for densitometry assessment must be within the acceptance criteria or justified by the practitioner. Request must be initialled and dated by the practitioner or an authorised scan technician working under an approved and written protocol. The operator must deiced themselves whether other densitometry imaging is required as part of FRAS on the FRAS pro forma and this must be added onto CRIS. Finding are recored annually and any errors are reported on DATIX.

Clinical Governance/Chief or Senior Technician will address on actions required.

Ruling out pregnancy

Women of child bearing age are asked the date of their last period and their LMP must be recorded on the questionnaire. If LMP is more than 28 days prior to the scan, the patient must have been questioned about the possibility of pregnancy and this must be recorded on the questionnaire and signed by the patient. If the patient is unable to confirm there is no risk, a pregnancy test must be carried out and details of the result must be recorded on the questionnaire. The scan technician must also sign to confirm this has been performed. Findings are recorded annually and any errors reported on DATIX. Clinical Governance/Chief or Senior Technician will address on actions required.

Radiation Dose (DAP scores)

Radiation dose is recorded on CRIS and must the kept within the departmental dose constraints.

Completion of FRAS pro-forma and patient questionnaire

If decision is made to perform VFA, forearm, additional hip scans this must be initialled by the operator with a reason why they were required if not authorised by practitioner. If spine X-rays are required reason why should be given. If patient required a work up this should again be indicated. Patient name and DOB should be recorded on questionnaire if not already done so by patient All relevant boxes should be filled and initialled. If all scans could not be completed comments should be made to say why. Current and previous height and weight should be recorded on the

questionnaire.

Clinical Evaluation of scans

The responsibility of clinical evaluation is with the medical staff and should be monitored by the secretarial staff. The radiology information system is checked to ensure a clinical report was written. If an auto report is recorded for ███ clinic patients and is recorded on CRIS, patient centre needs to be checked to ensure a clinic letter is present. All actions here are addressed by the Clinical Lead.

8. Bone Densitometry

8.1 Physical Principles of Bone Densitometry

X-Ray is a type of electromagnetic radiation with the most familiar being light. Some properties of light are like waves and some are like particles. Wave like properties are seen as wavelength and frequency whereas particle like properties are seen as photons with a fixed amount of energy. The spectrum of electromagnetic radiation goes beyond the light we know, with lower energy photons carrying lower frequency with longer wavelengths and higher energy photons carrying higher frequency and shorter wavelengths. Lower energy photons include microwave and radio waves whereas higher energy photons include X-Rays and Gamma Rays. X-Rays have a shorter wavelength and greater photon energy than light.

In Medical X-Ray production the number of photons generated each second is determined by the current in the X-Ray tube. The energy of these X-Ray photons is determined by the voltage across the tube.

To form an X-Ray image there is a X-Ray tube above the patient that generates the X-rays and a detector below the patient, on the other side of the body. Some X-rays will pass through the body, some x-rays are absorbed and some X-rays are scattered by the body. The X-rays that pass straight through the body are detected and form a darker image, whereas the X-rays that are absorbed for example into the bone, will form a lighter image. The absorbed or scattered X-rays do not reach the detector. When X-ray photons pass through the body three things can occur;

1. They are transmitted

2. They are absorbed

3. They are scattered

The process of both absorption and scattering and the gradual reduction of energy or intensity of and X-ray beam as it traverses matter is also referred to as Exponential Attenuation. The proportion of energy transmitted is dependent on the energy of the photons, the elemental composition of material and the thickness of the material. The radiation intensity decreases by the same proportion as it moves though the material. With photon energy the higher energy x-rays penetrate further through the material whereas lower energy absorb more rapidly, for example lead is used for safety precautions on many scans as it quickly absorbs X-rays and stops them. Bone on the other hand is not as absorbing as lead but is much more absorbing of X-rays then soft tissue.

8.2 Dual Energy X-Ray Absorptiometry (DEXA)

Dual Energy X-Ray Absorptiometry (DEXA) (Figure 4) helps to establish how much bone mineral is present. This is done by measuring how much the X-ray beam is attenuated at 2 different x-ray energies (dual energy). The Hologic DEXA scanner has an X-ray tank located under the scanner bed and a C-arm to the detector system over head. The detector moves in the same direction as the X-ray tank and the array is lined along with it. The X-ray fan beam passes through a collimator that shapes

the beam. The C-arm can be moved up and down and in and out by the X-Y drives. This is all connected to a computer system where the scan is gradually built up to form an image for analysing the scan. Fan beams allow a quicker scanning time of about 30-60 seconds (around 10 seconds on express mode) than the older pencil beam scanners which took around 5-10 minutes, however magnification does effect the result with fan beams as the projected area is used to calculate the BMC to get the BMD and therefore patients need to be positioned in the same position each visit to make sure that BMD changes are due to actual changes and not due to the magnification effects. DEXA scans use a low dose of radiation equivalent to 2-3 days of background radiation. Axial DXA scans the spine, femur and forearm and the X-ray tube voltage is

Figure 4: A Hologic Dual Energy X-Ray absorptiometry (DXA) scanner within the ████████████████ at ████████████████████

~70-140kv. Peripheral DXA can scan the forearm and heel and uses a very low dose of radiation and has a X-ray tube voltage of 40-60kv. Bone density using DEXA changes fairly slowly and therefore if you were to re-measure a patient within 2 years then you cannot be sure if the changes are just variability in measurement or real change. Serial BMD measurement can be helpful in monitoring

patients; response to therapy, untreated patients, patients taking medications known to cause bone loss or those with diseases that cause osteoporosis. To calculate the intervals between scans and BMD measurements, a patients clinical status should be taken into account along with baseline BMD, anticipated changes and the Least Significant Change (LSC). The LSC is the amount a measurement must change in order for it to reflect a real change in a patients bone mass and not just an error of the measurement. It is defined as 2.77 x the precision error (coefficient of variance) for the scanning equipment at a centre and maybe expressed as an absolute change in

BMD (g/cm2)[11]. The precision error is usually stated as precision error (%CV) and smaller the number, smaller the error and greater the precision. Precision error is important for follow ups so we can identify that the change seen is real and not just a precision error. Factors that can affect precision include; equipment errors, patient positions errors and patient physiology. Further information on statistical analysis and result section can be found under the scan analysis section below.

8.3 <u>Patient Preparation</u>

On arrival into the department, the patient will sign themselves in on the e-check in system and hand in their completed lifestyle questionnaire to reception staff. This questionnaire is sent out to the patient prior to their appointment and should be completed prior to the scan. A member of the reception team will check the patient in and upload their demographic details onto the trusts radiology system, CRIS. The patient information will then be sent across to the scanner and this will initiate the start of the scan. Once the patient details have loaded onto CRIS, the clinical paperwork will be collected from reception. It is important that I assess whether the patient has had any previous spine imaging in accordance with the ALARA (as low as reasonably achievable) principle. This is to ensure that the patient is not over exposed to radiation, even if it is a small dose as it would not clinically benefit the patient and therefore should be avoided. It is also important that I check if the patient has had any recent radiological contrast imaging as oral contrast agents such as Iodine and Barium can remain in

the gastrointestinal tract for several days and affect the DXA result. If the patient has had any recent contrast imaging their appointment will be postponed.

After these checks have been completed. The patient will be collected from reception and taken to the relevant scan room. At the start of the appointment I will ask the patient to confirm their name and date of birth and I will cross check both the patients ID and address details against any patient documentation for further identification purposes. If the patient is female and of childbearing age it is imperative that I check whether there is any chance of pregnancy under the 28 day rule, due to radiation exposure during the scan. If the patient confirms they still have regular periods but are unable to confirm the date of their last menstrual period (LMP) then I will ask the patient if they are happy to undertake a pregnancy test to rule out pregnancy. If the patient does not wish to take a pregnancy test, then the scan is postponed until pregnancy is ruled out. If the patient is pregnant the scan would be postponed until the patient has given birth.

After these checks are verified, I will take the patients height and weight measurements and record it on the back of the patient's lifestyle questionnaire. I will also input these measurements onto the patient's biography on the scanner. If the patient has had a scan previously then their previous height and weight is noted down on their lifestyle questionnaire or the patients printed clinic ticket to ensure any loss of height is recorded. If the patient has lost more than 2cm in height since their previous scan or 4cm height loss since the age of 25 but is under 65 years of age then the patient would need a vertebral fracture assessment (VFA) performed after their BMD measurement is taken. If the patient is a new patient a new biography will be created. If the patient has had a scan previously I will need to retrieve their biography for any bone density comparisons to be made.

Before the scan commences, I will visually check the patient for any external artefacts around the anatomical sites that will be scanned so that they can be removed or re-positioned away from the area of interest eg: zips, buttons, metal studs, belts, jewellery, personal alarms, clothing with pearls or

sequins as these can affect the results of the analysis and visualisation of the VFA lateral and anteroposterior view. I will also at this point ask the patient if they have anything in their pockets for example, keys, wallets, bank cards, loose change or any piercings that may not be easily visible such as naval or other piercings. Female patients will be asked if they are wearing an underwired bra with hooks and eyes as this would also need to be removed prior to the scan. It is extremely important to identify whether a patient has any objects or items within the area of interest as these artefacts affect the results of the hip and lumber spine analysis and can cause difficulty when visualising the lumber and thoracic spine region during the vertebral fracture assessment (VFA). If items of clothing need to be removed due to an unremovable artefact on the garment, then hospital gowns are available to wear. There may be times when the patient has internal artefacts that fall within the area of interest (figure 5), interfering with the scan analysis, these can include surgical clips, ostomy pouching systems, pacemaker leads, orthopaedic screws and plates, metal implants,
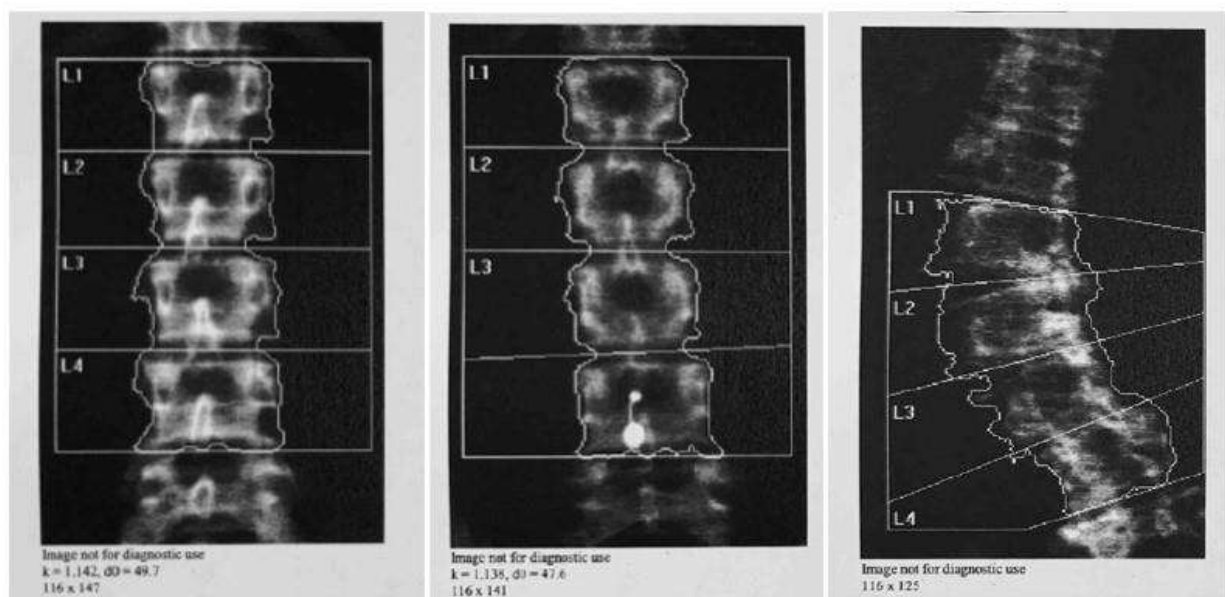

Figure 5: DXA scan images of the Lumber Spine (LS) L1-L4. Far left shows a DXA scan of a normal LS analysis, Middle image shows LS with L4 excluded due to an unremovable external artefact (navel piecing), far right shows the LS of a patient with scoliosis.

femoral calcification, aortic calcification, kidney stones, degeneration, vertebral fractures, laminectomy, radioactive isotopes for nuclear medicine scans or contrast material for other types of

investigations. It is also important to identify any previous spinal or hip orthopaedic surgery that might affect the scan. Within the ███████████████████ the right hip is scanned and analysed, however there may be occasions when the patient has had previous right hip surgery, such as a hip replacement and although previous history can be pre-checked on CRIS and the radiology system PACS (Picture Archiving Communication System), I always ensure to double check with the patient whether they have had any recent hip or spine surgery before starting the scan. If they have had right hip surgery their left hip will be scanned as per our department protocol.

8.4 Scanning Technique

Scan Technique Proximal Femur

The patient is firstly asked to lie down in a supine position in the middle of the scan bed with their head resting on the head positioner/support. If the patient suffers from any breathing difficulties or pronounced kyphosis, then further pillows may be used. Their feet are placed either side of the angled foot support so that their leg on the chosen leg is abducted approximately 15° from the midline so the ischium is separated from the lesser trochanter.

Scan Analysis Proximal Femur

Once a good quality scan has been obtained, I can proceed to analyse the image. For a new patient, the first step in the analysis is to determine the global region of interest (ROI) by positioning a box onto the scan image over the hip and then manually adjusting its edges to set guidelines. The superior line of the ROI should be placed 5 lines (5mm) above the top of the femoral head whilst the inferior line should be positioned 10 lines (10mm) below the lowest part of the lesser trochanter. For a right hip scan, the right vertical line should be placed 5 lines from the side of the femoral head whilst the left vertical line should be positioned 5 scan lines (5mm) from the lateral outside edge of the greater

trochanter. If the left hip is scanned, the right and left vertical line positions are reversed. The contrast and brightness of the scan image can be adjusted to optimally visualise various parts of the image and aid in defining the ROI parameters.

Once the ROI has been established, the operator can then verify the bone map which is automatically generated by the machine software using an edge detection algorithm. However, if parts of the bone have a density which falls below the threshold value, the algorithm will be unable to detect these areas resulting in an incorrect bone map. If this occurs, the superior ROI line can be moved up 2 lines (2mm) to try and improve edge detection. If this is unsuccessful, the bone map may be edited manually by adding in the missing bone however, this should be kept to a minimum and avoided if possible. In addition, it is sometimes necessary to manually delete bone from the ischium if it is too close to the femoral shaft as the femoral neck box.

Scan Technique Lumbar Spine

The patient is asked to lie in a supine position down the centre of the scan bed with their head resting on the head-support at the right end of the table. Additional pillows can be placed under the patient's head if they suffer from severe breathing difficulties or pronounced kyphosis and are unable to lie completely flat. It is important to ensure the patients shoulders lay within the scanner threshold which is marked onto the bed with two small black lines, so it may be necessary to ask the patient to shuffle down the scanner bed slightly. The patient is then asked to lift their legs and flex their knees so that a support block can be placed underneath, this angles the hips to approximately $90°$. Elevating the legs in this way allows any natural lumbar lordosis to reduce and disc spaces to relax/increase which in turn produces a better visual read for analysis, whilst for many also helps reduce existing back pain. For this scan, the patient is asked to lay their arms by their sides and remain as still as possible.

The scanner C-arm is positioned so that the laser cross hairs lie approximately 3cm below the iliac crest/5-10cm below the naval and run centrally through the patients' midline. An 'express' scan is performed first to allow positioning to be checked and any fine adjustments to be made if necessary; for example, repositioning the patient on the bed or repositioning the laser cross hairs. This ensures that the lumbar vertebrae of interest, L1-L4, are present on the scan for subsequent analysis. Optimal positioning for this scan is where the lumbar spine is straight and sitting centrally in the field of vision with equal areas of soft tissue on either side. The scan should start at the fifth lumbar vertebra (L5) and running until the twelfth thoracic vertebra (T12) is visualised which should demonstrate the location of the first set of ribs. Not always possible straight as some people have scoliosis of the spine. Once the operator is satisfied with the positioning, the scan is then carried out in 'array' mode to produce a higher resolution image for the analysis.

Scan Analysis Lumbar Spine

Once a good quality scan has been obtained, I can proceed to analyse the image. For a new patient, the first step in the analysis is to determine the global region of interest (ROI) by positioning a box onto the scan image over the lumbar spine. The width of the ROI is not changed from the default value of 116; however, the length can be altered so that the ROI includes L1-L4. The superior ROI line is positioned in the intervertebral disc space between T12 and L1 equidistant from the endplates, and the inferior ROI line is placed in the intervertebral disc between L5 and L4 again equidistant from the endplates. This ensures that only the four lumbar vertebrae of interest are measured. These lines can be angled using the point mode if the spine is naturally curved. The ROI box is then moved laterally over the scan image so that there is an equal area of soft tissue on either side of the spine within its parameters. Next, the bone map is automatically created by the scanner software only identifying bone within the ROI and this is then checked/adjusted to ensure there is good edge detection and that no internal artefacts such as aortic calcification have been picked up in addition.

Following this, the sub regions need to be set to allow the four vertebrae to be analysed individually. Three intervertebral lines are positioned between the four vertebrae; these should be placed through the disc spaces at L1/L2, L2/L3 and L3/L4, each lying equidistant from the endplates of the superior and inferior vertebra. It isn't always possible to position the spine straight as some people suffer with scoliosis (figure 5), therefore the intervertebral lines can be angled using the point mode to divide the disc space equally if this is the case.Finally, the results of the analysis are calculated; this is achieved by the machines software after the 'results' icon is selected on screen.

The results are displayed in a table and include the BMD, BMC, Area, T Score, PR%, Z Score and AM% for each individual vertebra, L1-L4, and as a total. Sometimes it is necessary to exclude certain vertebra from the analysis due to the presence of vertebral fractures, artefacts, previous surgery or degenerative change. These can be visually identified from the scan image or distinguished from a large variation between scores.

Scan Technique Forearm

In some cases, the patient will be required to have a forearm scan due to medical conditions such as primary hyperthyroidism. Firstly, I need to establish which forearm is to be scanned. The arm selected needs to be free from any external artefacts such as a watch and must not have sustained any previous distal fractures. It is also favourable for the patients non dominant arm to be scanned unless this has been fractured previously and the dominant arm has not. The scanner C-arm is centred, and the patient is asked to sit on a chair next to the side of the scan bed. The forearm is then positioned under the laser cross hairs, often requiring the patient to lean into the bed so that their arm is central and runs parallel to the table length. The forearm needs to be as straight and as flat to the bed as possible with the vertical laser crosshair running down the length of the forearm between the ulna and radius. The patient is also asked to form a loose fist with their hand.

For a left forearm scan, the patients fingers should be pointing towards the right/head end of the table and the laser cross hairs should be positioned midway down the forearm so when the scanner is started it runs towards the first row of carpel bones and is stopped when these are visualised. For a right forearm scan, the patient fingers should be pointing towards the left end of the table and the laser cross hairs should be positioned at the first row of carpel bones and stopped when the scanner has reached the mid forearm. Once the operator is satisfied with the positioning of the forearm, the patient is asked to keep their arm as still as possible and the scan can begin. For all forearm scans, unlike hip and spine scans, the default mode selected automatically by the machine is 'Array'. The operator must still ensure that the forearm is central with equal amounts of soft tissue on either side; this is aided by guideline parameters which appear on the scan window when the reposition icon is selected. This icon is also used if the position of the forearm requires adjustment due to lying at an angle.

Scan Analysis Forearm

Once a good quality scan has been obtained, I may proceed to analyse the image. Firstly, the length of the patient's forearm, from the tip of the ulna styloid process to the base of the elbow, is measured in centimetres and is inputted into the computer. Analysis cannot proceed until this measurement has been entered as the system uses this to automatically calculate the length of the ROI. Under the whole mode setting, the ROI box is then moved up/down over the scan image for correct positioning; for a right forearm scan the inferior ROI line should be placed on the top/edge of the ulna styloid process and for a left forearm it's the superior ROI which is placed on the ulna styloid process. Next, the line mode is selected to move the right and left vertical ROI lines inwards until the blue analysis aid lines first touch the bone edge of the ulna and radius. The bone map is generated automatically by the scanner software after its icon is selected identifying the bone within the ROI only. This can be edited manually if some of the bone is not detected by the software, however this should be kept to a minimum. Once the operator is satisfied that the bone map is correct, the final step is to position the

MID/UD line so that it sits inferior to the radial endplate with the vertical division line running centrally between the radius and the ulna. The results icon is then selected to complete the analysis and the results are displayed in a table showing BMD, BMC, area, T-score, PR%, Z-score and AM% for the ultra-distal, mid, 1/3 and total forearm. 8.5 <u>Technical Interpretation of Bone Densitometry results</u>

<u>Header Block</u>

The header block is located at the top of the page and identifies the name, address and contact details of the department where the patient attended for the scan.

<u>Patient demographics</u>

The patient demographics are located just below the header block and include the patient name, date of birth (DOB), patient I.D/unique hospital number, sex, ethnicity, height, weight and age. These details are obtained from the patient's biography and I must ensure to correctly input these at the beginning of each scan. To ensure that the details can be kept up to date with each scan they may be altered at any time, this is extremely important so that the correct reference data can be used when results are being generated especially in terms of their age, sex and ethnicity. This ensures that the correct T and Z-scores are computed so that appropriate clinical advice can be given to the patient.

<u>Referring Physician</u>

This is the name of the physician who requested the DXA scan for the patient and is located below the patient demographics. The referring physician must be a registered healthcare professional who has a legal obligation in making the referral to comply with IRM(ER) 2017.

The image displayed on the scan print-out is the analysed version of the chosen anatomical site, in

this case the lumbar spine (Figure 6). The information displayed shows the Region of Interest (ROI),

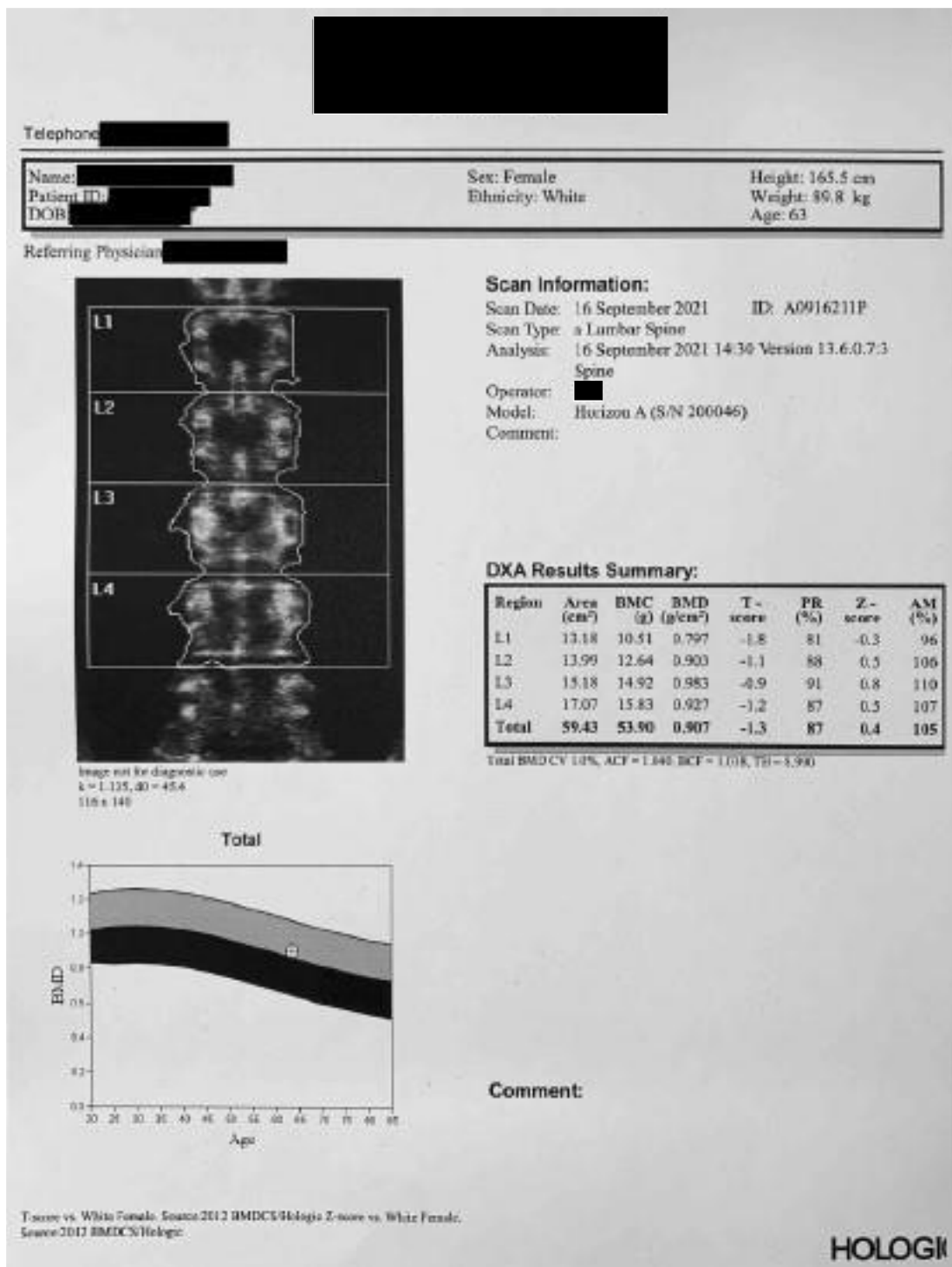bone map, vertebral levels and the intervertebral lines. The image allows the reporting

Figure 6 : Technical Interpretation: An example of a DXA Lumber Spine BMD Result

clinician to not only identify if there were any issues with positioning, but also helps them to identify any artefacts or degenerative change which may affect the accuracy of the patients results.

- Beneath the scan image displays the specific calibration data, this is outlined below:

- **Keith Unit (k)** - represents the measure of the amplitude of a single pulse measured by the detector.

- **dO** - represents the measurement value of the high-energy x-rays in the tissue of the scan image.

- **The height and width of the ROI** are displayed here; the width is 116 and this is set as the default and should not alter between scans

- **The dose area product is represented here by the initials, DAP**. Multiplying the absorbed dose to air by the area of tissue exposed measures the patient's radiation exposure per scan.

<u>Scan Information</u>

The section located to the right of the scan image shows all information relevant to the day of the scan. The scan date shows the day, month and year that the scan was performed. The information following scan type refers to what anatomical site was scanned and in which mode, for example; 'a Lumbar spine' shows that the lumbar spine was scanned in 'array mode'. An I.D number is also displayed; this number is automatically generated by the computer software and is made up of the scan date and the chronological number for the scan that day. The analysis information details the exact time and date when the scan was analysed and what software version was used, this is extremely important to know for follow up patients as they will need to be scanned again after the appropriate length of time using the same software and scanner to ensure the reliability of results.

The operator's initials are displayed here along with the model of the densitometer used, where necessary is it important to scan a patient on the same machine for every follow up appointment they have. Finally, there is a comment section where any extra information can be added.

DXA results summary

The below information is a summary of the information contained in a DXA result.

Region: This separates the lumber spine into separate vertebral levels (L1, L2, L3 and L4) as well as showing them as a total.

Area (cm2): the area of each individual vertebrae as well as the total area for all vertebra included in analysis.

BMC (g): the amount bone mineral content measured in grams for each individual vertebra as well as the overall total for all vertebrae included in analysis.

BMD (g/cm2): the bone mineral density measured for each individual vertebra. It is expressed as an areal density and shows the amount of bone mineral content within a given area:

$$\text{BMD (g/cm}^2\text{)} = \frac{\text{BMC (g)}}{\text{Area (cm}^2\text{)}}$$

The value for the total BMD is shown as mean value for all vertebras included when analysed.

T-Score: This value is expressed in terms of standard deviation and compares the measured BMD result for the patient against the mean BMD of a young healthy adult (approximated around the age of 30) that is the same gender and ethnicity.

$$\text{T score} = \frac{\text{Measured BMD} - \text{Young adult mean BMD}}{\text{Young adult SD}}$$

PR %: Percent relative is the T-score value expressed as a percentage. This may be helpful to explain the outcome of the scan to patients and the referrer to make it clearer to understand.

Z-Score: This value is calculated by comparing the measured BMD result for the individual against the mean BMD for an age-matched population of the same gender and ethnicity.

$$Z \text{ score} = \frac{\text{Measured BMD- Age matched mean BMD}}{\text{Age matched SD}}$$

AM %: Age match percent is the Z-score expressed as a percentage. This can be a clearer way of explaining the outcome of the scan to a patient.

The T-score values obtained are preferred to be used when discussing a patients BMD if they are a post-menopausal woman or a male over 50. Z-Scores can also be used but low bone density in the older population can be quite common, so they are recommended to be used when reporting in premenopausal women and men under 50 instead. The International Society for clinical densitometry (ISCD) recommends that a Z-Score >-2.0 is normal, anything below can prompt further investigations.

The World Health Organisation (WHO) classifies T-scores into four different categories used to diagnose osteoporosis, they are summarised in the table below:

T-Score	WHO Classification
≥-1.0	Normal
<-1.0 but > -2.5	Osteopenia
≤-2.5	Osteoporosis
≤-2.5 plus a fragility fracture	Severe Established Osteoporosis

The WHO criteria are applicable to BMD measurements made in the lumbar spine, proximal femur and distal forearm. When a decision is being made the T-scores are considered plus any other relevant risk factors that are taken from the patient's questionnaire. The WHO classification category and current fracture risk can be seen under the results summary box.

Along with the WHO classification and fracture risk information, there are further numerical values which are of high importance and these are positioned under the results summary table and include;

The Coefficient of Variation (CV) - this measures the precision of the lumbar spine measurement and has a manufacturer stated value of 1%.

Calibration Correction Factors; Area Correction Factor (ACF) and Bone Correction Factor (BCF) - These factors are used to calibrate the densitometer to the phantom so that BMD results measured remain accurate.

Value for Tissue Height (TH) - is measured and is approximately the thickness of the patient measured in inches. The higher a patient's BMI, the higher value for TH will be given. If TH passes 11, reliability of the results becomes limited.

Reference Graph

The reference graph shows total BMD plotted against age. The centreline represents the mean BMD value which changes with age, whilst the upper and lower threshold lines represent ± 2SD from the mean. The patient's BMD measurement is plotted on the graph and indicates whether the value is within the expected threshold limits for their age, gender and ethnicity. The lighter shaded area represents values that are above average for age whilst the darker shaded area represents values that are below average for age.

Detailed below the graph is the source of reference, in this case the reference population is white females and the source of the data comes from the manufacturer which is Hologic.

For the proximal femur, the reference population is derived from the NHANES study and for a white female the reference source is NHANES III.

<u>Comment</u>

This allows for the operator or clinician to add any extra comments with regards to the scan or patient. This is also useful if the patient needs to be moved onto another scanner due to mechanical breakdown as this will affect the overall result and will need to be considered in case of a drop in results.

Factors that affect the precision in clinical bone densitometry include the patient anatomy for example tissue depth and lean and fat mass of the patient so I must always take into account any large changes in weight for follow up scans, positioning for example if optimum positioning in unachievable due to physical changes in the patient and finally inconsistent follow up analysis in comparison to a patient's previous scan.

8.6 <u>Vertebral Fracture Assessment (VFA)</u>

Vertebral Fracture Assessment (VFA) is a valuable way to screen for the presence of vertebral fractures using a very low dose of ionising radiation compared to that of a conventional spinal image. VFA can identify fractures that have no clinical signs and thus predict the presence of further fracture risk. Fan beam DXA scanners can acquire both anteroposterior and lateral imaging of the thoracic and lumber spine usually T4 to L4 in most patients. The Limitations of VFA's are that they use a lower resolution imagine than the standard spine radiographs so at times may not be as clear and thus fractures can be missed if fall out of visualisation. The result are also operator dependent and therefore fractures may be missed due to misinterpretation of the scan.

When interpreting the results, I use visual inspection of the imaging. I firstly check the VFA imaging against any previous VFA scans the patient may have had. I also check CRIS and PACS for other spine imaging to check for any new fractures or known fractures. I will also compare the VFA to

other spine imaging to look for any differential diagnosis eg: history of malignancy. If a vertebral fracture is suspected on a VFA, further imaging can be requested to confirm or refute a fracture.

8.7 Bone Densitometry in Children

DXA BMD measurements are two dimensional. They represent a composite of bone size and bone density and are highly related to body size. Children may have lower BMC either because they have smaller bones or because they have less mineral content than expected for the size of their bones. It is worth distinguishing between these 2 factors, in terms of underlying pathology and need for treatment. T-scores are meaningless as they are the equivalent of comparing a child's height to that of an adult therefore Z scores should be used but only if the child is of normal size for their age.

Bone densitometry in children and younger adults have yet to be related to clinical outcome and no fracture threshold has been defined. Measurements require special care in growing children due to the underestimation of BMD in small bones and the overestimation of BMD in large bone so inaccuracies do not occur. Algorithms used to separate bone from soft tissue have been designed to only optimise measurements in adults and so changing body size and low mineralisation of the bones, especially in smaller children may cause problems with bone edge detection and effect the overall result. Special paediatric software programmes have been introduced to help with this problem. This software uses paediatric aBMD reference database and enables a patients aBMD to be expressed as SDS. However inconsistencies in diagnosis of osteopenia can arise if the child has a chronic disease. They are also not gender or ethnic specific and are based on a small umber of subjects so do not use accurately normal variations of aBMD for age[12].

DXA scans on smaller children of pre-pubertal age are performed on the lumber spine or whole body, but not the femur as the growth plates may not be fused. In older children bone density can be taken at the spine and the femur. Problems that can arise during scanning include, movement especially in

smaller toddlers and artefacts that can't be removed but may effect follow up scans such as feeding tubes and plaster casts.

8.8 Other Densitometric Techniques

Other Densitometric techniques include;

• Peripheral dual-energy x-ray absorptiometry (pDXA) Smaller portable machine that can measure bone density in the forearm or heel. X-ray tube voltage is around 40- 60kv Radiation dose is extremely low with the effective dose being ~0.1μsv. However, they can only be used as screening and as a fracture risk assessment tool [13].

• Quantitative computed tomography (QCT) Three dimensional method that can measure trabecular bone in milligrams per cubic centimetre in the hip and spine. It does this by indirectly quantifying hydroxyapatite in comparison to reference phantom. Limitations are that the radiation dose of the QCT is relatively higher that that of a DXA scan (0.06–2.9 mSv)[14].

• Peripheral Quantitative Computed Tomography (pQCT) Used for making measurements of BMD in either the forearm or leg. Compared to DXA can measure stress strain index (SSI). Good accuracy and precision and low dose radiation at ~3mSv per scan. However, pQCT scan the appendicular bone with low turnover, has low spatial resolution, not much data available and the exact repositioning is required for follow up scans[15].

• High-resoluAon peripheral quanAtaAve computed tomography (HR-pQCT) - State of the art for bone imaging which has a low radiation dose per scan. Scanner can image down to 80 microns so you are able to visualise individual trabecular bone and individual cortical pores. Limitations are that it only assess bone at 2 sites, the distal radius and distal tibia. There are also many technical issues with the scans[16].

- Quantitative Ultrasound (QUS) - Estimated bone mineral status. QUS is quick to perform, cost effective, portable, widely available and is radiation free. It is also a great alternative to scanning children. Its limitations include, more research data needed, technological diversity, use of different QUS variables to estimate BMS and it is difficult to compare results with other bone densitometry techniques [17].

- Trabecular Bone Score (TBS) - An analytical tool that performs novel-grey texture measurements on LS DXA imaging. Cant be used as a stand alone tool but can be useful in combination with aBMD and FRAX [18].

8.9 Evidence of DXA scans & analysis

Evidence of a range of DXA scans that I have performed and analysed can be found in Appendix 5 of this portfolio.

9.0 Case Studies

9.1 Case Study 1

Referral reason and Clinical History

This 69 year old, white female was referred for her first DXA scan due to a diagnosis of Primary hyperparathyroidism (PHPT). PHPT is an endocrine disorder in which excessive amounts of the parathyroid hormone (PTH) are produced which is secreted by the parathyroid glands and is essential to maintaining the levels of calcium, phosphorus and Vitamin D in the blood and bones. If blood calcium levels are low (Hypocalcaemia), then naturally more PTH is produced to raise the levels. It works by reducing the loss of calcium through the kidneys, encourages the absorption of calcium through the gut and release of calcium from bones. In PHPT the function of the parathyroid glands becomes disrupted due to them becoming enlarged and overactive due to the presence of a tumour, this increases the production of PTH causing high levels of calcium in the blood (Hypercalcaemia) resulting in the calcium within the bone becoming reduced.

There are four parathyroid glands and therefore PHPT can be treated with surgery to remove the parathyroid gland with abnormal function, in this case the patient was diagnosed with a mild form of PTH and therefore did not require surgery.

Scan Acquisition and Analysis

The standard pre-checks were undertaken and following departmental protocol for patients presenting with PHPT; the forearm (figure 9) was scanned in addition to the right hip (figure 7) and lumbar spine (figure 8). This allows us to check the BMD at the cortical site where rapid changes may be observed in patients with this disease. Each anatomical site was scanned in array mode and there were no issues with positioning.

Due to the patient having her first DXA scan, the global ROI and bone map had to be identified for all three anatomical sites; this sets a baseline for any future assessments.

There were no issues when analysing the hip, the femoral midline and neck box were adjusted to fit correctly. The intervertebral lines were placed correctly but required the use of point mode to angle them slightly, so they fit more accurately in between each disc space to follow the slight curve in which the spine presented. The right forearm was selected and there were no issues with analysis, the image was central allowing the ROI to be easily identified and the MID/UD line to be positioned correctly.

Scan Results

Due to the presence of degeneration on the region of interest at the lumber spine the Total BMD was not included for this patient as the result was unreliable. The source of the reference population is white female with the reference data being acquired from Hologic.

The result of the hip scan showed the patient to have a total BMD of 0.973g/cm2 which measured at 0.3 for their T-score; this puts the patient into the normal population as stated by the WHO classification. A Z-score was also measured giving a value at 1.7, this translates into an age matched percentage of 127%, again placing this patients BMD above average for their age. The source of the reference population is white female and the reference data coming from NHANES III.

For the forearm scan, results are taken from the 1/3 section and not the total, this is because this section most accurately represents cortical bone which can have rapid turnover in patients presenting with PHPT. BMD was recorded at 0.767g/cm2 with a T-score of 1.2 which is defined as normal by the WHO. The Z-score was calculated at 3.2 giving an age matched percentage at this site of 133% which is above average for age. The reference population is white female and the reference population has been taken from Hologic.

As the patient is female and over the age of 65 a VFA was performed as per departmental protocol. The VFA showed no evidence of fracture and the assessment did not suggest a high risk of fragility fracture (figure 10).

Clinical Outcome

The reporting clinician suggested that the patient should be given appropriate lifestyle advice to maintain bone health but that no additional intervention is required at this stage. It was decided the patient would benefit from a repeat scan in 3-5 years if the PHPT remains mild and is managed conservatively. The clinician also advised Vitamin D supplementation in addition to good dietary calcium intake.