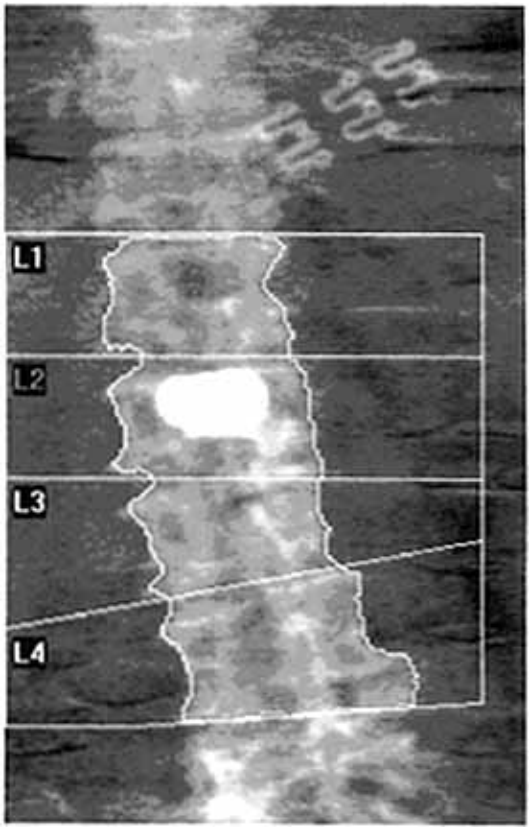
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.473	-4.9	-3.5
L2	0.829	-2.7	-1.2
L3	0.650	-4.9	-3.3
L4	0.685	-4.9	-3.2
Total	0.656	-4.5	-2.9

13b

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.479	-4.9	-3.5
L3	0.658	-4.8	-3.2
L4	0.694	-4.8	-3.1
Total	0.621	-4.9	-3.3

13c

Fig. (13a). DXA scan of a 60-year-old lady. The scan shows vertebral collapse at the level of L2 vertebra (Fig. **13b**). The values of L2 were not included in the final report. The spine T-score confirms the presence of osteoporosis (Fig. **13c**).



14a

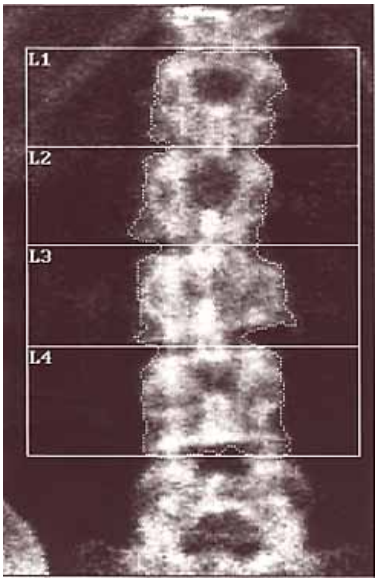
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.585	-3.1	-0.9
L2	1.951	8.4	10.8
L3	0.784	-2.7	-0.2
L4	0.745	-3.4	-0.7
Total	1.026	-0.2	2.3

14b

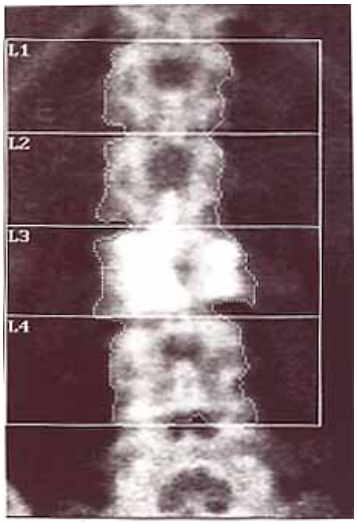
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.585	-3.1	-0.9
L3	0.784	-2.7	-0.2
L4	0.745	-3.4	-0.7
Total	0.708	-3.1	-0.6

14c

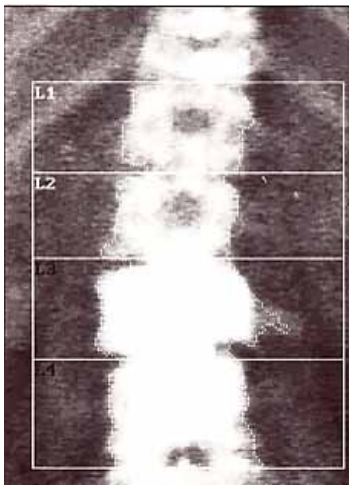
Fig. (14a). DXA scan showing vertebroplasty at the level of L2 vertebra. The values of L2 (Fig. **14b**) were not included in the final analysis (Fig. **14c**) and T-score of the rest of the spine confirms osteoporosis. As always it is essential to exclude vertebrae with artefacts.



15a



15b



15c

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.588	-3.1	-2.2
L2	0.675	-3.2	-2.2
L3	0.798	-2.6	-1.5
L4	0.824	-2.7	-1.6
Total	0.731	-2.9	-1.8

15d

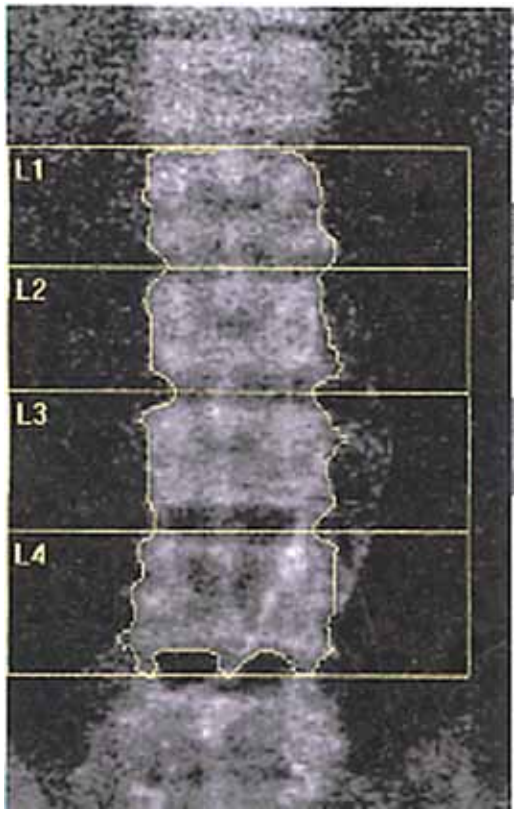
Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.621	-2.8	-1.8
L2	0.681	-3.2	-2.1
L3	1.288	1.9	3.0
L4	0.823	-2.7	-1.5
Total	0.870	-1.6	-0.5

15e

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.627	-2.7	-1.7
L2	0.689	-3.1	-1.9
L3	1.853	7.0	8.2
L4	1.419	2.8	4.0
Total	1.243	1.8	3.0

15f

Fig. (15 a, b&c). DXA scans of a 66 year-old lady with breast cancer. Serial follow up scans at annual intervals show progressive sclerotic changes in the spine due to metastatic disease resulting in elevation of T-scores of the L3-L4 lumbar vertebrae (Fig **15d-f**).

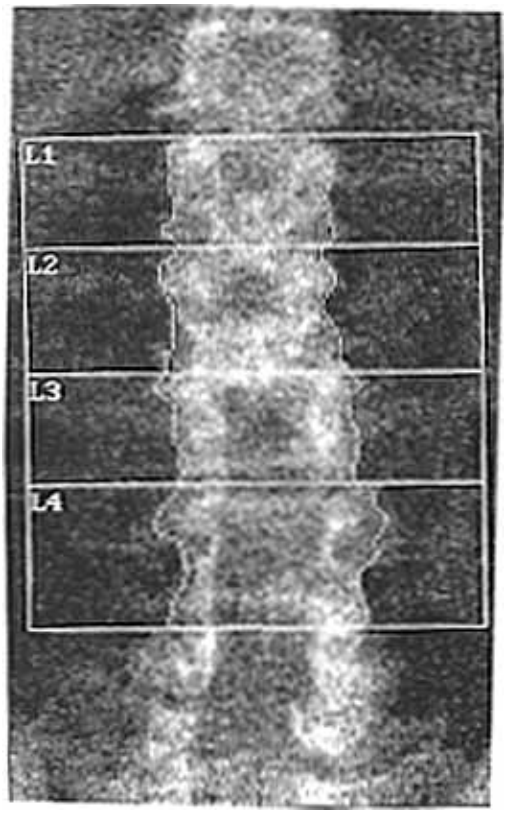


16a

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.776	-2.1	-1.8
L2	0.813	-2.6	-2.2
L3	0.689	-3.8	-3.4
L4	0.714	-3.9	-3.6
Total	0.744	-3.2	-2.8

16b

Fig. (16a &16b). DXA scan showing a calcified aorta in a 49-year-old male. The affected vertebral values should probably not be used although in general aortic calcification seems to make little difference to overall BMD.



17a

Region	BMD (g/cm^2)	T-Score	Z-Score
L1	0.800	-1.1	-0.5
L2	0.965	-0.6	1.2
L3	0.821	-2.4	-0.5
L4	0.776	-3.0	-1.0
Total	0.837	-1.9	-0.0

17b

Fig. (17a,b). DXA scan of a patient after laminectomy. The T scores reflect this with reduced values in L3-4 vertebra.

Table 2. Conditions Affecting BMD Values [9-11]

Common causes for artificially high bone mineral density	Common causes for artificially low bone mineral density
Metabolic bone disorders (Hypervitaminosis [A/D], fluorosis, heavy metal poisoning etc)	Surgical (Laminectomy)
Degenerative disease/arthritis/ vertebral collapse	Wheel chair bound patients (for hip BMD)
Bone Metastases	
Paget's disease	
Dysplasias and dysostoses (Craniodiaphysial dysplasia, osteopetrosis, melorheostosis,	
Engelmann disease etc)	
Metallic implants/prosthesis (surgical)	
Metallic ornaments	
(Navel ring)	
Diffuse idiopathic skeletal hyperostosis (DISH)	
Osteomyelitis	
Strontium ranelate treatment	

18a

Region	BMD (g/cm^2)	T-Score	Z-Score
Neck	1.288	3.9	5.1
Troch	0.751	0.5	1.2
Inter	1.137	0.2	0.8
Total	1.045	0.8	1.6
Ward's	0.892	1.3	3.2

18b

Fig. (18a,b). DXA scan of a lady with severe osteoarthritis with artificial elevated BMD values in the right hip. If the spine and other hip are affected too, the forearm values should be used for scan interpretation.

CONCLUSION

The presence of artefacts are unavoidable, not only in DXA, but also in all other diagnostic or imaging modalities. Familiarity with pitfalls, variants and recognition of artefacts will lead to better interpretation without erroneous results. Factors such as patient positioning, scan acquisition mode, quality and data analysis are also crucial for correct interpretation of the findings. Careful scrutiny of DXA scan images and obtaining appropriate history from the patients will help in anticipating/ recognizing these artefacts.

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