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Prevalence and type of errors in dual-energy x-ray absorptiometry

Carmelo Messina · Michele Bandirali · Luca Maria Sconfienza · Nathascja Katia D'Alonzo · Giovanni Di Leo · Giacomo Davide Edoardo Papini · Fabio Massimo Ulivieri · Francesco Sardanelli

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Abstract
Objectives Pitfalls in dual-energy x-ray absorptiometry (DXA) are common. Our aim was to assess rate and type of errors in DXA examinations/reports, evaluating a consecutive series of DXA images of patients examined elsewhere and later presenting to our institution for a follow-up DXA.

Methods After ethics committee approval, a radiologist retrospectively reviewed all DXA images provided by patients presenting at our institution for a new DXA. Errors were categorized as patient positioning (PP), data analysis (DA), artefacts and/or demographics.

Results Of 2,476 patients, 1,198 had no previous DXA, while 793 had a previous DXA performed in our institution. The remaining 485 (20 %) patients entered the study (38 men and 447 women; mean age ± standard deviation, 68±9 years). Previous DXA examinations were performed at a total of 37 centres. Of 485 reports, 451 (93 %) had at least one error out of a total of 558 errors distributed as follows: 441 (79 %) were DA, 66 (12 %) PP, 39 (7 %) artefacts and 12 (2 %) demographics.

Conclusions About 20 % of patients did not undergo DXA at the same institution as previously. More than 90 % of DXA presented at least one error, mainly of DA. International Society for Clinical Densitometry guidelines are very poorly adopted.

Key Points
- *More than 90 % of DXA examinations/reports presented one or more errors.*
- *About 80 % of errors are related to image data analysis.*
- *Errors in DXA examinations may have potential implications for patients' management.*

Keywords Osteoporosis · Dual-energy x-ray absorptiometry · Bone mineral density · Densitometry · Pitfalls

C. Messina (✉) · M. Bandirali · N. K. D'Alonzo
Scuola di Specializzazione in Radiodiagnostica, Università degli Studi di Milano, via Festa del Perdono 7, 20122 Milano, Italy
e-mail: carmelomessina.md@gmail.com

M. Bandirali
e-mail: michele.bandirali@hotmail.it

N. K. D'Alonzo
e-mail: natdalonzo@gmail.com

L. M. Sconfienza · G. Di Leo · G. D. E. Papini · F. Sardanelli
Unità di Radiologia, IRCCS Policlinico San Donato, via Morandi 30, 20097 San Donato Milanese, Italy

L. M. Sconfienza
e-mail: io@lucasconfienza.it

G. Di Leo
e-mail: gianni.dileo77@gmail.com

G. D. E. Papini
e-mail: docgde@gmail.com

F. Sardanelli
e-mail: francesco.sardanelli@unimi.it

L. M. Sconfienza · F. Sardanelli
Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, via Morandi 30, 20097 San Donato Milanese, Italy

F. M. Ulivieri
Mineralometria Ossea Computerizzata e Ambulatorio Malattie Metabolismo Minerale e Osseo, Servizio di Medicina Nucleare, IRCCS Fondazione Ca' Granda Ospedale Maggiore Policlinico, via Francesco Sforza 9, 20122 Milano, Italy
e-mail: ulivieri@gmail.com

Introduction

Osteoporosis is a skeletal disorder characterized by low bone mass and microarchitectural deterioration of bone tissue, determining an increase in bone fragility and predisposition to fragility fractures [1]. As a result of population ageing,

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osteoporosis is becoming an emerging medical and socioeconomic threat: hip and vertebral fractures are associated with increased mortality [2].

Osteoporosis is commonly evaluated through a quantitative assessment of bone mineral density (BMD), which represents a major determinant of bone strength [3]. In daily practice, BMD is more often described as a T or Z score, both of which are units of standard deviation (SD). The T score describes the number of SDs by which the BMD in an individual differs from the mean value expected in young healthy individuals, while Z score describes the number of SDs by which the BMD in an individual differs from the mean value expected for age and sex. According the World Health Organization, osteoporosis is defined as a T score less than or equal to −2.5 [4].

Several techniques allow for the measurement of BMD [5], the most widely used being dual energy x-ray absorptiometry (DXA) which is considered the standard of care for diagnosing the disease [6]. DXA has high reproducibility and is capable of detecting very small BMD variations in the range of 1.0–1.5 % for lumbar spine and femurs [7]. This is of great relevance, as BMD variation between two subsequent examinations (usually after 1 or 2 years) is very small (1–2 %) [8]. As a consequence, great attention should be paid to reproducibility and quality controls.

To achieve high reproducibility, each DXA system manufacturer provides a detailed technical manual in which all necessary indications are included. Furthermore, the International Society for Clinical Densitometry (ISCD) periodically releases official positions to support physicians in BMD measurement and data interpretation [9]. Disregarding these criteria may lead to improper diagnosis, treatment and follow-up of patients who routinely undergo DXA. In the literature, two descriptive reviews of DXA errors in the adult population were published in 2004 by Watts [10] and in 2013 by Garg and Kharb [11]. They reported some of the most common errors in positioning, image analysis and interpretation for both femur and lumbar spine DXA examinations. However, no data exist regarding the rate and type of these errors in clinical practice.

The aim of this study was to assess rate and type of errors in DXA examinations and reports, evaluating a consecutive series of DXA images of adult patients examined elsewhere and later presenting to our institution for a follow-up DXA.

Materials and methods

Study population

This retrospective study was approved by the institutional review board. During 2012, 2,476 patients underwent DXA at our university hospital. Of them, 1,198 patients did not provide any previous DXA report while 793 patients had had a previous DXA performed at our institution. The remaining 485 patients entered our analysis. They were 447 women and 38 men; age was 68±9 years (mean±standard deviation).

Categorization of errors

A radiologist with 4 years of experience in DXA and osteoporosis management reviewed all DXA images to check for adherence to correctness criteria as reported in ISCD 2013 guidelines [9]. Also, the user manuals of the main DXA system manufacturers (Hologic, Lunar and Norland) were considered. According to Watts [10] and Garg and Kharb [11], errors were classified in the following four categories:

- *Patient positioning*: errors related to correct positioning of lumbar spine or femur. The lumbar spine is correctly positioned when straight, unrotated and centred in the image field (with balanced soft tissue on each side). Also, a correct scan should include part of the last thoracic vertebra with ribs, as well as the ischium of the pelvis. For correct hip positioning, the patient should keep the femur straight with the shaft parallel to the image edge and an internal rotation of 25°, obtained by the use of positioning devices [12].
- *Data analysis:* post-acquisition analysis errors, such as the definition of the analysis box, inclusion or exclusion of vertebrae, and those related to misplacement of specific analysis box of femurs.
- *Presence of artefacts:* artefacts (metallic devices, surgical clips or vascular prosthesis, etc.) that may alter BMD and need to be excluded from the analysis.
- *Demographics*: inaccuracies in date of birth, gender and ethnicity that are crucial data to calculate Z and T scores.

Statistical analysis

Data are presented as mean±standard deviation or as median and interquartile (IQ) range according to their distribution. Error frequency was given separately for lumbar spine and femur. The presence in each centre of a clinical unit dedicated to the diagnosis and treatment of osteoporosis was recorded.

All calculations were performed using an Excel electronic database (Microsoft Excel® 2010, Redmond, WA).

Results

Distribution of examinations

Of the 2,476 patients who presented to our institution for a DXA examination, 485 (20 %) were previously evaluated at a

different centre. In particular, these 485 examinations were performed from 2008 to 2011 at 37 different centres in the Milan area (Lombardy, Italy) with 13±8 examinations (mean ±standard deviation) per centre. With reference to the current DXA examination performed at our institution, previous DXA were performed 1 year before in 20 patients (4.1 %), 2 years before in 175 (36.1 %), 3 years before in 259 (53.4 %) or 4 years before in 31 (6.4 %).

Out of 485 analysed reports, 70 (14 %) were performed on the lumbar spine, 107 (22 %) on one femur, and 308 (64 %) on both lumbar spine and one femur.

Distribution of errors

Out of 485 reports, 34 (7 %) had no errors, 360 (74 %) had one error, 75 (16 %) had two errors, and 16 (3 %) had three errors. Overall, 451/485 (93 %) had at least one error. We found 295 (53 %) errors in lumbar spine reports and 263 (47 %) in femur reports, 558 errors in total. Errors were distributed as follows: patient positioning, 12 % (66/558); data analysis, 79 % (441/558); presence of artefacts, 7 % (39/558); and demographics, 2 % (12/558).

Regarding the lumbar spine, the most frequent error concerned the inclusion or exclusion of vertebrae (136/295, 46 %); regarding the femur, it was a poor definition of the analysis box (79/263, 30 %). Further details are reported in Table 1.

Limiting our analysis only to 20 centres that provided at least ten DXA reports, the rate of previous scans with at least one error ranged from 40 % to 100 %. Among these 20 centres, eight had a clinical unit dedicated to the diagnosis and treatment of osteoporosis and were assumed to have longstanding experience in DXA examinations.

Figures 1, 2, 3, 4 and 5 illustrate some errors we found in our study.

Discussion

The main finding of our work is that more than 90 % of DXA examinations performed in clinical practice are affected by at least one error, with potential relevant implications for patients' osteoporosis diagnosis and management. Except for one centre, a high rate of errors was observed even in hospitals with a clinical osteoporosis unit.

Previous studies explored the frequency of errors in analysis of DXA in children [13–15]. In the paediatric population, DXA interpretation is further complicated by the necessity to adopt the Z score (that is calculated with reference to a healthy population of the same age, gender and ethnicity) instead of T score, representing an additional source of error [16]. In 2004, Gafni and Baron [15] reviewed the DXA examinations of 34 children to assess accuracy and presence of pitfalls, reporting a high rate of interpretation errors (88 %). The most frequent error was the use of T score instead of Z score (62 %), followed by the use of inappropriate BMD reference database (21 %) and incorrect bone mapping (21 %). To our knowledge, no data are available on the frequency of DXA errors in the adult population.

In our 1-year consecutive series of previous DXA performed outside our institution, 93 % of examinations

Table 1 Details of errors detected in outsource DXA reports of 485 patients

Lumbar spine	*N* (%)	Femur	*N* (%)
Data analysis	243 (44 %)	Data analysis	198 (35 %)
Inclusion or exclusion of vertebrae	136 (24 %)	Incorrect analysis box	79 (14 %)
Incorrect analysis box	38 (7 %)	Ischium not excluded	67 (12 %)
Incorrect placement of intervertebral lines	30 (5 %)	Bone mapping inaccuracies	52 (9 %)
Misidentified vertebral levels	22 (4 %)		
Bone mapping inaccuracies	17 (3 %)		
Patient positioning	29 (5 %)	Patient positioning	37 (7 %)
Not centred/tilted spine	19 (3 %)	Excessive abduction/adduction	22 (4 %)
Incorrect spine positioning	10 (2 %)	Suboptimal internal rotation	10 (2 %)
		Incorrect femur positioning	5 (1 %)
Presence of artefacts	18 (3 %)	Presence of artefacts	21 (4 %)
External	8 (1 %)	Metallic	15 (3 %)
Metallic	6 (1 %)	External	6 (1 %)
Movement	4 (1 %)		
Demographics	5 (1 %)	Demographics	7 (1 %)
Wrong ethnicity	5 (1 %)	Wrong ethnicity	7 (1 %)
Total	295 (53 %)		263 (47 %)

DXA dual-energy x-ray absorptiometry

contained at least one error. The most frequent error (79 %) was inappropriate analysis during the image processing. Usually, densitometers automatically detect the bone map using an algorithm distinguishing density gradients between soft tissue and bone. The software sets up regions of interest, both in spine and femurs. In case of incorrect mapping, drawing or misplacement of analysis boxes, the operator should manually correct inaccuracies, also excluding abnormal vertebrae from analysis. Errors that occurred in any step of this procedure were classified in this study as data analysis errors, with a potential impact on BMD. Since only reports (printouts) and not entire examinations were analysed, we could not estimate the clinical implication of these errors.

Structural changes, such as osteophytes, calcifications or fractures are more common in the lumbar spine than proximal femur [11] and potentially determine an artefactual increment of BMD [10, 17]. In particular, the presence of spinal degenerative disease is the most common structural change, being able to erroneously increase BMD even by one or more T score units [18, 19]. For this reason, ISCD guidelines suggest to exclude abnormal vertebrae from analysis when the T score difference between the vertebra under evaluation and those adjacent is larger than one. A minimum of two vertebrae have to be analysed to obtain reliable results; if only one evaluable vertebra remains after the exclusion process, diagnosis should be done on a different skeletal site [9]. Among analysis errors, inaccuracies in the inclusion or exclusion of such vertebrae were the most frequent in our series (see Table 1).

Patient positioning is the most important aspect of the acquisition procedure and misplacement is also a very

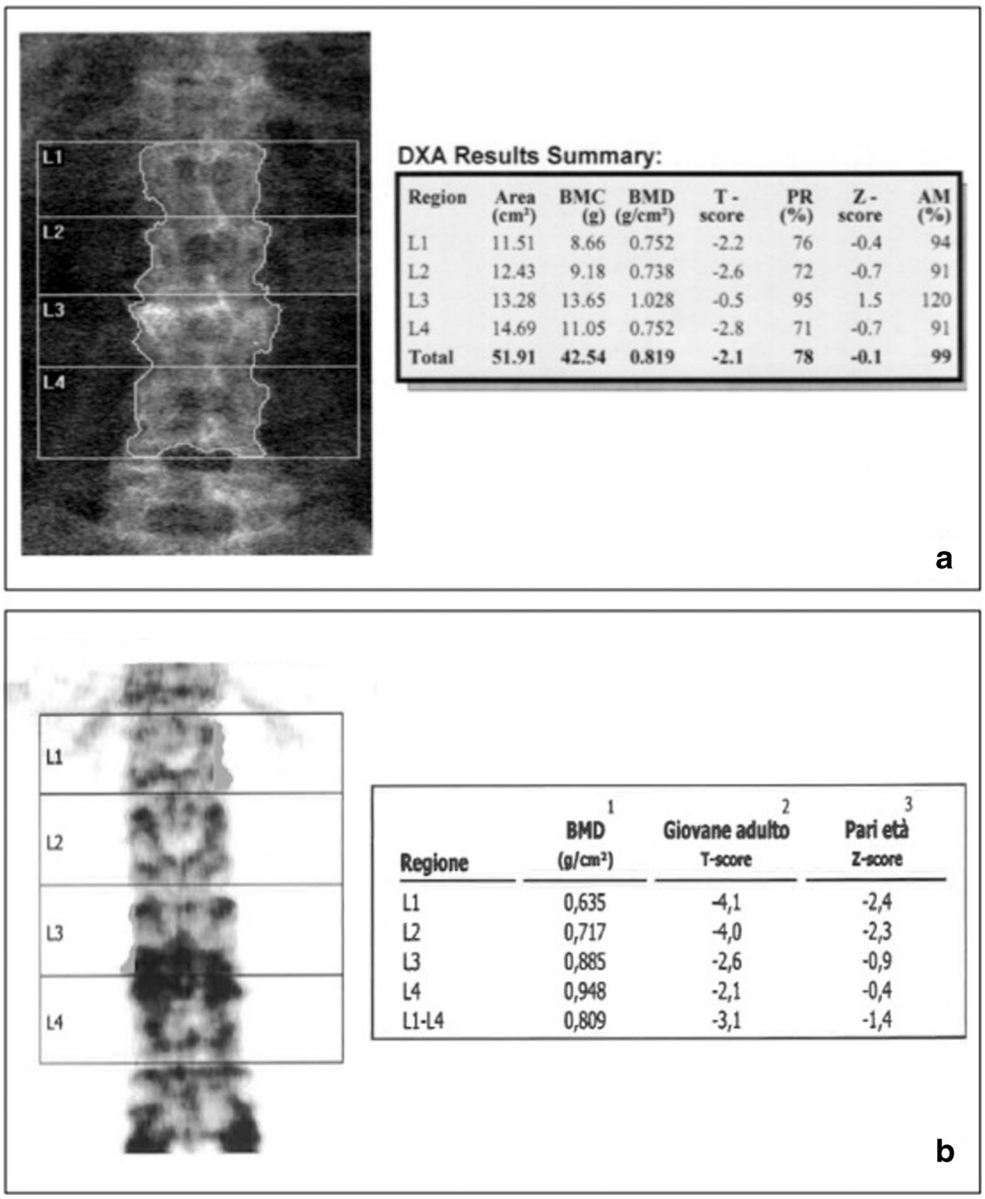

Fig. 1 Lumbar spine data analysis pitfalls: two examples of erroneous vertebral inclusion, the most common observed error. **a** Osteophyte at L3 that falsely increases bone mineral density, determining a T-score difference of more than 2.0 between L3 and adjacent vertebrae. **b** A similar error as in **a**, with both L3 and L4 affected by osteophytes. Whereas in **b** the error did not affect WHO diagnosis (osteoporosis), in **a** we may speculate that correct exclusion would have determined a change in the final diagnosis (from osteopenia to osteoporosis)

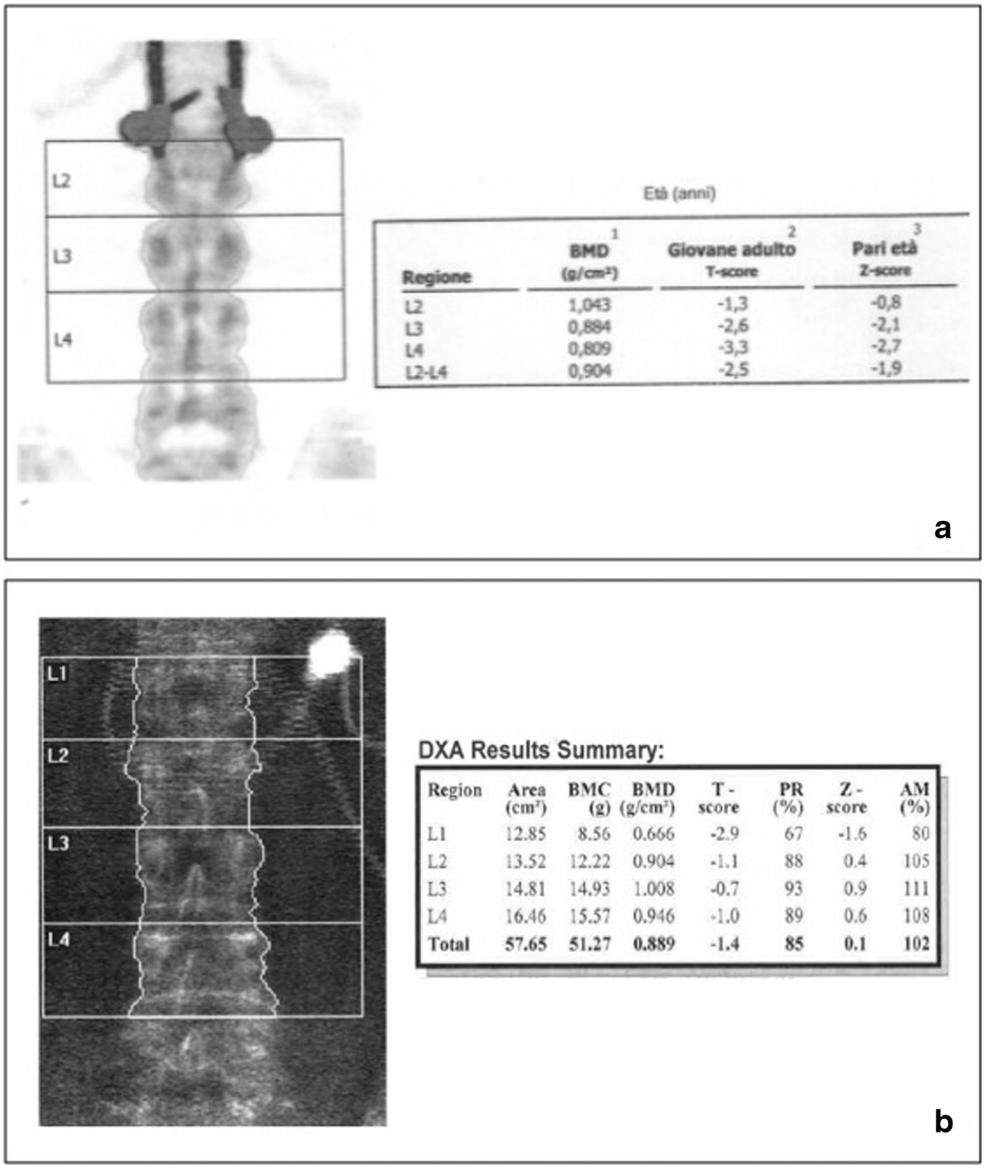

Fig. 2 The presence of artefacts may alter bone mineral density (BMD) and T score. **a** The presence of spine stabilization needles over L2 spuriously elevate BMD. **b** A metallic artefact increases the density of soft tissue box, determining a misleading BMD and T score reduction of the adjacent L1 vertebra

common error. The consequences of improper patient positioning have two implications: on the one hand, important anatomical regions may be missed; on the other hand, excessive internal or external rotation of proximal femur implies non-negligible changes in BMD values [20]. Anyway, in clinical practice, circumstances occur when an individual patient cannot be positioned properly because of patient-related conditions (e.g. scoliosis, reduced mobility, etc.). Thus, it is likely that some of these errors were unavoidable.

It is noteworthy that 7 % of errors concerned the presence of metal artefacts (e.g. parts of bras, surgical clips, navel rings, vascular prosthesis, etc.). The presence of metallic parts in the scan area greatly alters the final BMD, resulting in overestimation if the metal is included in the region of interest (ROI), or in an underestimation when is outside the ROI [10]. As it is for spinal degenerative disease, ISCD guidelines clearly state that the involved vertebrae must be excluded.

Apart for the high rate of observed errors, we acknowledge that there is a general lack of awareness of the clinical importance of always repeating DXA examinations on the same densitometer. Indeed, 20 % of the total number of patients (n=2,476) who underwent a DXA at our institution during 2012 were previously investigated in a different centre. Regardless of the reasons, there is a need for improving the communication between physicians and patients to increase patient awareness of this issue.

Variability was observed concerning the time interval for the repetition of DXA. This was rather expected, considering the lack of a consensus about the optimal interval for repeated

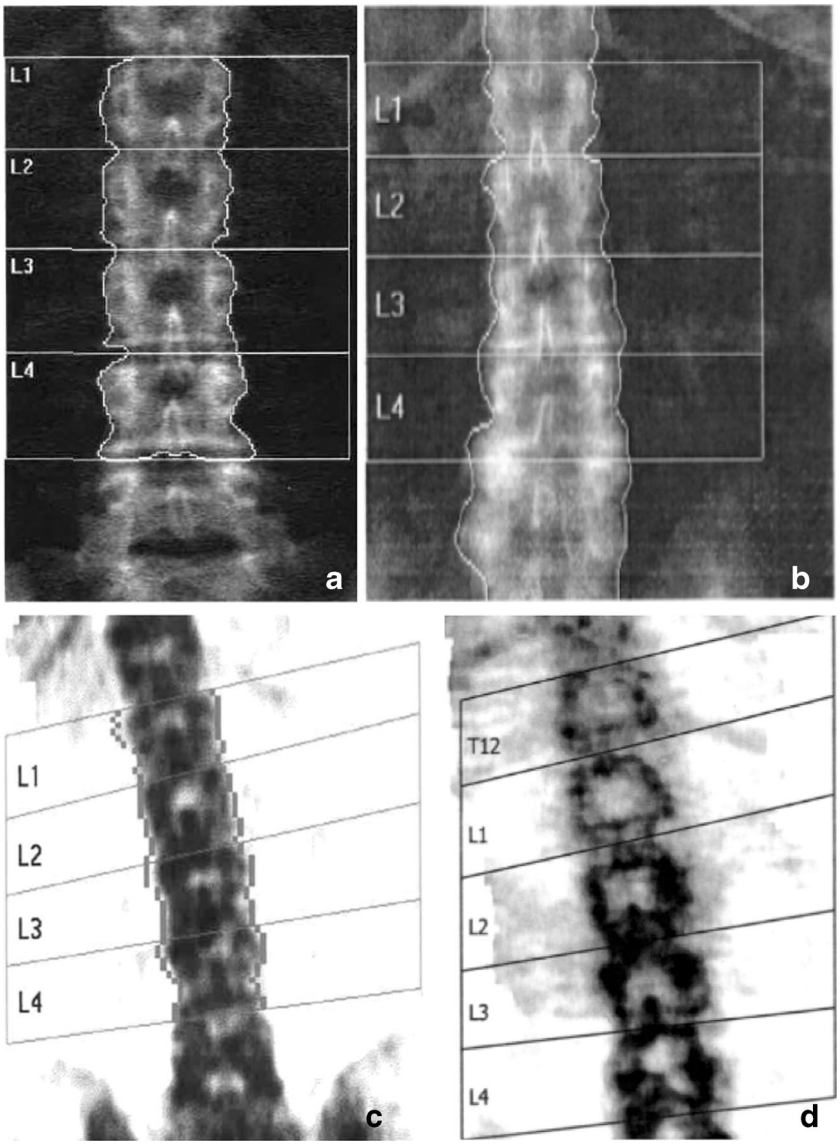

Fig. 3 Pitfalls in lumbar spine positioning. **a** Proper positioning and analysis of the L1–L4 spine. **b** The spine is not centred, being closer to the left side of the image matrix. In **c** and **d** the spine is not straight in the image field. Also, in **d** the last thoracic vertebra was included in the analysis. International Society for Clinical Densitometry suggests to use L1–L4 for spine measurement

screening. To date, a minimum of 2 years is considered the proper time interval to reliably measure a change in BMD [21].

We voluntarily decided to exclude previous DXA performed at our institution. This was done as we currently have a quality program at our department which helps us to continuously correct for errors. Prior to this quality check, our internal error rate ranged from 11 % to 18 %, depending on the DXA operator (unpublished data).

The main limitation of this study was the impossibility to estimate the impact of errors on BMD and T score calculation, as we could not re-analyse previous examinations. Also, we point out that we mainly evaluated DXA reports performed in our territory. As a consequence, our results only apply to our local situation. However, the unexpected high rate of errors has a general implication for quality checks of this kind of examination, which is a typical example of quantitative imaging. Moreover, we evaluated only a minimal portion of DXA reports per centre. Thus, we do not know whether their error rate can be higher or lower compared to what we found in our series. Also, we should acknowledge a potential selection bias due to the fact that patients in this study were referred to our institution after having undergone DXA scans elsewhere instead of repeating the exam at the same centre. Our institution is a medium-sized university hospital that may potentially attract patients. However, we do not have a clinical unit fully dedicated to the osteoporosis management. Thus, it is unlikely that we observe cases more complicated than usual. A possible explanation why these patients were referred to us after having undergone DXA scans elsewhere is that our waiting list is shorter than other centres. Finally, we should note that the check for ethnicity

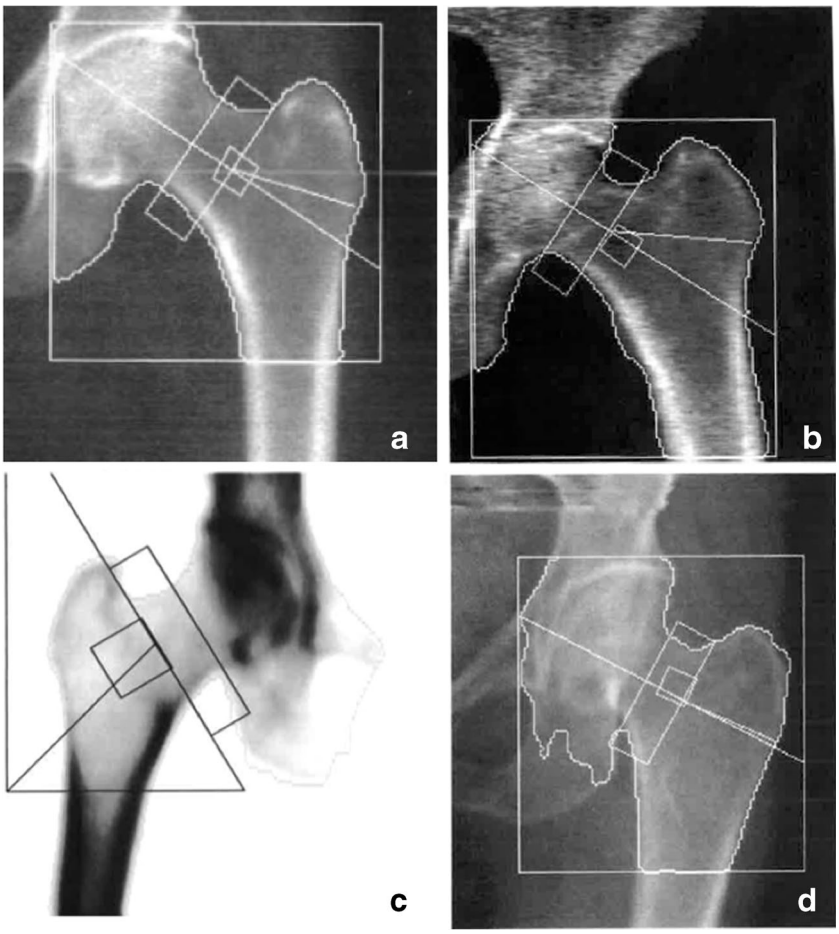

Fig. 4 Pitfalls in data analysis of the femur. **a** Proper positioning and analysis of the proximal femur. **b** Femoral neck box misplaced in a Hologic scan: the neck box is not adjacent to the greater trochanter. **c** Femoral neck box misplaced in a Lunar scan, with the neck box also including part of the greater trochanter and the ischium. **d** Very poor bone mapping, probably due to erroneous software detection

was performed considering our demographics as a reference. Thus, we cannot exclude that some of the 12 errors in ethnicity observed were due to an error that occurred at our institution. However, the rate of ethnicity errors account for 2 % only.

In conclusion, our study demonstrates that errors can be encountered in more than 90 % of DXA examinations. DXA is a multistep procedure including demographics information, patient positioning, correct image analysis and artefacts identification. Pitfalls may occur at each step and errors should be avoided for a proper diagnosis and therapy. If radiologists want to accept the future challenge of quantitative imaging, they should not lose today the clinical task of good clinical practice in DXA.

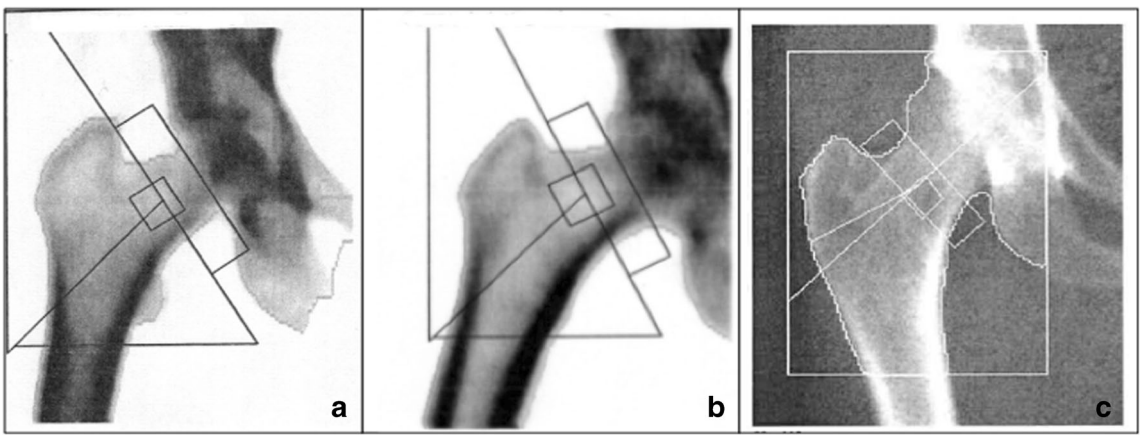

Fig. 5 Pitfalls in femur positioning. **a** Inadequate internal rotation, with the lesser trochanter excessively shown. **b** The femur is abducted. **c** The femur is adducted

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