

CROSS CALIBRATION OF DEXA BY USING EUROPEAN SPINE PHANTOM

by

Serkan Uğur Bayraktar

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ABSTRACT

Osteoporosis is a disease characterized by low bone mass and micro-architectural degradation of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk. Among many risk factors for osteoporosis, bone mineral density (BMD) measured by dual energy X-ray absorptiometry (DEXA) scanners is the most accepted predictor of osteoporotic fractures. The World Health Organization (WHO) also uses BMD to define osteoporosis. As a result, BMD is an important risk factor, and among other things, has been used in the diagnosis of the disease, selection of treatment strategy, and evaluation of treatment efficacy.

Since DXA technology has become widely acceptable and available as a screening tool for osteoporosis, standardization of BMD values and calibration among scanners are important objectives for the osteoporosis community. In this study we scanned 28 densitometers with one ESP (s.n. 03-208) and calculated the accuracy of each densitometer and observed the variation among different models and manufacturers.

We calculated cross-calibration formulas by linear regression analysis for different models of 4 main manufacturers. When we calculate the MSE (Mean Squared Error) between the original values measured on the densitometers and the calculated with cross calibration formulas we found maximum error of 0.0042.

With the BMD measurements obtained by each densitometer the reproducibility of the device are observed. And as a high lightening result, 27.74% of the total BMD values obtained from the device are out of reproducibility acceptance range of $\pm 1.5\%$ of the mean.

Keywords: Spine phantom, cross calibration, DEXA

KEMİK YOĞUNLUĞU CİHAZLARININ AVRUPA OMURGA FANTOMU KULLANILARAK ÇAPRAZ KALİBRASYONU

ÖZET

Osteoporoz kemik kırılabilirliğini artırarak kırık riskinin yükselmesine sebep olan düşük kemik kütlesi ve kemik dokusunda mikro-yapısal deformasyonla tanımlanır. Osteoporozu sebep olan bir çok risk faktörü için Dual X-ray Absorptiometry(DXA) cihazları ile ölçülen Kemik Mineral Yoğunluğu (BMD) en yaygın kabul gören teşhis yöntemidir. Dünya Sağlık Örgütü (WHO) de osteoporozu tanımlamak için BMD'yi kullanmaktadır. Sonuç olarak BMD önemli bir risk faktörüdür ve diğer faktörlerden daha yoğun olarak hastalığın teşhisi, tedavi stratejisinin seçimi ve tedavi etkinliğinin değerlendirilmesinde kullanılmaktadır.

DXA teknolojisi geniş çevrelerce kabul görüp osteoporoz taraması için kullanılır olduğundan, BMD değerlerinde standartlaşma ve cihazlar arası kalibrasyon osteoporoz çevreleri için önemli hedefler haline gelmiştir. Bu çalışmada 28 DXA cihazı bir Avrupa Omurga Fantomu (ESP 03-208) kullanılarak taranmış ve her bir cihazın doğruluğu hesaplanarak değişik cihaz üreticileri ve modelleri arasındaki değişim incelenmiştir.

4 ana üreticinin 10 farklı modeli için çapraz kalibrasyon formülleri doğrusal regresyon analizi ile hesaplanmıştır. Bu çapraz-kalibrasyon formülleri kullanılarak hesaplanan değerler ile orjinal değerler arasındaki hataların karelerinin ortalaması hesaplandığında maksimum 0,0042 bulunmuştur.

Ayrıca cihazlardan alınan BMD değerleri ile her bir cihazın tekrarlanabilirlik değerleri incelenmiştir. Ve ilgi çekici bir şekilde tüm cihazlardan alınan toplam 840 BMD değerlerinden %27,74'ü, alınan cihazın ortalamasının $\pm 1,5$ 'i olan kabul edilebilir tekrarlanabilirlik sınırlarının dışında gözlemlendi.

Anahtar Sözcükler: Omurga fantomu, çapraz kalibrasyon, kemik yoğunluğu

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LIST OF SYMBOLS

I_{out}	Intensity of transmitted X-rays
I_{in}	Intensity of transmitted X-rays
μ_{λ}	Wavelength-dependent mass attenuation coefficient (cm^2/g)
ρ	Volume density of absorbing medium (g/cm^3)
keV	Kilo Electron Volt
W	watt
m^2	meter square
Ca	Calcium
D_1	Data group 1
D_2	Data group 2
β_2	Multiplier obtained by regression analysis
β_2	Constant obtained by regression analysis

LIST OF ABBREVIATIONS

BMD	Bone mineral density
ISCD	International Society for Clinical Densitometry
DXA/DEXA	Dual Energy X-ray Absorptiometry
SXA	Single Energy X-ray Absorptiometry
DPA	Dual Photon Absorptiometry
SPA	Single Photon Absorptiometry
WHO	World Health Organization
SD	Standard Deviation
RIO	Region of Interest
EDE	Effective Dose Equivalent
Ca	Calcium
ROI	Region of interest
QC	Quality Control

1. OSTEOPOROSIS

1.1 What is Osteoporosis

Osteoporosis or porous bone is a disease in which bones become fragile and more likely to break, also known as fracture. It is defined as “...a skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture. Bone strength reflects the integration of two main features: *bone mineral density* and *bone quality*...” [1]

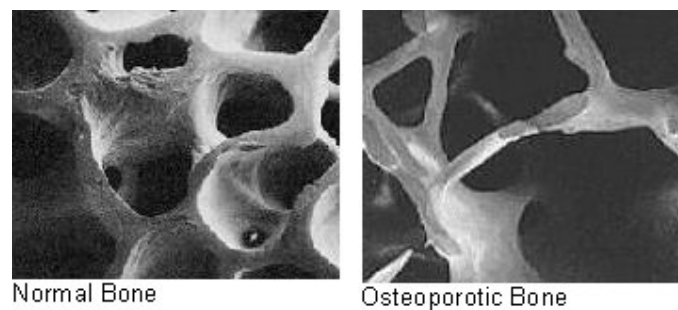


Figure 1.1 Normal & Osteoporotic Bone [2]

It is important to understand that bone is not a hard and lifeless structure; it is, in fact, complex, living tissue. Our bones provide structural support for muscles, protect vital organs, and store the calcium essential for bone density and strength. Because bones are constantly changing, they can heal and may be affected by diet and exercise. Until the age of about 30, body builds and store bone efficiently. Then, as part of the natural aging process, bones begin to break down faster than new bone can be formed. In women, bone loss accelerates after menopause, when ovaries stop producing estrogen - the hormone that protects against bone loss.

Osteoporosis is a silent condition; that means it causes no signs or symptoms unless or until there are fractures that occur, typically in the hip, spine, or wrist. And because there is no clinical tool to assess bone quality, measurement of bone mineral density (BMD) is required to identify patients before fractures occur.

Any bone can be affected, but of special concern are fractures of the hip and spine. A hip fracture almost always requires hospitalization and major surgery. It can impair a person's ability to walk unassisted and may cause prolonged or permanent disability or even death. Spinal or vertebral fractures also have serious consequences, including loss of height, severe back pain, and deformity.

1.2 Osteoporosis With Numbers

Osteoporosis is a major public health threat for an estimated 44 million Americans or 55 percent of the people 50 years of age and older. In the U.S. today, 10 million individuals are estimated to already have the disease and almost 34 million more are estimated to have low bone mass, placing them at increased risk for osteoporosis [2] which puts them at increased risk of developing fractures. One in two women and one in four men over age 50 will have an osteoporosis-related fracture in her/his remaining lifetime. Significant risk has been reported in people of all ethnic backgrounds. [2]

While osteoporosis is often thought of as a women's disease, it can strike men as well. Of the 10 million Americans estimated to have osteoporosis, eight million are women and 2 million are men [2].

Eighty percent of those affected by osteoporosis are women. Women can lose up to 20 percent of their bone mass in the five to seven years following menopause, making them more susceptible to osteoporosis. Five percent of non-Hispanic black women over age 50 are estimated to have osteoporosis; an estimated additional 35 percent have low bone mass that puts them at risk of developing osteoporosis. Ten percent of Hispanic women aged 50 and older are estimated to have osteoporosis, and 49 percent are estimated to have low bone mass. Twenty percent of non-Hispanic white and Asian women aged 50 and older are estimated to have osteoporosis, and 52 percent are estimated to have low bone mass [2].

Twenty percent of those affected by osteoporosis are men. Seven percent of non-Hispanic white and Asian men aged 50 and older are estimated to have osteoporosis and 35 percent are estimated to have low bone mass. Four percent of non-Hispanic black men aged 50 and older are estimated to have osteoporosis and 19 percent are estimated to have low bone mass. Three percent of Hispanic men aged 50 and older are estimated to have osteoporosis and 23 percent are estimated to have low bone mass [2].

One in two women and one in four men over age 50 will have an osteoporosis-related fracture in their remaining lifetime. Osteoporosis is responsible for more than 1.5 million fractures annually, including; over 300,000 hip fractures; and approximately 700,000 vertebral fractures, 250,000 wrist fractures, and 300,000 fractures at other sites [2].

The estimated national direct expenditures (hospitals and nursing homes) for osteoporotic and associated fractures were \$17 billion in 2001 (\$47 million each day) and the cost is rising [2].

1.2.1 Risk Factors

Certain people are more likely to develop osteoporosis than others. Factors that increase the likelihood of developing osteoporosis are called "risk factors." These risk factors include [2]; personal history of fracture after age 50, current low bone mass, history of fracture in a first-degree relative, being female, being thin and/or having a small frame, advanced age, a family history of osteoporosis, estrogen deficiency as a result of menopause, especially early or surgically induced, abnormal absence of menstrual periods (amenorrhea), anorexia nervosa, low lifetime calcium intake, vitamin D deficiency, use of certain medications, such as corticosteroids and anticonvulsants, presence of certain chronic medical conditions, low testosterone levels in men, an inactive lifestyle, current cigarette smoking, excessive use of alcohol, being Caucasian or Asian, although African Americans and Hispanic Americans are at significant risk as well.

2. BMD TESTS

2.1 Introduction

Osteoporosis is often called the "silent disease" because bone loss occurs without symptoms. People may not know that they have osteoporosis until their bones become so weak that a sudden strain, bump or fall causes a fracture or a vertebra to collapse. So bone density measurements are essential. Specialized tests called bone density tests can measure bone density in various sites of the body. A bone density test can:

- Detect osteoporosis before a fracture occurs.
- Predict your chances of fracturing in the future.

Determine your rate of bone loss and/or monitor the effects of treatment if the test is conducted at intervals of a year or more.

Most official groups recommend screening healthy women for osteoporosis at age 65, and testing higher-risk women earlier [3 4 5 6]. The ISCD recommends screening men without risk factors for osteoporosis at age 70, and screening higher-risk men earlier [7]. Of course, BMD testing is an appropriate tool in the evaluation of patients who have diseases (e.g. hyperthyroidism, hyperparathyroidism, celiac disease, etc.) or use medications (e.g. glucocorticoids, suppressive doses of thyroxine, etc.) that might cause bone loss.

BMD tests cannot stand-alone; they should always be a part of a complete medical workup supervised by a knowledgeable doctor.

2.2 Types of BMD Tests

2.2.1 Single photon absorptiometry (SPA)

Single photon absorptiometry (SPA) was introduced by Cameron and Sorenson in 1963 [8]. The method overcame the problems for radiographic photodensitometric techniques, caused by polychromatic X-rays and non-uniformity of film sensitivity and development, by using a single energy γ -ray source (^{125}I , photon energy 27.3 KeV) and a scintillation detector to measure transmitted photons. The radionuclide source and detector were coupled and scanned in a rectilinear fashion across the area of interest. To correct for overlying soft tissue the anatomical site in which BMD was being measured has to be surrounded either by water, water bags or water equivalent moldable material, with an addition correction for adipose tissue being made. The technique was generally only applicable to peripheral sites, usually the non-dominant forearm. Early equipment used a horizontal scan with the hand in a pronated position. Subsequently vertical scans with the hand gripping a rod in a water bath provided improved precision. Bone density measurements were provided as bone mineral content (BMC) in g/cm of bone length or as bone mineral density (BMD) in g/cm^2 . This is an areal rather than a true volumetric density and is calculated from BMC divided by bone width, the margins of the bone being detected automatically from the scan data. BMD is a less precise measure than is BMC, but partially compensates for the effect of patient size on bone density and is a better indicator of fracture risk. SPA measured integral (cortical and trabecular) bone and was applied to different sites along the shaft of the radius, which contain differing proportions of cortical and trabecular bone. The mid shaft consists entirely of cortical bone, in the distal metaphysis there is a cortical / trabecular ratio of 6:1, in the ultra distal site trabecular bone (95 %) predominates [9]. SPA had a very low radiation dose (effective dose equivalent EDE approximately 0.6 mSv). Precision (coefficient of variation CV %) for BMC in the mid shaft and distal metaphysis was 1 %. With the shape of the bones being less uniform in the ultra distal site repositioning errors are more critical and precision is 2–3 %. Accuracy was between 4–6 % [10,11]. The scanning time was 10–15 min. With a half-life of 60 days the radionuclide source of ^{125}I degraded and required replacement two or three times a year. SPA was a widely used and established bone density technique, the results of which were predictive of fracture risk in the appendicular skeleton, hip and spine. SPA has now

been superseded by single energy X-ray absorptiometry (SXA) in which the radionuclide source has been replaced by a low dose X-ray source.

2.2.2 Dual photon absorptiometry (DPA)

The limitation of SPA was that it could be applied only to peripheral skeletal sites. DPA was introduced in the 1960 s to enable bone density measurements to be made in more clinically relevant sites such as the spine, hip and whole body. The simultaneous measurement of γ -radiation of two different energies allows for the correction of soft tissue and fat of the torso without the need for a water bath. The most widely used radionuclide was ^{153}Gd that produces photons at energies of 44 and 100 KeV. The transmitted photons of the two energies were counted separately by scintillation detectors. The low (44 KeV) and high (100 KeV) energy photons were attenuated differently in bone and soft tissue. The difference in relative attenuations allowed the mass of bone mineral in the beam to be calculated and expressed as BMC in 'g' or as an areal bone density BMD in ' g/cm^2 '. From scanning of the whole body could be derived total body mineral, lean (muscle) and fat contents. The equipment scanned in a rectilinear fashion and because of the low photon flux, images were of low spatial resolution and took a considerable scanning time (lumbar spine 30 min, whole body 40–60 min), which limited precision (2–4 %) due to patient movement during scanning. In DPA an assumption was made that soft tissue is of uniform composition but of unknown thickness, but this is not so in practice and non-uniform thickness of adipose tissue contributes to accuracy errors of up to 9%. Due to decay the radionuclide source had to be replaced annually. DPA has now been replaced by dual energy X-ray absorptiometry (DXA).

2.2.3 Single energy X-ray absorptiometry (SXA)

The physical principles of SXA are the same as SPA, except that the photon source is an X-ray system (55 kV, 300 μA) with K-edge filtration and solid-state detectors (Osteometer MediTech A/S, Rødovre, Denmark). If a single energy X-ray beam is used then the arm is placed in a water bath to allow correction for soft tissue overlying bone. If a dual energy X-ray beam is used the water bath is not necessary. The equipment is relatively compact and mobile; scanning takes about 5 min. The position of the forearm is standardized by the patient gripping a vertical rod. The scans are performed in a rectilinear fashion in a distal (87 % cortical bone) and ultra distal (predominantly [65%] trabecular

bone) site. Results are expressed as BMC in g or BMD in g/cm^2 . Accuracy is 3 %, precision is better than 1 % and radiation dose EDE is 0.1 μSv .

2.2.4 Dual energy X-ray absorptiometry (DXA)

The physical principles of DXA are similar to those of DPA, except that a low dose X-ray tube replaces the gadolinium as a source of photons. The first commercially available DXA scanner was introduced in 1987. X-ray beams of two peak energies are produced by a variety of techniques by different manufacturers. The energies used are selected to optimize separation of the mineralized and soft tissue components of the area analyzed. Scanners manufactured by HOLOGIC (Waltham, Massachusetts, USA) use an energy switching system in which the X-ray tube potential is switched rapidly from 70 kVp to 140 kVp alternating at 60/s. The problems of beam hardening and background radiation usually associated with polychromatic beams produced by X-ray tubes in quantitative applications are overcome by appropriate corrections and simultaneous calibration by continuously interposing known amounts of bone- and soft tissue- equivalent material in the beam. This reference calibration material is mounted on a disc, which rotates synchronously with the X-ray pulses (Fig. 2). The scanners manufactured by the LUNAR Corporation (Madison, Wisconsin USA), NORLAND Corporation (Atkinson, Wisconsin, USA) and Sopha use a constant potential X-ray source combined with a rare earth filter with energy-specific absorption characteristics due to K-edges of the atomic structure of the element (K-edge filtration). The K-edge filter separates the X-ray distribution into two separate components of 'high' and 'low' energy photons (70 KeV and 40 KeV) [12]. The technique is most commonly applied to scanning of the lumbar spine (L1 to L4), femoral neck (regions of analysis include neck, trochanter, and Ward's area) and whole body.

3. DUAL ENERGY X-RAY ABSORPTION

3.1 Introduction

Since its introduction in 1987 by Stein et al [13], dual X-ray absorptiometry (DXA) has become the most widely used bone densitometry technique. Growing awareness of the dual X-ray absorptiometry scanners have led to impact of osteoporosis on the elderly population, the costs of healthcare, and the development of new treatments to prevent fractures have all contributed to the rapid growth in demand for bone densitometry services. Today, scans to measure BMD play an essential role in the evaluation of patients at risk for osteoporosis. With its advantages of high precision, short scan times, low radiation dose, and stable calibration, DXA is well-suited to meet the need for test equipment to diagnose osteoporosis and to guide decisions about which patients should receive treatment [14].

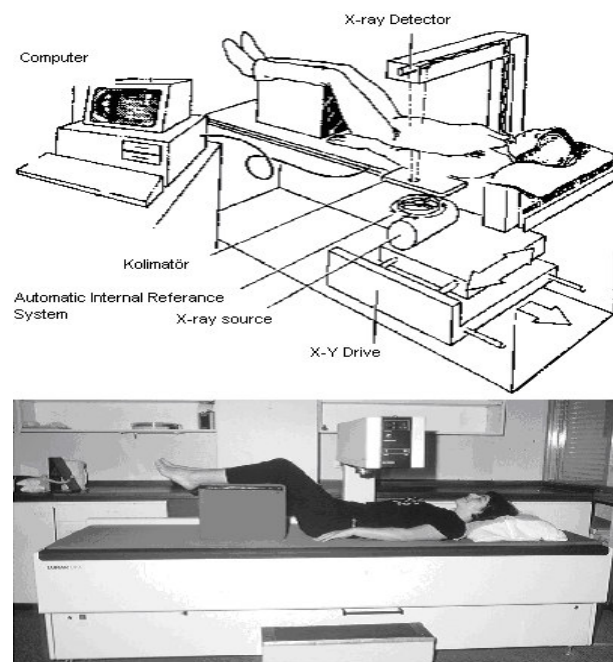


Figure 3.1 Scheme and Photograph of DEXA densitometer [15].

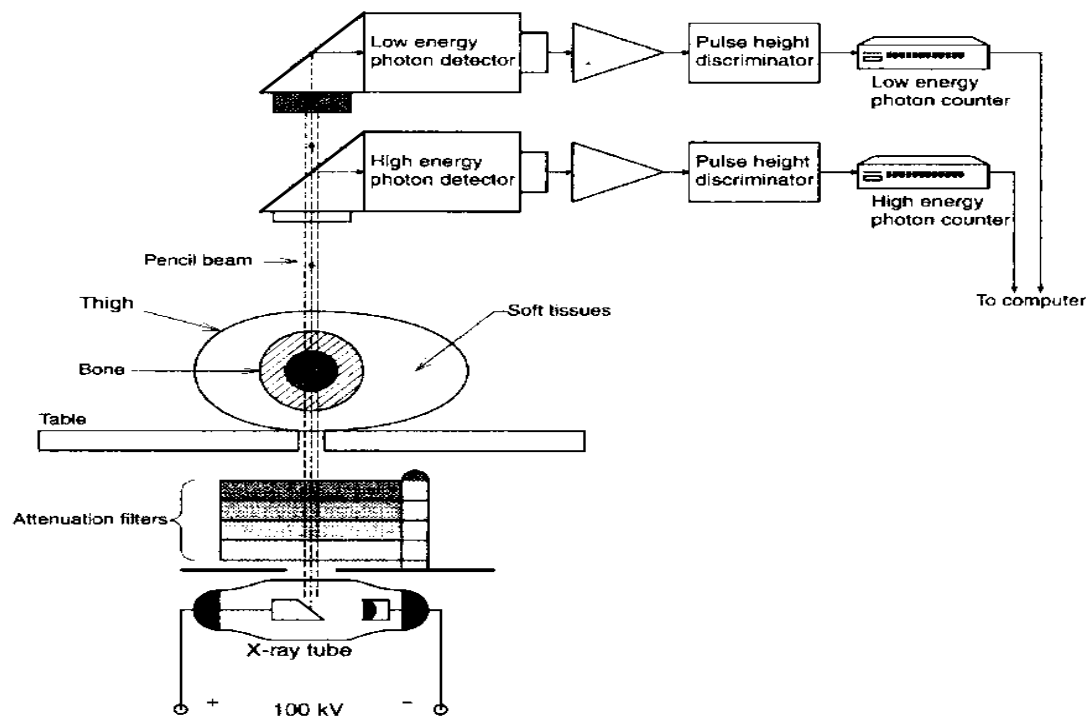


Figure 3.2 Scheme of operating theory of DEXA system [18].

Dual energy x-ray absorption (DEXA) method is an accurate means of measuring bone mineral density, primarily from the calcium content in bone salts [15]. DEXA is typically used on the heel, wrist or forearm, proximal femur or lumbar spine. A typical DEXA system is shown in picture and scheme.

3.2 Theory of DEXA System

The basic principle is to count the high and low energy x-ray photons. The difference of the number of the high energy and low energy photons give a smooth idea of absorbed energy by bone and of the bone mineral density. The Figure shows the attenuation coefficients of different tissue types

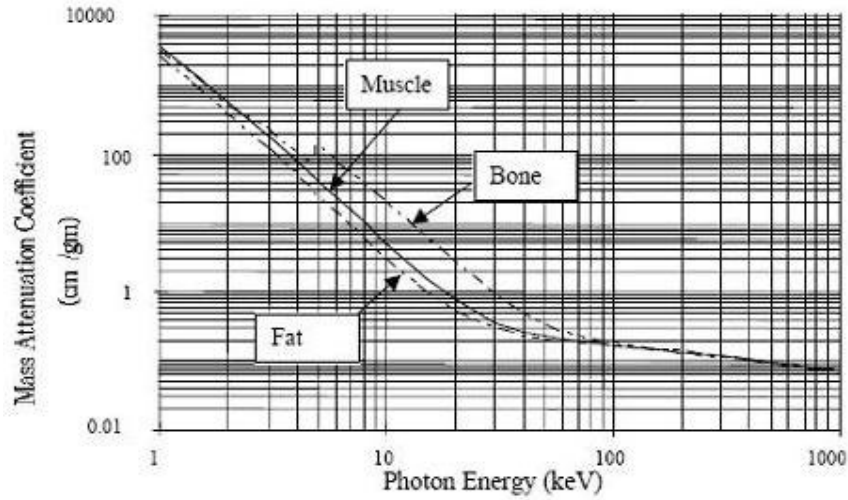


Figure 3.3 Mass attenuation coefficients of tissues.[16]

X-rays are characterized by their photon energy (keV) and their intensity (W/m^2). X-rays can be formed into fairly collimated pencil beams or floodlight-like fan beams. Both types are used in various DEXA systems. The operation of a DEXA system is reminiscent of pulse oximetry using light at two different wavelengths. The law that governs X-ray absorption (or transmission) in bone is;

$$\frac{I_{out}}{I_{in}} = \exp [- \mu_{\lambda} \rho L] \quad (3.1)$$

where:

- I_{out} is Intensity of transmitted X-rays
- I_{in} is Intensity of transmitted X-rays
- μ_{λ} is wavelength-dependent mass attenuation coefficient (cm^2/g)
- ρ is Volume density of absorbing medium(g/cm^3)
- L is bone of thickness

At the figure below the relative intensity/hv vs. X-ray photon energy hv in keV at the various conditions in a DEXA x-ray system is illustrated. The top curve is the intensity spectrum of X-ray photons leaving the X-ray tube. The second curve is the attenuated photons entering the tissue and bone, and the bottom curve is the intensity spectrum of

photons exiting the bone. (The X-ray tube is bombarded with 100keV electrons.) The two triangular graphs on the spectrum plots represent the spectral sensitivities of low- and high-energy X-ray detectors that respond to the photon intensities in the exiting X-ray beam[16].

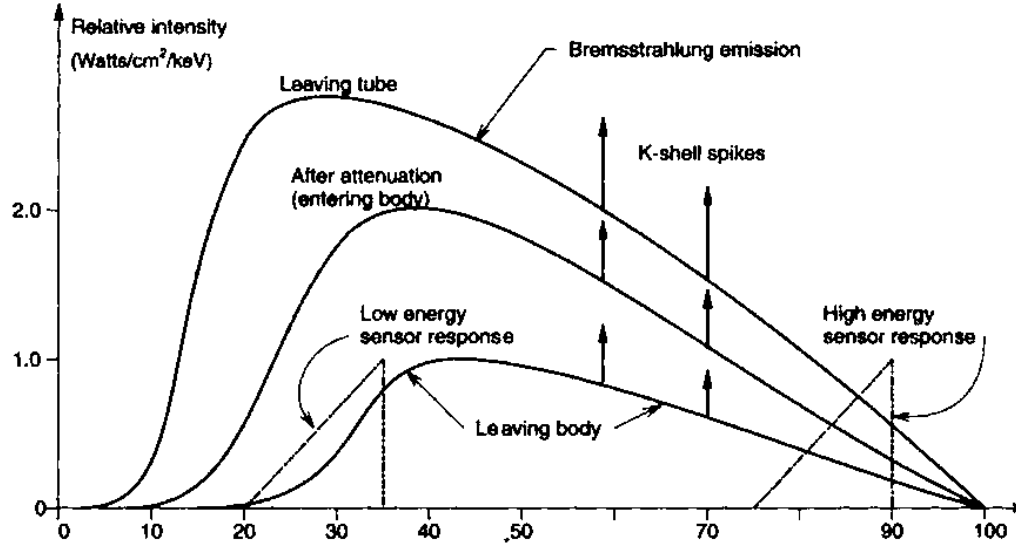


Figure 3.4 Photon Energy, $h\nu$, keV [19]

The X-ray absorption equation can be modified to find the effective density of calcium in a bone of thickness L . One approach to this problem is to consider the incident X-ray spectrum to be absorbed by the calcium in the bone and “other tissue” including the soft tissue surrounding the bone, and the collagen in the bone matrix. Because the X-ray photon detectors select low- and high-energy photons and two absorbers have been defined (Ca and “other”), there are four mass attenuation coefficients associated with the DEXA system:

μ_{HC} : The mean mass attenuation coefficient for Ca at high energy

μ_{LC} : The mean mass attenuation coefficient for Ca at low energy

μ_{HO} : The mean mass attenuation coefficient for “other” at high energy

μ_{LO} : The mean mass attenuation coefficient for “other” at low energy

All four mass attenuation coefficients are assumed to be known from prior measurements. Thus, the detected X-ray intensities can be written:

$$I_L = I_{inL} \exp[-\mu_{Lc} \rho_c L] \exp[-\mu_{Lo} \rho_o L] \quad (3.2)$$

$$I_H = I_{inH} \exp[-\mu_{Hc} \rho_c L] \exp[-\mu_{Ho} \rho_o L] \quad (3.3)$$

where;

I_{inL} and I_{inH} are the total intensity of X-ray to the tissue defined by the low and high-energy detectors' acceptance spectrum,

I_L and I_H are the transmitted intensity of the low and high energy X-ray

L is the path length through the sample

ρ_c is the unknown physical density of Ca in the bone

ρ_o is the mean mass density of other tissues in the sample

The equations can be rewritten as;

$$I_L = I_{inL} \exp[-\mu_{Lc} \rho_c L - \mu_{Lo} \rho_o L] \quad (3.4)$$

$$I_H = I_{inH} \exp[-\mu_{Hc} \rho_c L - \mu_{Ho} \rho_o L] \quad (3.5)$$

When the natural logarithms of both sides of each equation are taken;

$$\ln(I_{inL} / I_L) = \rho_c \mu_{Lc} L + \rho_o \mu_{Lo} L \quad (3.6)$$

$$\ln(I_{inH} / I_H) = \rho_c \mu_{Hc} L + \rho_o \mu_{Ho} L \quad (3.7)$$

These equations are solved for the Ca density, ρ_c , g/cm³ by the DEXA system computer, which has the values for the μ matrix, L , I_{inL} and I_{inH} stored in memory.

$$\rho_c = \frac{\mu_{Ho} \ln(I_{inL} / I_L) - \mu_{Lo} \ln(I_{inH} / I_H)}{L[\mu_{Lc} \mu_{Ho} - \mu_{Hc} \mu_{Lo}]} \quad (3.8)$$

Once measured on a patient, ρ_c and ρ_o are compared with the database value for the same bone in a healthy person at age 30 or the same age.

4. ANALYSIS

4.1 T-Score

BMD is ratio of the measured bone mineral content (BMC) in grams divided by the measured two-dimensional projected area in cm^2 of the bone(s) being measured; thus the units of BMD are g/cm^2 . However, most clinical decisions are based on the T-score, which is calculated by comparing the patient's BMD with the mean value for young normal individuals and expressing the difference as a standard deviation score. The T-score is calculated using the formula: “(patient's BMD – young normal mean)/SD of young normal”. For example, if a patient has a BMD of $0.700 \text{ g}/\text{cm}^2$, the young normal mean is $1.000 \text{ g}/\text{cm}^2$, and the young normal standard deviation is $0.100 \text{ g}/\text{cm}^2$, then this patient's T-score would be $(0.700-1.000)/0.100$, or $-0.300/0.100$, or -3.0 .

A T-score of 0 is equal to the young normal mean value, -1.0 is 1 SD low, -2.0 is 2 SD low, etc. A working group of the World Health Organization (WHO) proposed a classification based on T-scores that have been widely used: T-score of

- 1.0 and above is considered normal;
- 2.5 and below is considered osteoporosis [17].

The cut-point of -2.5 was selected so the proportion of patients diagnosed with osteoporosis would be roughly equivalent to the lifetime risk of fracture at age 50 [17]. Although it is not intended to be applied to individual patients, the WHO classification works well to define normal (T-score -1.0 and above) and osteoporosis (T-score -2.5 and below). Several large studies have shown an unacceptably high risk of fracture in patients who have T-scores of -2.5 and below and a significant reduction in fracture risk with treatment, making this threshold an evidence based criterion for the diagnosis of osteoporosis and for the initiation of treatment [18], although other factors such as age, health status, prior fracture, etc. must be considered in deciding to initiate treatment.

The relationship between BMD and fracture is a continuous gradient: there is no fracture threshold. Although it is often useful to think categorically when dealing with a

continuous variable, the category of low bone mass (osteopenia) creates problems because it includes people with a wide range of fracture risk, from low to high. Most subjects who are in the upper part of this borderline range are perfectly normal (and because the distribution is on a bell-shaped curve, most subjects in this borderline range are in the upper part of the range). Applying a medical label such as osteopenia to a healthy young person (e.g. a 30-year-old who has a T-score of -1.1) can create considerable anxiety that may last a lifetime. At the other extreme, subjects who are in the lower part of this borderline range (e.g. -2.4) are almost as likely to fracture as patients on the lower side of the arbitrary cut point (perhaps more likely to fracture, depending on other risk factors for fracture). The term osteopenia should be avoided as it relates to bone densitometry results; rather, people in this category can be said to have borderline low bone mass (upper part of the intermediate range) or low bone mass (lower part of the intermediate range), non-judgmental terms that should make the clinician stop and think about the result and its context [19]. Patients who appear healthy and have BMD in the upper part of this range should be reassured and checked again, usually in 5–10 years, depending on the anticipated rate of bone loss. Patients in the lower part of the range should at least be checked every year or two, and may even be candidates for intervention, depending on how low their BMD is, and if they have other risk factors, such as older age or prevalent fractures [20].

At least in postmenopausal Caucasian women, there is a predictable relationship between low bone density and high fracture risk. In untreated subjects, the risk of fracture roughly doubles for each SD reduction in BMD [e.g. someone who has a T-score of -1.0 is twice as likely to fracture as someone (with other similar characteristics) who has a T-score of 0, someone with a T-score of -2.0 is 4 times more likely to fracture, someone at -3.0 is 8 times more likely to fracture, etc. [21].

4.2 Z-Score

In addition to the T-scores, DXA reports also provide Z-scores, which are calculated similarly to the T-score, except the patient's BMD is compared with an age-matched (and race- and gender-matched) mean, and the result expressed as a standard deviation score. A low Z-score indicates that bone density is lower than expected (i.e. bone loss more than could be explained by age or menopause), and should trigger a search for an underlying cause.

5. PURPOSE OF THE STUDY

5.1 Quality Control of DEXA

In normal conditions, the bone loss speed of osteoporosis disease is very slow. Typical postmenopausal BMD loss speed is 10 mg/cm² per year. So a bone densitometer shall distinguish such small differences, and give precise results not to misinform the physician.

In a panel organized by the members of Australian and New Zealand Bone and Mineral Society, The Australian and New Zealand Association of Physicians in Nuclear Medicine, The Royal Australian and New Zealand College of Radiologists and The Australasian College of Physical Scientists and Engineers in Medicine, some standards regarding the operating and maintaining bone densitometers are proposed [22]. According to those standards the long- and short-term precision and accuracy of bone densitometers shall be controlled regularly.

For the short-term precision in-vitro and in-vivo tests are described. For in-vitro short-term precision control, manufacturer's recommended quality control (QC) phantom shall be scanned 10-20 times. From these measurements the mean BMD of the Phantom and the coefficient of variation (CV) of the results shall be calculated.

$$CV = \frac{\text{Standard deviation}}{\text{Mean}} \times 100\% \quad (5.1)$$

Besides in-vitro precision, in-vivo short-term precision shall also be controlled on each machine, by obtaining voluntary follow-up scans within a short timeframe (maximum 1 month), or duplicating scans on the same day, on at least 28 subjects. The volunteers shall be in an age range appropriate to the generally scanned population and should give informed consent. From these values in-vivo short-term precision for BMD shall be obtained.

Calibration and quality control shall be performed according to manufacturer's specifications. The QC phantom shall be scanned at least twice weekly (and preferably daily) using the same scanning parameters. This phantom is not the daily calibration phantom, but is an anthropomorphic (or quasi-anthropomorphic) phantom recommended by (or at least acceptable to) the manufacturer. The QC phantom data shall be recorded and checked for medium-term precision error and systematic bias using the appropriate statistical analysis.

Examination of trends in QC parameters (particularly BMD) over periods of years is a necessary precaution for establishing the integrity of long-term studies of individual patients, or for the reporting of results from clinical trials. The statistical methods used to examine long-term trends are the same as those used for medium term studies. However, it should be noted that statistical analyses become more powerful and illuminating, with the acquisition of larger data groups - so that analyses are worth periodically repeating as the QC history of a machine accumulates.

Reproducibility of the measurements is an other quality parameter of bone densitometers. The reproducibility shall be controlled by scanning the QC phantom 10-20 times without repositioning it. And for acceptable reproducibility none of the BMD results must be out of the range of $\pm 1.5\%$ of mean.

5.2 Cross Calibration

Besides the unique device performance there is a standardization problem between bone densitometers. The reference values are based on different reference populations with uncertain selection criteria. As a result, measurements for the same individual obtained on different scanners, even when using the same procedures and technology, cannot easily be compared. This causes particular problems when the patient moves from the town, or in multi-center studies in which data should be pooled, and in follow-up studies of patients that continue beyond the life cycle of a particular scanner (equipment replacement).

Because of equipment ageing and rapid advances in technology, over periods of 5 to 10 years, older absorptiometers are likely to be replaced [23]. It is widely recognized that, owing to differences in technology, software and calibration, the replacement of an absorptiometer by one from a different manufacturer can make it difficult to maintain the

continuity of the in vivo BMD scale [24]. However, when a DXA scanner is replaced by a newer model from the same manufacturer it should be possible using the manufacturer's recommended procedure (usually based on scanning suitable phantoms) to ensure continuity of calibration for future patient BMD measurements [25 26].

Clinicians, however, need to consider the effect of variability in BMD measurements in order to assess an individual's true BMD or the true response to treatment. Therefore the effect of BMD measurement variability may lead not only to osteoporosis misclassification but also to misinterpretation of treatment response. Unfortunately, compared with standard laboratory practices for measuring chemical analytes, DXA does not allow an experimental design that continuously evaluates analytical performance. The lack of an appropriate universal calibration (reference) standard further compounds such problems, especially if comparative calibration is attempted between different DXA instruments [1]. Also, because the yearly postmenopausal decrease in BMD is so low, typically $<10 \text{ mg/cm}^2$ at the femoral neck [2,3], extremely high in vivo precision is necessary to confirm normal or slightly increased bone loss within a 1 to 2 year time frame – a requirement present-day DXA technology does not satisfy.

5.3 Aim of the Study

We aim to scan different densitometers by a standart technique with a single European Spine Phantom (ESP 03-208) so that we can calculate cross calibration formulas. Because we perform 10 repeated scans on each bone densitometer without repositioning the phantom, we can analyze the reproducibility of the densitometers as well.

We calculate cross calibration formulas for the most common models we meet during the measurements as well as formulas for each device. We compare the cross calibration formulas with the previously calculated formulas in the literature. And also we control our formulas for fitting values.

6. THE EUROPEAN SPINE PHANTOM

6.1 Introduction

The design study of the European Spine Phantom started in 1989 funded by the European Union under its organization COMAC-BME(Committee d'Actions Concertées-BioMedical Engineering) within the project Quantitative Assessment of Osteoporosis[27]. The European Spine Phantom was intended to serve both for daily quality control and for cross-calibration between different scanning systems.

6.2 General Design Considerations

From the start of the process, a number of general considerations were decided upon and adhered to consequently:

The phantom was to be constructed in a geometrically well-defined form with different materials of specified physical densities. This should ensure that true values could be specified for all quantities to be measured and thereby qualify the phantom as a potential calibration standard.

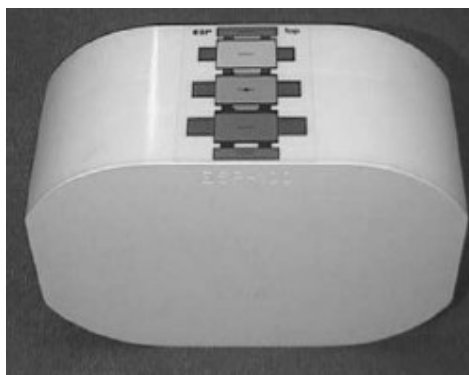


Figure 6.1 The European Spine Phantom

The phantom had to be fit for use on both DXA and QCT scanners. It was felt that a diversity of phantoms with different ones for each modality would only enhance existing irritation or confusion and would potentially add to cost in general.

The phantom should be closely anthropomorphic so that standard protocols for measurement and evaluation could be used on all scanners without alterations. This should make the use of phantom easier and more practical above all however this is required for its use in cross-calibration of scanners where conversion equations are to be obtained which reflect relations measured between patient populations.

The number of different tissue substitute materials used should be kept to a minimum. This took into account the fact that it would be difficult and impractical to represent all possible tissue combinations and their changes with age and sex in one phantom. not to mention the difficulty in arriving at widely accepted definitions.

6.3 Tissue Substitute Materials

To avoid controversy with respect to the definition of different tissue substitute materials it was decided to limit the phantom constituents to water- and bone-equivalent solid materials. For such purposes polyethylene-based [28] and epoxy-resin-based [29] plastics are used. Polyethylene plastics are attractive for large volume production because industrial processes can be used; cross-sections should be limited to a few centimeters only to achieve adequate homogeneity. Epoxy-resins offer the advantage that they can be moulded in arbitrary shapes and cross-sections but they require considerable manual labor and only limited quantities can be processed at a time. Epoxy-resin-based materials are decided to be used to be able to easily adapt to arbitrary design modifications.

Water equivalent materials are here defined as plastics that exhibit the same attenuation characteristics as water with respect to x-ray photons in the energy range of 30-150 keV. In addition to the epoxy-resin system. 3.98%(by weight) CaCO_3 has been added to adjust the effective atomic number. 2.96% phenolic microspheres to adjust the density of material and 15% polyethylene to control the viscosity of the final mixture. Bone-equivalent tissues are provided by adding calcium hydroxyapatite {HA defined as $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ } to the water-equivalent mixture.

6.4 Phantom Vertebra Density Parameters

Reference values for spongiosa densities have been reported in a large number of reports on QCT studies; a range of 50-200mg/cm³ HA density appeared representative for

covering all age groups. For cortical densities few reliable data are available from QCT studies since a mixture of cortical and spongy structures is mostly averaged due to the limited spatial resolution of the standard imaging modalities; reported values typically range from 200 to 500 mg/cm³ [30]. In the literature density values of up to 1200 mg/cm³ bone mineral equivalent are quoted [31]. The density of 800 mg/cm³ is selected for the vertebral cortical walls and the vertebral arch the highest value provided with the present resin technology. For the appendicular structures spinous and transverse process, a value of 400 mg/cm³ was selected to represent a mixture of spongy and compact bone.

For the densities measured in PA DXA, values of 0.5, 1.0 and 1.5 g/cm² HA density were considered to span the range found in clinical practice; this is in agreement with a large number of studies [24,27]. These values are provided by the phantom for the projected area of the vertebral bodies including the intervertebral spaces.

Table 6.1
Design Parameters of the Vertebral Inserts in the ESP [32].

	<u>L1</u>	<u>L2</u>	<u>L3</u>
Geometry (mm)			
Body Diameter	36	36	36
Arch Diameter	28	28	28
Height	25	25	25
Body wall	0.5	1.0	1.5
Endplate	1.0	1.0	2.0
Arch thickness	5.2	6.0	7.0
Spinous process thickness	6.0	8.0	10.0
Spinous process length	11.7	14.6	21.0
Hydroxyapatite densities (mg/cm³)			
Spongiosa	50	100	200
Endplates	400	800	800
Arch	400	800	800
Processes	400	400	400
PA projection of vertebral body			
Area (cm ²)	10.12	10.12	10.12
BMC (g)	5.06	10.12	15.18
BMD (g/cm ²)	0.50	1.00	1.50
Lateral projection of vertebral body			
Area (cm ²)	7.33	7.33	7.33
BMC (g)	2.66	5.17	8.54
BMD (g/cm ²)	0.36	0.71	1.17

6.5 Geometric Parameters

The basic geometric parameters are summarized in Table-1. An oval phantom cross-section of 18cm x 28 cm was chosen; with the sides flattened by 1 cm to allow for easy lateral positioning. A lateral diameter of 26 cm results the PA thickness of 18 cm of solid water appears realistic to approximate attenuation by the mean 20 cm PA thickness found in human which includes fat and/or abdominal gas; the lateral thickness of 26 cm of solid water is recommended as typical for lateral measurements in the decubitus position [33].

The outer dimensions of the vertebrae were chosen in accordance with measurements taken from PA and lateral radiographs. Vertebral height is chosen as 25 mm; this value is relatively small. But it represents the female population well and tends to limit the overall size and weight of the phantom. The diameter of the vertebral bodies was chosen of 36 mm; intervertebral spaces were set at 4 mm. The geometric cross-section of the transverse processes was chosen as triangular. This allows one to test the cutoff criteria employed in different DXA systems in a relatively easy manner. Cortical wall thicknesses are selected at 0.5 1.0 and 1.5 mm respectively. Even thinner walls might be of interest but cannot be easily produced with tight tolerances. Other design parameters such as lengths and thickness of the spinous processes and arch thickness are determined by computer calculations to arrive at the desired BMC and consequently BMD values in PA projection of 0.5, 1.0 and 1.5 g/cm² HA density respectively.

6.6 Manufacturing Tolerances and Quality Control on Phantom

Tolerances for the vertebral inserts of the ESP were set as follows:

Geometric measures: $\pm 0.1\%$ (at best 0.1 mm)

Hydroxyapatite concentrations: $\pm 1.0\%$ of certified value (at best 1.0 mg/cm³)
 $\pm 3.0\%$ of specified value (at best 3.0 mg/cm³)

Geometric measures are controlled with gauge measurements on the vertebral inserts before they are immersed in solid water. CT constitutes the method of the choice to check densities, CT value stability and homogeneity of the materials. CT values of the solid water are specified to lie in the range of ± 10 HU, measured in reference to distilled water.

Phantoms were scanned contiguously with 5 mm slice thickness to check for homogeneity and possible manufacturing defects. In addition a standard QCT study of the

three midvertebral slices was carried out with 10 cm slice thickness at 80 kVp on a SOMOTOM PLUS CT scanner (Siemens AG. 91052 Erlangen. Germany). DXA measurements were taken on scanners of three different manufacturers (HOLOGIC Waltham. MA. USA; LUNAR. Madison. WI. USA; NORLAND. Fort Atkinson. WI. USA) to compare these scanners and to check and to document consistency of production.

Table 6-2
BMD measurements on the first 30 ESPs

	L1 BMD (g/cm²)	L2 BMD (g/cm²)	L3 BMD (g/cm²)
Reference Value	500	1000	1500
HOLOGIC QDR 1000 W	494 ± 8	924 ± 13	1358 ± 24
LUNAR DPX	589 ± 22	1063 ± 12	1516 ± 19 (14)
NORLAND	567 ± 19	927 ± 24	1312 ± 35

7. PHANTOM SCANS

The European Spine Phantom (serial number ESP 03-208) is used in all measurements. 28 bone densitometers in 26 centers were scanned with this phantom. The centers include private 12 hospitals, 5 polyclinics, 6 university hospitals, and 5 diagnostic imaging centers. Densitometer manufacturers are namely LUNAR, HOLOGIC, MEDILINK and NORLAND.

Table 7.1
Manufacturer & Model Distribution of Included Densitometers

Manufacturer	Model	Number of Densitometers
HOLOGIC	QDR 1000	1
HOLOGIC	QDR 1500	1
HOLOGIC	QDR 4000	3
HOLOGIC	QDR 4500	7
LUNAR	DPX	7
LUNAR	DPX – IQ	3
LUNAR	DPX – NT	3
MEDILINK	OSTEOCORE – 2	1
MEDILINK	OSTEOCORE – 3	1
NORLAND	XR	1

7.1 Measurement Technique

The densitometers are scanned with the ESP (s.n. 03-208) phantom after the devices' self calibration procedure with the manufacturers' phantoms. The ESP (s.n. 03-208) phantom is first placed on the table by centering the x-ray arm path and scanned for 10 times without repositioning it. The scans are performed in normal scan mode. None of the “turbo” or “fast” modes are used. Array mode is let when applicable.

Immediately after each scan the analysis were performed. The systems are let to detect the region of interest (ROI) unless very big mis-detections were observed. The interface borders of the vertebrae are manually adjusted by the technician.

7.2 Statistical Analysis

We shall briefly remind some basic statistical terms:

Accuracy: It refers to the closeness of an observed result to the true or accepted value.

Precision: It refers to the variance of the method when used to make repeated measurements under specified conditions.

Bias: It is a systematic displacement of all observations in a sample from the true or accepted value.

Error: In statistical usage it does not connote a mistake or blunder but usually refers to the chance deviation between an observation and its expected or average value.

Correlation: It is used to determine whether a linear relationship is present between 2 quantitative variables. To measure the strength of this relationship we calculate the Pearson's correlation coefficient, which will range from -1.0 to $+1.0$.

Regression: A regression analysis studies the strength of a relationship between 2 variables when one of them depends on the other. This allows us to predict one variable given the value of the other. The simplest way to think of linear regression is that the relationship is summarized by a single line through the data points. The standard method for fitting this line is known as the least squares regression, meaning that the distance squared from all points to the line is as small as possible.

The BMC, area and BMD data obtained from the measurements were analyzed in the MATLAB[®]. First of all basic statistical information is obtained; the mean, standard deviation and coefficient of variation of each center's results were calculated and the graphs were plotted. Then the cross-calibration formulas were described by using the Regression Analysis.

8. MEASUREMENT RESULTS

As mentioned before in 26 centers, 28 densitometers are scanned. 13 densitometers are LUNAR (7 DPX, 3 DPX-IQ, 3DPX-NT), 12 are HOLOGIC (7 QDR-4500, 3 QDR4000, 1 QDR-1500 and 1 QDR-1000), 2 are MEDILINK (1 is Osteocore 3 and 1 is Osteocore 2), and the last densitometer is NORLAND (XR series). All of the densitometers are scanned with the same phantom, using AP Lumbar Spine examination in normal scan mode. After each scan the report is plotted. The measurement results are stored in PC and statistical analyses are performed using MATLAB®.

In the appendix there are tables and figures of BMD results and reproducibility acceptance range (If there is any scan out of reproducibility acceptance range it will be mentioned by **BOLD** characters.), mean, SD and $\pm 1.5\%$ mean range of BMD results, daily system test report (if available).

As the statistical summary for the models and manufacturers is studied, it is easily realised that there are no brands or models that show particularly better performance than others do. All devices show the same trend and detect smaller area of interest for lower bone densities.

When the most common models are studied separately, HOLOGIC QDR 4500 seems to give smaller coefficient of variation than LUNAR DPX. The both models tend to give more accurate results as the bone density increases.

As it is seen in the graph in Figure 8, the BMC values vary between, 6,021 g and 1,387 g for L1; 11,312 g and 7,863 g for L2; and 17,552 g and 10,919 g for L3 where it should be 5,06 g for L1; 10,12 g for L2 ; and 15,18 g for L3.

As it is seen in the graph in Figure 9, the BMA values vary between, 11,94 cm² and 2,45 cm² for L1; 11,66 cm² and 7,93 cm² for L2; and 11,97 cm² and 8,27 cm² for L3 where it should be 10,12 cm² for all three vertebra.

As it is seen in the graph in Figure 10, the BMD values vary between, 0,491 g/cm² and 0,623 g/cm² for L1; 0,873 g/cm² and 1,075 g/cm² for L2; and 1,284 g/cm² and 1,579 g/cm² for L3 where it should be 0,50 g/cm² for L1; 1,0 g/cm² for L2; and 1,5 g/cm² for L3.

Table 8.1
BMD, BMA and BMC Measurement Results

HOLOGIC QDR 4500	BMD			BMC			BMA		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
Mean	0,52	0,92	1,36	4,19	9,19	14,14	7,99	9,98	10,38
STANDART DEVIATION	0,01	0,02	0,03	0,17	0,21	0,36	0,35	0,20	0,27
Coeff. of Variation (%)	1,65	1,78	2,12	3,98	2,29	2,55	4,38	2,01	2,62
LUNAR DPX	BMD			BMC			BMA		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
Mean	0,60	1,07	1,55	4,92	10,17	15,51	8,22	9,55	9,99
STANDART DEVIATION	0,02	0,02	0,03	0,41	0,15	0,25	0,67	0,13	0,19
Coeff. of Variation (%)	3,01	1,43	1,81	8,42	1,48	1,60	8,12	1,32	1,90

Table 8-2
LUNAR DPX- HOLOGIC QDR 4500 (most common models) Statistics

HOLOGIC QDR 4500	BMD			BMC			BMA		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
Mean	0,52	0,92	1,36	4,19	9,19	14,14	7,99	9,98	10,38
STANDART DEVIATION	0,01	0,02	0,03	0,17	0,21	0,36	0,35	0,20	0,27
Coeff. of Variation (%)	1,65	1,78	2,12	3,98	2,29	2,55	4,38	2,01	2,62
LUNAR DPX	BMD			BMC			BMA		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
Mean	0,60	1,07	1,55	4,92	10,17	15,51	8,22	9,55	9,99
STANDART DEVIATION	0,02	0,02	0,03	0,41	0,15	0,25	0,67	0,13	0,19
Coeff. of Variation (%)	3,01	1,43	1,81	8,42	1,48	1,60	8,12	1,32	1,90

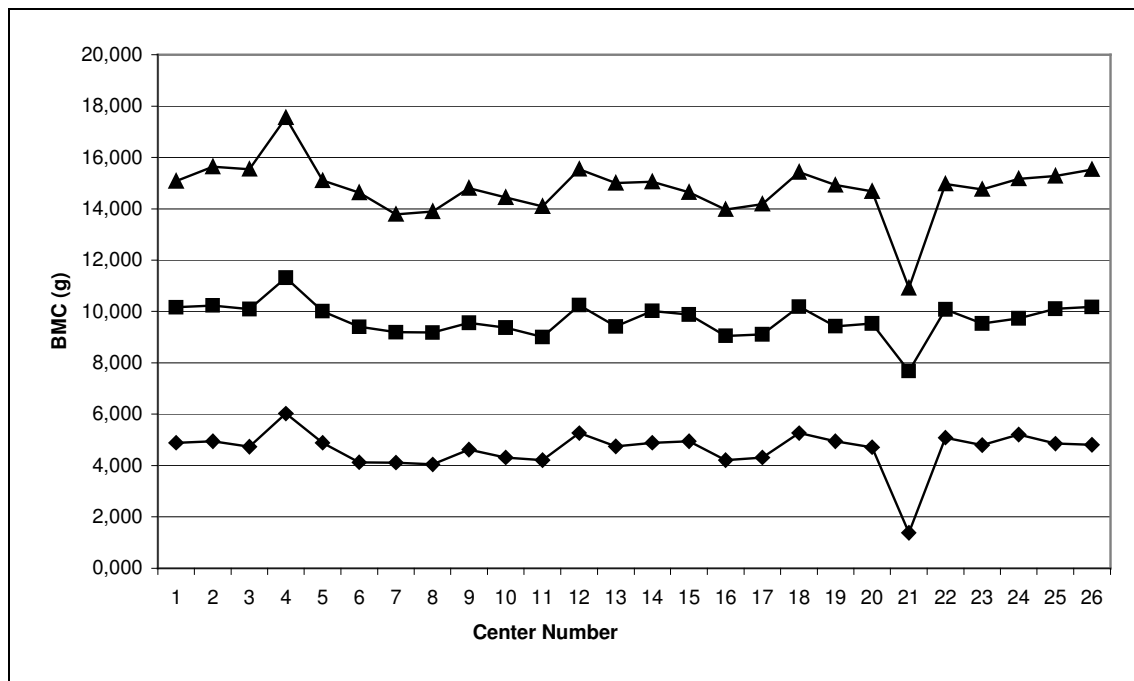


Figure 8.1 Variation of BMC (g) with Centers

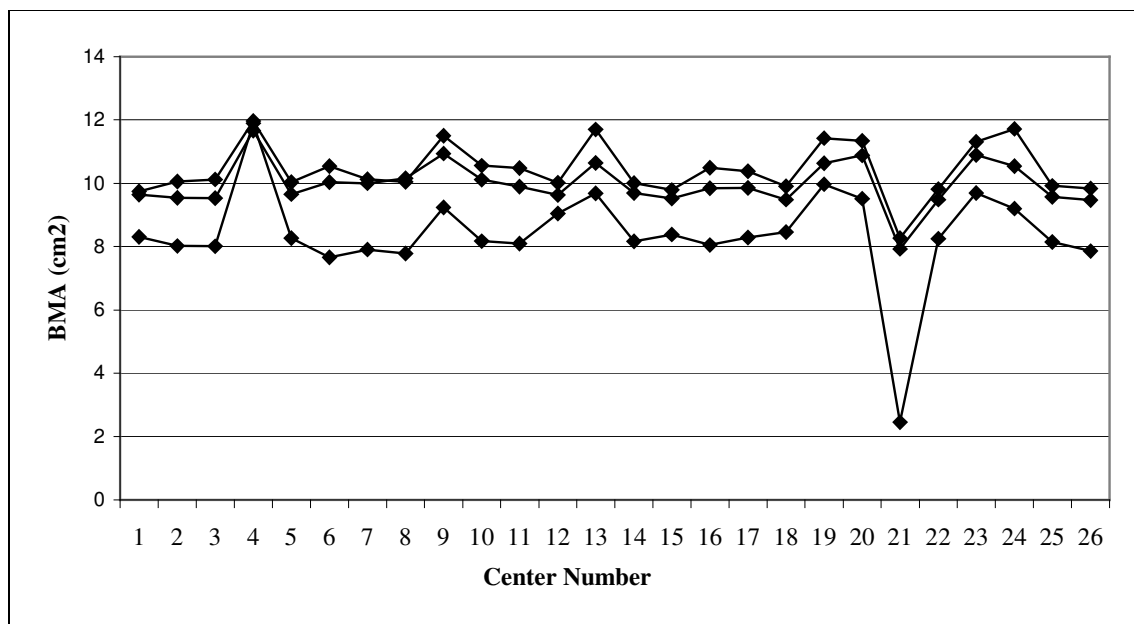


Figure 8.2 Variation of BMA (cm²) with Centers

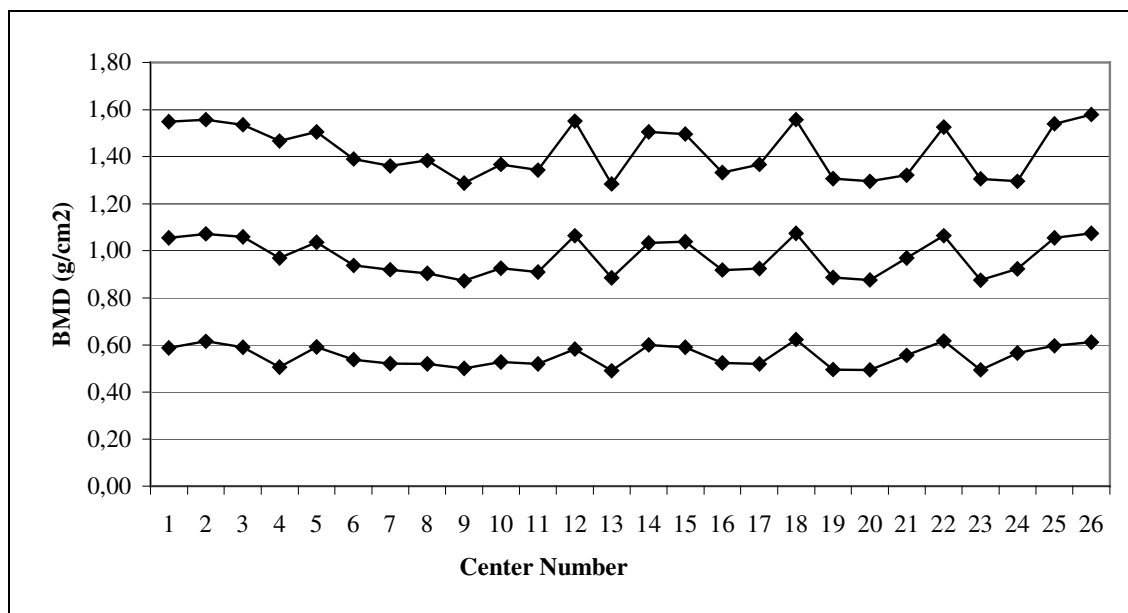


Figure 8.3 Variation of BMD (g/cm²) with Centers

8.1 Cross-Calibration Formulas for Types of DEXA's

For cross calibration formulas “REGSTATS” command in MATLAB[®] program is used. With the “REGSTATS” command, MATLAB[®] calculates the linear regression coefficients β_1 and β_2 :

$$D_1 = \beta_1 + \beta_2 D_2 \quad (8.1)$$

where;

D_1 , BMD data group from DEXA # 1

D_2 , BMD data group from DEXA # 2

Table 34 and Table 35 show the regression coefficients for the cross-calibrations of models. To calculate the value of the center at the first column you shall add (Table 34) or multiply (Table 35) the cell value that corresponds the center on the horizontal line.

Table 36 and Table 37 show the regression coefficients for the cross-calibrations for individual centers. To calculate the value of the center at the first column you shall add

Table .8-5
 β_0 for cross calibration formulas of 28 densitometers

	Alka	Alman	Ame- rikan	Ana- dolu	Capa	Center- med	Cerrah- pasa1	Cerrah- pasa2	Emar	Flo- rence	Gata	Gazi- hologic	Gazi- lunar	HSH
Alka	0,000	-0,032	-0,014	0,087	-0,033	-0,008	-0,002	0,028	-0,017	-0,014	-0,010	-0,014	-0,038	-0,040
Alman	0,040	0,000	0,026	0,122	0,006	0,035	0,038	0,068	0,021	0,026	0,029	0,025	0,002	-0,001
Amerika	-0,022	-0,017	0,000	0,100	-0,018	0,007	0,014	0,043	-0,002	0,001	0,005	0,002	-0,038	-0,024
Anadolu	-0,082	-0,117	-0,097	0,000	-0,117	-0,091	-0,085	-0,055	-0,102	-0,098	-0,094	-0,098	-0,121	-0,123
Capa	0,034	0,002	0,020	0,115	0,000	0,026	0,031	0,060	0,016	0,019	0,024	0,019	-0,004	-0,005
Centerm	0,013	-0,014	-0,001	0,088	-0,018	0,000	0,009	0,034	-0,004	-0,001	0,003	-0,001	-0,022	-0,023
Cerrahp	0,005	-0,024	-0,008	0,079	-0,025	-0,004	0,000	0,028	-0,012	-0,008	-0,005	-0,009	-0,030	-0,030
Cerrahp	-0,021	-0,049	-0,034	0,056	-0,051	-0,031	-0,024	0,000	-0,038	-0,035	-0,031	-0,035	-0,056	-0,056
Emar	0,017	-0,011	0,005	0,086	-0,012	0,010	0,014	0,038	0,000	0,004	0,007	0,004	-0,015	-0,017
Florence	0,017	-0,015	0,002	0,103	-0,018	0,008	0,015	0,044	-0,002	0,000	0,007	0,002	-0,022	-0,024
Gata	0,011	-0,019	-0,002	0,084	-0,019	0,003	0,008	0,034	-0,006	-0,002	0,000	-0,003	-0,023	-0,024
Gazihol	0,014	-0,015	0,002	0,086	-0,016	0,006	0,011	0,037	-0,003	0,001	0,004	0,000	-0,020	-0,021
Gazilun	0,038	0,006	0,024	0,119	0,005	0,029	0,035	0,064	0,020	0,024	0,028	0,023	0,000	-0,001
HSH	0,039	0,007	0,026	0,119	0,006	0,032	0,038	0,066	0,022	0,025	0,030	0,025	0,003	0,000
Hekimo	-0,005	-0,040	-0,020	0,080	-0,040	-0,014	-0,008	0,022	-0,025	-0,020	-0,016	-0,021	-0,045	-0,047
Hipokra	0,008	-0,018	-0,004	0,079	-0,020	0,001	0,007	0,031	-0,007	-0,004	0,000	-0,003	-0,023	-0,025
Hizmet	0,044	0,013	0,031	0,124	0,012	0,036	0,042	0,070	0,026	0,030	0,034	0,030	0,008	0,006
Intermed	0,030	0,002	0,017	0,101	0,000	0,022	0,027	0,052	0,014	0,014	0,021	0,017	-0,004	-0,005
Internati	0,000	-0,030	-0,013	0,074	-0,031	-0,009	-0,003	0,023	-0,017	-0,014	-0,011	-0,014	-0,035	-0,036
Kadikoy	0,051	0,017	0,037	0,133	0,016	0,043	0,048	0,077	0,032	0,036	0,039	0,035	0,012	0,011
Kadioglu	-0,002	-0,029	-0,014	0,072	-0,030	-0,009	-0,003	0,021	-0,016	-0,014	-0,010	-0,014	-0,034	-0,035
Medame	0,004	-0,025	-0,009	0,072	-0,025	-0,005	0,001	0,025	-0,014	-0,010	-0,006	-0,009	-0,029	-0,030
Medica	0,103	0,073	0,091	0,169	0,076	0,098	0,102	0,127	0,089	0,091	0,095	0,092	0,073	0,069
Megama	0,064	0,033	0,050	0,144	0,031	0,055	0,061	0,090	0,046	0,049	0,053	0,049	0,027	0,025
Memori	-0,006	-0,032	-0,018	0,066	-0,035	-0,016	-0,009	0,015	-0,022	-0,019	-0,015	-0,018	-0,039	-0,039
Osmano	0,122	0,096	0,110	0,186	0,096	0,115	0,120	0,142	0,108	0,109	0,114	0,111	0,092	0,091
SMSM	0,021	-0,012	0,006	0,104	-0,013	0,012	0,018	0,047	0,002	0,006	0,010	0,006	-0,018	-0,019
Tdv29m	0,019	-0,015	0,005	0,105	-0,015	0,010	0,016	0,046	0,000	0,004	0,008	0,004	-0,020	-0,022

Table 8.5
 β_0 for cross calibration formulas of 28 densitometers (Continue...)

	Hekim- oglu	Hipok- rat	Hiz-met	Inter- med	Internati- onal	Kadi- koysifa	Kadi- oglu	Medi- amerika- n	Medi-ca	Mega- mar	Memo- rial	Osmano- glu	SMSM	Tdv29m ayis
Alka	0,008	-0,008	-0,045	-0,033	0,003	-0,049	0,004	0,002	-0,102	-0,064	0,011	-0,155	-0,020	-0,017
Alman	0,046	0,032	-0,006	0,007	0,042	-0,011	0,043	0,039	-0,067	-0,024	0,052	-0,114	0,020	0,022
Amerika	0,023	0,007	-0,029	-0,017	0,018	-0,034	0,019	0,016	-0,087	-0,049	-0,049	-0,139	-0,005	-0,002
Anadolu	-0,076	-0,091	-0,129	-0,116	-0,081	-0,134	-0,077	-0,085	-0,189	-0,149	-0,072	-0,239	-0,104	-0,101
Capa	0,041	0,026	-0,010	0,001	0,036	-0,015	0,037	0,034	-0,065	-0,029	0,043	-0,115	0,014	0,017
Centerm	0,020	0,005	-0,028	-0,018	0,014	-0,032	0,015	0,012	-0,077	-0,046	0,019	-0,127	-0,006	-0,004
Cerrahp	0,011	-0,002	-0,035	-0,025	0,006	-0,040	0,008	0,005	-0,085	-0,053	0,013	-0,132	-0,013	-0,012
Cerrahp	-0,014	-0,028	-0,062	-0,051	-0,020	-0,066	-0,018	-0,021	-0,111	-0,079	-0,014	-0,162	-0,039	-0,038
Emar	0,022	0,010	-0,022	-0,011	0,018	-0,025	0,020	0,015	-0,068	-0,037	0,025	-0,111	-0,001	0,002
Florence	0,025	0,008	-0,029	-0,017	0,019	-0,034	0,021	0,016	-0,087	-0,049	0,027	-0,142	-0,004	-0,001
Gata	0,017	0,004	-0,030	-0,019	0,012	-0,034	0,015	0,010	-0,079	-0,047	0,019	-0,126	-0,007	-0,005
Gazihol	0,020	0,007	-0,026	-0,015	0,015	-0,030	0,017	0,014	-0,074	-0,043	0,022	-0,120	-0,004	-0,002
Gazilun	0,044	0,030	-0,006	0,005	0,039	-0,011	0,042	0,038	-0,060	-0,025	0,047	-0,111	0,018	0,020
HSH	0,046	0,031	-0,004	0,007	0,041	-0,009	0,043	0,040	-0,061	-0,023	0,049	-0,108	0,020	0,022
Hekimo	0,000	-0,014	-0,052	-0,040	-0,004	-0,057	-0,002	-0,006	-0,114	-0,072	0,005	-0,163	-0,027	-0,024
Hipokra	0,015	0,000	-0,029	-0,020	0,010	-0,033	0,012	0,009	-0,079	-0,046	0,016	-0,121	-0,009	-0,006
Hizmet	0,051	0,036	0,000	0,013	0,046	-0,003	0,048	0,044	-0,053	-0,017	0,053	-0,103	0,025	0,027
Intermed	0,035	0,022	-0,009	0,000	0,031	-0,013	0,032	0,030	-0,059	-0,026	0,038	-0,102	0,012	0,014
Internati	0,005	-0,008	-0,041	-0,031	0,000	-0,045	0,003	-0,001	-0,092	-0,059	0,008	-0,138	-0,019	-0,017
Kadikoy	0,057	0,042	0,006	0,017	0,052	0,000	0,054	0,051	-0,052	-0,014	0,060	-0,102	0,030	0,033
Kadioglu	0,005	-0,008	-0,040	-0,030	0,001	-0,044	0,000	0,000	-0,088	-0,056	0,007	-0,134	-0,018	-0,017
Medame	0,009	-0,004	-0,036	-0,025	0,005	-0,039	0,007	0,000	-0,084	-0,052	0,011	-0,128	-0,015	-0,012
Medica	0,106	0,095	0,067	0,075	0,105	0,062	0,106	0,103	0,000	0,051	0,113	-0,023	0,087	0,089
Megama	0,070	0,056	0,021	0,031	0,065	0,016	0,068	0,064	-0,035	0,000	0,073	-0,084	0,044	0,047
Memoria	0,001	-0,013	-0,045	-0,034	-0,005	-0,048	-0,003	-0,006	-0,092	-0,061	0,000	-0,138	-0,023	-0,021
Osmano	0,127	0,115	0,087	0,096	0,124	0,084	0,124	0,121	0,042	0,072	0,129	0,000	0,106	0,108
SMSM	0,028	0,012	-0,025	-0,013	0,022	-0,029	0,025	0,020	-0,081	-0,044	0,030	-0,133	0,000	0,003
Tdv29m	0,026	0,011	-0,027	-0,015	0,021	-0,032	0,022	0,019	-0,086	-0,047	0,029	-0,138	-0,002	0,000

Table 8-6
 β_1 for cross calibration formulas of 28 densitometers

	Alka	Alman	Amerika	Anadolu	Capa	Centerr	Cerrahy	Cerrahy	Emar	Florence	Gata	GaziHo	Gazilun	HSH
Alka	1	1,0132	1,0148	0,9957	1,0506	1,1218	1,1409	1,1069	1,2185	0,9907	1,1412	1,1653	1,0498	1,059
Alman	0,979	1	0,994	0,978	1,03	1,096	1,118	1,083	1,195	0,971	1,119	1,143	1,029	1,039
Amerika	1,0333	0,9974	1	0,9808	1,0341	1,1045	1,1229	1,0892	1,1993	0,9759	1,1234	1,147	1,0498	1,0423
Anadolu	0,9991	1,0156	1,015	1	1,0515	1,1223	1,1414	1,1072	1,2209	0,9919	1,1432	1,1671	1,0509	1,0601
Capa	0,95	0,9634	0,9644	0,9476	1	1,0663	1,0847	1,052	1,159	0,9427	1,0852	1,1086	0,9989	1,0074
Centerr	0,8862	0,896	0,8998	0,8836	0,9315	1	1,013	0,9844	1,0809	0,8795	1,0124	1,034	0,9314	0,9384
Cerrahy	0,8734	0,8853	0,8866	0,8709	0,9184	0,9817	1	0,9685	1,066	0,866	0,9981	1,0195	0,9183	0,925
Cerrahy	0,8993	0,9102	0,9126	0,8964	0,9451	1,0123	1,0277	1	1,0976	0,8926	1,0273	1,0494	0,9449	0,9523
Emar	0,8182	0,8306	0,8305	0,817	0,8606	0,9187	0,935	0,9072	1	0,8119	0,9353	0,9555	0,8604	0,8676
Florence	1,006	1,0197	1,022	1,0037	1,0585	1,1304	1,1485	1,1156	1,2277	1	1,1493	1,1737	1,0575	1,0664
Gata	0,8741	0,887	0,8874	0,8726	0,9192	0,9815	0,9985	0,9685	1,0668	0,8669	1	1,0204	0,9187	0,9262
GaziHo	0,8561	0,8691	0,869	0,8545	0,9007	0,9616	0,9784	0,949	1,0454	0,8492	0,9788	1	0,9003	0,9077
Gazilun	0,9504	0,9642	0,9648	0,9482	1	1,0674	1,086	1,053	1,1601	0,9429	1,086	1,1095	1	1,0076
HSH	0,9426	0,9569	0,9568	0,9403	0,9916	1,0573	1,0755	1,0433	1,15	0,9348	1,0763	1,0997	0,9906	1
Hekimo	1,0071	1,0227	1,0226	1,0051	1,0591	1,1303	1,1503	1,1152	1,2292	0,9989	1,1508	1,1752	1,0589	1,0679
Hipokrat	0,8255	0,8365	0,8382	0,823	0,8682	0,9267	0,9421	0,9144	1,0067	0,8191	0,9428	0,9625	0,8673	0,8751
Hizmet	0,9419	0,9558	0,9563	0,9401	0,9904	1,0575	1,0755	1,0437	1,1498	0,9344	1,076	1,0989	0,99	0,9983
Interme	0,8419	0,854	0,8548	0,8396	0,8859	0,9455	0,9613	0,9328	1,0271	1,0271	0,9616	0,9825	0,8853	0,8928
Internat	0,8817	0,8941	0,8951	0,88	0,9274	0,9907	1,0072	0,9776	1,0763	0,8748	1,008	1,0293	0,9272	0,9347
Kadikoy	0,9725	0,988	0,9872	0,9706	1,0233	1,0914	1,1112	1,0771	1,1872	0,9647	1,1117	1,1356	1,0228	1,0312
Kadiogl	0,8446	0,856	0,857	0,8404	0,8873	0,9484	0,9639	0,9357	1,0291	0,8369	0,9634	0,9845	0,8868	0,8945
Medam	0,8318	0,8448	0,8451	0,8321	0,8751	0,9355	0,9505	0,9228	1,017	0,8265	0,9515	0,9715	0,8747	0,8821
Medica	0,7949	0,8102	0,8077	0,7946	0,8361	0,8905	0,9068	0,8781	0,9696	0,7887	0,9077	0,9268	0,8349	0,8443
Megam	0,9447	0,9582	0,9594	0,943	0,9943	1,0618	1,0791	1,0465	1,153	0,9377	1,0799	1,1029	0,9937	1,0018
Memori	0,8441	0,8542	0,8571	0,8414	0,8871	0,9501	0,9644	0,9371	1,0296	0,8374	0,964	0,9844	0,8869	0,8937
Osman	0,7582	0,7694	0,7703	0,7562	0,7971	0,852	0,8659	0,8401	0,925	0,753	0,8662	0,8842	0,7968	0,8033
SMSM	0,9806	0,9946	0,9957	0,9785	1,0313	1,1011	1,1196	1,0865	1,1968	0,973	1,1203	1,1442	1,0308	1,0395
Tdv29r	1,0057	1,0203	1,0209	1,003	1,0573	1,1298	1,1488	1,1148	1,2269	0,9974	1,1487	1,1735	1,0571	1,0658

Table 8.6
 β_1 for cross calibration formulas of 28 densitometers(Continue...)

	Hekimo	Hipokra	Hizmet	Interme	Internat	Kadikoy	Kadiogl	Medam	Medica	Megam	Memori	Osman	SMSM	Tdv29r
Alka	0,9901	1,2085	1,0596	1,1852	1,1312	1,0258	1,182	1,1946	1,2288	1,0549	1,1809	1,313	1,0184	0,9928
Alman	0,972	1,183	1,039	1,162	1,109	1,007	1,158	1,173	1,21	1,034	1,155	1,288	0,998	0,973
Amerika	0,9747	1,1898	1,0432	1,1668	1,1136	1,0097	1,1631	1,1768	1,2107	1,0388	1,0388	1,2935	1,0027	0,9771
Anadolu	0,9914	1,209	1,0612	1,186	1,133	1,0272	1,1803	1,1992	1,2326	1,0566	1,1812	1,3141	1,0197	0,9935
Capa	0,9415	1,1492	1,0076	1,1277	1,076	0,9761	1,123	1,1365	1,1687	1,004	1,1223	1,2484	0,9685	0,9438
Center	0,8778	1,0717	0,9399	1,0515	1,0042	0,9094	1,0486	1,0615	1,0875	0,9367	1,0501	1,1656	0,9034	0,8811
Cerrah	0,8657	1,0559	0,9264	1,0361	0,9893	0,8973	1,0328	1,0452	1,0733	0,9225	1,033	1,1481	0,8902	0,8682
Cerrah	0,8907	1,0875	0,9539	1,0668	1,019	0,923	1,0639	1,0767	1,1028	0,9494	1,0652	1,182	0,9167	0,8941
Emar	0,8114	0,9895	0,8686	0,9709	0,9273	0,8408	0,9671	0,9808	1,0065	0,8645	0,9673	1,0756	0,8346	0,8133
Floren	0,997	1,2174	1,0674	1,1942	1,1396	1,0332	1,1893	1,2053	1,2379	1,0632	1,1897	1,3242	1,0261	0,9997
Gata	0,8664	1,057	0,9272	1,0368	0,9905	0,8981	1,0327	1,0467	1,0747	0,9236	1,033	1,1489	0,8911	0,8685
Gazihol	0,8488	1,0352	0,9083	1,0161	0,9702	0,88	1,0123	1,0251	1,0526	0,9048	1,0118	1,1249	0,873	0,8511
Gazilun	0,9424	1,1495	1,0083	1,1283	1,0771	0,9767	1,1237	1,1374	1,1686	1,0046	1,1234	1,2494	0,9692	0,9447
HSH	0,9344	1,1402	0,9997	1,1187	1,0674	0,9681	1,1144	1,1277	1,1617	0,9957	1,1129	1,2382	0,9609	0,9365
Hekimo	1	1,2181	1,0681	1,1953	1,1413	1,0348	1,1908	1,2059	1,2431	1,0645	1,1897	1,3244	1,027	1,0008
Hipokra	0,818	1	0,8755	0,9795	0,9346	0,8475	0,9758	0,9875	1,0175	0,8718	0,9758	1,0855	0,8414	0,82
Hizmet	0,9332	1,1392	1	1,117	1,0667	0,9673	1,1133	1,1282	1,1583	0,9947	1,1137	1,2383	0,9604	0,9358
Interme	0,8347	1,0185	0,8927	1	0,9539	0,8649	0,9956	1,0074	1,037	0,8898	0,9949	1,1063	0,8584	0,8367
Internat	0,8744	1,0663	0,9354	1,0466	1	0,9058	1,042	1,0557	1,0844	0,932	1,0426	1,1583	0,8992	0,8763
Kadikoy	0,9644	1,1763	1,0317	1,1544	1,1018	1	1,1498	1,1639	1,1978	1,0277	1,1489	1,2782	0,9916	0,9666
Kadiogl	0,8364	1,0206	0,8949	1,0014	0,9552	0,8665	1	1,0088	1,0379	0,8908	0,998	1,1099	0,8601	0,8389
Medam	0,8254	1,0065	0,8837	0,9874	0,9431	0,8548	0,9831	1	1,0246	0,8796	0,9843	1,0953	0,8491	0,827
Medica	0,7905	0,9636	0,843	0,9443	0,9	0,8173	0,9397	0,952	1	0,8403	0,9379	1,0465	0,8108	0,7903
Megam	0,9371	1,143	1,0022	1,1217	1,0709	0,9707	1,1165	1,1314	1,1633	1	1,1168	1,2424	0,9636	0,9389
Memori	0,8359	1,021	0,8955	1,001	0,9561	0,8661	0,9983	1,0104	1,0363	0,8913	1	1,1099	0,8604	0,8387
Osman	0,7518	0,9176	0,8045	0,8993	0,8581	0,7785	0,897	0,9084	0,9341	0,8011	0,8967	1	0,773	0,7535
SMSM	0,9721	1,186	1,0404	1,1635	1,1108	1,0071	1,1591	1,1743	1,2068	1,036	1,1591	1,289	1	0,9744
Tdv29r	0,9967	1,216	1,0666	1,1932	1,139	1,0328	1,1894	1,2032	1,2376	1,0621	1,1887	1,3218	1,0251	1

Table 8-7
Mean square errors of cross calibration results

	Alka	Alman	Amerika	Anadolu	Capa	Centerr	Cerrah	Cerrah	Emar	Floren	Gata	Gazihol	Gazilun	HSH
Alka	0	0,0013	0,0002	0,0009	0,0003	0,0008	0,0004	0,0006	0,0003	0,0006	0,0003	0,0003	0,0003	0,0003
Alman	0,001	0	0,001	0,001	0,001	0,002	0,001	0,002	8E-04	0,002	9E-04	8E-04	0,001	9E-04
Amerika	0,0002	0,0013	0	0,0008	0,0004	0,0008	0,0006	0,0008	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004
Anadolu	0,0009	0,0011	0,0007	0	0,0005	0,0011	0,0008	0,001	0,0003	0,0007	0,0003	0,0003	0,0005	0,0005
Capa	0,0003	0,0013	0,0004	0,0006	0	0,0009	0,0005	0,0008	0,0003	0,0004	0,0003	0,0002	0,0002	0,0002
Centerr	0,001	0,0029	0,001	0,0014	0,001	0	0,0007	0,0005	0,0008	0,001	0,0008	0,0007	0,0009	0,0011
Cerrah	0,0006	0,0017	0,0007	0,001	0,0006	0,0007	0	0,0006	0,0004	0,0009	0,0004	0,0003	0,0004	0,0008
Cerrah	0,0008	0,0023	0,0009	0,0012	0,0009	0,0005	0,0006	0	0,0005	0,0007	0,0006	0,0005	0,0007	0,0009
Emar	0,0005	0,0011	0,0006	0,0004	0,0004	0,0009	0,0004	0,0006	0	0,0005	0,0003	0,0001	0,0003	0,0003
Floren	0,0006	0,0016	0,0004	0,0007	0,0003	0,0008	0,0007	0,0006	0,0004	0	0,0005	0,0004	0,0004	0,0005
Gata	0,0004	0,0012	0,0005	0,0004	0,0004	0,0008	0,0004	0,0007	0,0002	0,0006	0	0,0001	0,0003	0,0005
Gazihol	0,0004	0,001	0,0005	0,0005	0,0002	0,0007	0,0003	0,0005	0,0001	0,0005	0,0002	0	0,0002	0,0003
Gazilun	0,0004	0,0012	0,0004	0,0006	0,0002	0,0007	0,0003	0,0007	0,0002	0,0005	0,0003	0,0001	0	0,0003
HSH	0,0005	0,001	0,0005	0,0006	0,0004	0,001	0,0005	0,0009	0,0003	0,0007	0,0004	0,0003	0,0003	0,0003
Hekimo	0,0004	0,0016	0,0004	0,0008	0,0003	0,0009	0,0007	0,0007	0,0004	0,0005	0,0004	0,0004	0,0004	0,0003
Hipokrat	0,0003	0,0011	0,0004	0,0004	0,0003	0,0008	0,0005	0,0006	0,0001	0,0005	0,0003	0,0002	0,0003	0,0003
Hizmet	0,0003	0,0009	0,0004	0,0005	0,0002	0,001	0,0007	0,0009	0,0003	0,0005	0,0004	0,0002	0,0003	0
Interme	0,0003	0,0012	0,0004	0,0007	0,0002	0,0007	0,0005	0,0006	0,0003	0,0004	0,0004	0,0002	0,0002	0,0002
Internat	0,0004	0,0014	0,0005	0,0005	0,0003	0,0007	0,0005	0,0005	0,0002	0,0005	0,0002	0,0002	0,0002	0,0003
Kadikoy	0,0004	0,0008	0,0005	0,0005	0,0002	0,001	0,0004	0,0008	0,0002	0,0006	0,0002	0,0001	0,0001	0,0002
Kadiogl	0,0003	0,0014	0,0005	0,0013	0,0005	0,0007	0,0006	0,0006	0,0005	0,0008	0,0006	0,0004	0,0005	0,0005
Medam	0,001	0,0015	0,0009	0,0004	0,0008	0,0009	0,0008	0,0009	0,0003	0,0006	0,0005	0,0005	0,0008	0,0008
Medica	0,0038	0,0031	0,0035	0,0034	0,0034	0,0041	0,0034	0,0042	0,0027	0,004	0,0031	0,0029	0,0036	0,0028
Megam	0,0006	0,0015	0,0005	0,0006	0,0003	0,0007	0,0006	0,0009	0,0004	0,0005	0,0003	0,0003	0,0003	0,0004
Memori	0,0005	0,0022	0,0005	0,001	0,0007	0,0003	0,0005	0,0002	0,0005	0,0006	0,0005	0,0005	0,0005	0,0008
Osman	0,0007	0,0015	0,0006	0,001	0,0007	0,0009	0,0007	0,0009	0,0006	0,0005	0,0006	0,0006	0,0007	0,0008
SMSM	0,0002	0,0011	0,0003	0,0004	0,0002	0,0007	0,0004	0,0005	0,0001	0,0003	0,0002	0,0001	0,0001	0,0002
Tdv29r	0,0003	0,0011	0,0004	0,0006	0,0003	0,0006	0,0003	0,0004	0,0002	0,0005	0,0003	0,0002	0,0002	0,0003

Table 8-7
Mean square errors of cross calibration results (Continue...)

	Hekimo	Hipokrat	Hizmet	Interme	Internat	Kadiko	Kadiogl	Medam	Medica	Megam	Memori	Osman	SMSM	Tdv29r
Alka	0,0005	0,0003	0,0003	0,0002	0,0003	0,0004	0,0002	0,0007	0,0025	0,0005	0,0004	0,0004	0,0002	0,0003
Alman	0,001	0,001	0,001	9E-04	0,001	8E-04	0,001	0,001	0,002	0,001	0,002	9E-04	0,001	0,001
Amerika	0,0005	0,0003	0,0004	0,0003	0,0004	0,0005	0,0004	0,0006	0,0024	0,0005	0,0004	0,0003	0,0003	0,0004
Anadolu	0,0006	0,0006	0,0003	0,0005	0,0004	0,0005	0,0009	0,0002	0,0022	0,0005	0,0007	0,0006	0,0004	0,0006
Capa	0,0005	0,0003	0,0003	0,0001	0,0003	0,0002	0,0004	0,0006	0,0024	0,0003	0,0005	0,0005	0,0002	0,0004
Centerr	0,0013	0,0008	0,0009	0,0007	0,0007	0,0012	0,0006	0,0008	0,0034	0,0008	0,0003	0,0007	0,0008	0,0008
Cerrah	0,0007	0,0006	0,0005	0,0005	0,0005	0,0005	0,0005	0,0008	0,0028	0,0007	0,0004	0,0006	0,0005	0,0004
Cerrah	0,0011	0,0006	0,0006	0,0006	0,0005	0,0009	0,0005	0,0007	0,0034	0,001	0,0002	0,0007	0,0006	0,0005
Emar	0,0004	0,0004	0,0002	0,0003	0,0003	0,0003	0,0006	0,0003	0,0026	0,0005	0,0005	0,0005	0,0002	0,0004
Floren	0,0007	0,0003	0,0004	0,0003	0,0004	0,0005	0,0005	0,0004	0,0025	0,0005	0,0004	0,0003	0,0003	0,0005
Gata	0,0005	0,0004	0,0003	0,0004	0,0002	0,0003	0,0006	0,0005	0,0026	0,0004	0,0005	0,0005	0,0003	0,0004
Gazihol	0,0004	0,0004	0,0003	0,0002	0,0002	0,0001	0,0004	0,0005	0,0026	0,0003	0,0005	0,0005	0,0002	0,0002
Gazilun	0,0004	0,0003	0,0003	0,0001	0,0002	0,0001	0,0004	0,0006	0,0026	0,0003	0,0004	0,0004	0,0001	0,0002
HSH	0	0,0004	0,0005	0,0003	0,0003	0,0003	0,0005	0,0005	0,0018	0,0004	0,0006	0,0004	0,0003	0,0004
Hekimo	0,0006	0	0,0004	0,0003	0,0004	0,0005	0,0005	0,0007	0,0021	0,0005	0,0004	0,0004	0,0003	0,0005
Hipokrat	0,0005	0,0003	0	0,0003	0,0003	0,0003	0,0004	0,0003	0,0025	0,0005	0,0003	0,0004	0,0001	0,0003
Hizmet	0,0004	0,0003	0,0003	0,0001	0,0003	0,0003	0,0004	0,0006	0,0021	0,0004	0,0006	0,0005	0,0002	0,0003
Interme	0,0004	0,0003	0,0004	0	0,0002	0,0002	0,0004	0,0006	0,0022	0,0003	0,0005	0,0005	0,0002	0,0003
Internat	0,0003	0,0004	0,0003	0,0002	0	0,0003	0,0005	0,0005	0,0026	0,0003	0,0004	0,0006	0,0002	0,0003
Kadiko	0,0004	0,0003	0,0003	0,0002	0,0003	0	0,0004	0,0006	0,0023	0,0004	0,0006	0,0005	0,0002	0,0003
Kadiogl	0,0007	0,0005	0,0006	0,0004	0,0006	0,0006	0	0,0009	0,0026	0,0008	0,0004	0,0004	0,0005	0,0004
Medam	0,0008	0,0007	0,0004	0,0006	0,0006	0,0008	0,001	0	0,0026	0,0007	0,0006	0,0005	0,0005	0,0008
Medica	0,0029	0,0022	0,0035	0,0024	0,0031	0,0033	0,0029	0,0028	0	0,0033	0,0033	0,0021	0,0034	0,0037
Megam	0,0004	0,0004	0,0005	0,0002	0,0002	0,0004	0,0006	0,0006	0,0024	0	0,0005	0,0005	0,0003	0,0005
Memori	0,0009	0,0004	0,0004	0,0005	0,0004	0,0008	0,0004	0,0006	0,003	0,0007	0	0,0005	0,0004	0,0005
Osman	0,0007	0,0004	0,0006	0,0006	0,0008	0,0008	0,0005	0,0006	0,0024	0,0007	0,0006	0	0,0006	0,0007
SMSM	0,0003	0,0002	0,0001	0,0001	0,0002	0,0002	0,0004	0,0003	0,0023	0,0003	0,0003	0,0003	0	0,0002
Tdv29r	0,0004	0,0003	0,0003	0,0002	0,0002	0,0003	0,0003	0,0006	0,0023	0,0004	0,0003	0,0004	0,0002	0

9. CONCLUSION

For the thesis studies I have visit a lot of medical centers that have a DEXA system. Most of them are interested in standardization studies of DEXA systems. As I have spoken to the physicians I noticed that all of them were aware of the standardization problem and also use some informal, rough cross calibration opinions in their minds. This opinion suggests that HOLOGIC and NORLAND give low BMD values while LUNAR gives higher.

As a primitive solution for this standardization problem physicians try not to change the densitometer that scans the patient. If a patient starts measurements on a densitometer he or she shall go on measurements on the same densitometer as long as possible. For this reason, where two densitometers are occupied, new ones are rarely used because the old patients go on using the old densitometer.

Although there are lots of studies in the literature I have not met any example of cross-calibration studies of new and old systems even in the centers where the old and the new systems are both occupied. This makes us to think that companies don't lead the user to cross-calibration studies.

Although number of densitometers from different brands included are not equal, we can say that the results gathered from different brands show different specifications. LUNAR gives high BMD results while NORLAND, HOLOGIC and MEDILINK give lower. In the following table there are the mean values of the four manufacturers measured for the three vertebrae.

Table 9-1
Mean BMD values of different brands.

	LUNAR	MEDILINK	NORLAND	HOLOGIC
L1 (g/cm ²)	0,601	0,531	0,566	0,512
L2 (g/cm ²)	1,057	0,970	0,923	0,903
L3 (g/cm ²)	1,537	1,394	1,295	1,335

All of the medical centers perform manufacturer defined quality control procedures using the densitometers' QA phantoms. The reports of the daily system tests' are gathered where available. There is no error notice in the daily system check reports. But as we investigate the reproducibility of the devices 22.5% of the scanned BMD values are out of the accepted reproducibility which is

$$mean \otimes (1 \pm 0.015) \quad (9.1)$$

Only 1 densitometer does not have any BMD values out of range. 1 of them has 22 values out. This shows us that there is a clear reproducibility problem on most of the scanned densitometers.

The reproducibility problem reaches such rates that measurements acquired from the same densitometer can vary up to 0,2 g/cm² where the critical interface between normal and osteoporotic bone densities is 0,15 - 0,2 g/cm² width. So the inconsistency of the devices can easily cause misdiagnoses.

Cross calibration formulas are calculated for both model groups and unique densitometer groups. The fitting value of the cross calibration formulas are analyzed by calculating mean squared errors of original and calculated BMD values. Maximum MSE of 0.0047 was calculated showing that cross calibration formulas are successfully fitting.

APPENDIX A

In this appendix par densitometers result are summarized. The mean, standart deviation, , coefficient of variation and upper/lower limits are given. The values, which are out of the upper and lower acceptable limits, are indicated by **bold** characters. The daily system control reports are also added for the available centers.

The names of the hospitals, or clinics or medical imaging centers are not given for ethical reasons. They are reffered as to “Center X”, where “X” shows the number given to the institutions.

A.1. Center 1

Scanner Type: LUNAR DPX-IQ
 Measurement date: 27/10/2004
 Facility Type: Medical Imaging center

Table A 1
 Center # 1 BMD results

Center # 1			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,580	1,072	1,526
2	0,589	1,059	1,526
3	0,581	1,048	1,555
4	0,586	1,055	1,531
5	0,599	1,041	1,565
6	0,597	1,061	1,524
7	0,582	1,031	1,565
8	0,592	1,082	1,556
9	0,593	1,044	1,559
10	0,583	1,053	1,574
MEAN	0,588	1,055	1,548
upper limit	0,597	1,070	1,571
lower limit	0,579	1,039	1,525
STD	0,007	0,015	0,019
CV	1,164	1,419	1,241

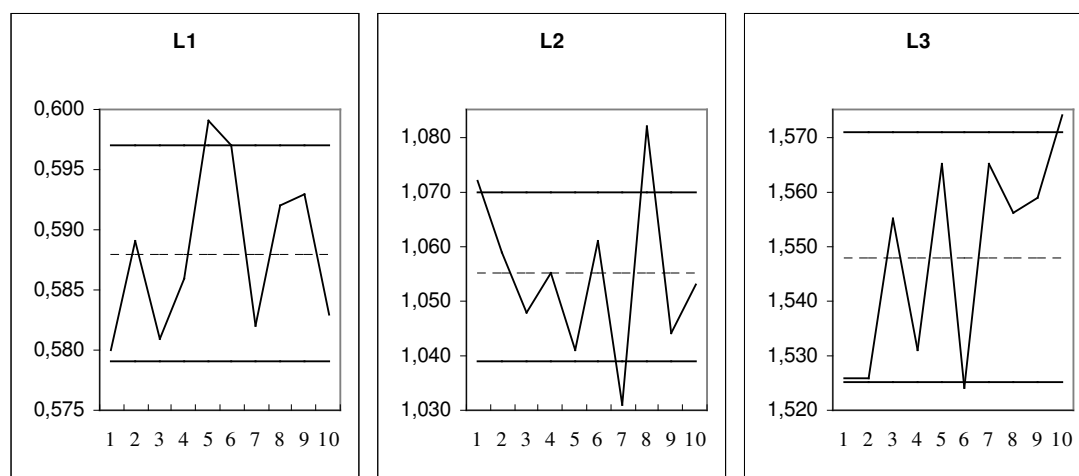
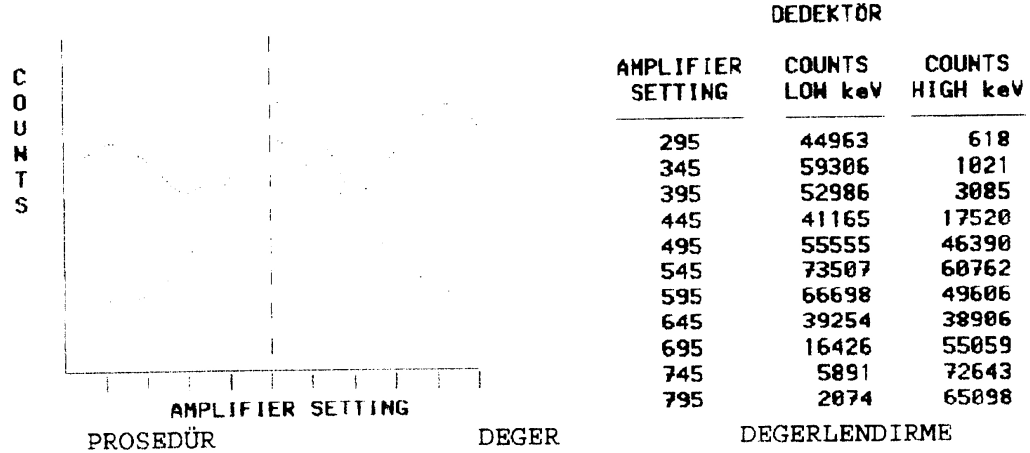


Figure A1 Center # 1 L1, L2 and L3 BMD (g/cm²) reproducibility control charts



PROSEDÜR	DEGER	DEGERLENDIRME
Lambalar	-	Kontrol
Peak Setting	545 ünite	Kontrol
Background (Low keV)	2 cps	
(High keV)	1 cps	Kontrol
Isin Durdurma	-	Kontrol
Isin Dagilim Yüzdesi	7.84 %	
Ki Kare	2	Kontrol
Hava Sayımı (Low keV)	774385 cps	Kontrol
(High keV)	414305 cps	Kontrol
Hava Oranı	0.54	Kontrol
Transvers Mekanik	12448/12449 adım	Kontrol
Longitudinal Mekanik	19719/19719 adım	Kontrol
Doku Degeri	1.308	Kontrol
Kolimasyon Oranı	3.932	Kontrol

	1	2	3	4	5	MEAN	SD	%CV
BÜYÜK BM	273.0	272.1	272.0	270.8	273.0	272.2	0.83	0.30
WIDTH	498	498	496	496	495	497	1.20	0.24
ORTA BM	203.8	203.1	204.9	203.2	206.1	204.2	1.12	0.55
WIDTH	430	433	433	432	432	432	1.10	0.25
KÜÇÜK BM	144.2	143.6	145.3	144.2	143.5	144.2	0.64	0.44
WIDTH	364	362	365	359	366	363	2.48	0.68

Figure A2 Center # 1 daily system test report

A.2. Center 2

Scanner Type: LUNAR DPXL

Measurement date: 20/10/2004

Facility Type: Hospital

Table A 2
Center # 2 BMD results

Center # 2			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,622	1,093	1,587
2	0,621	1,104	1,612
3	0,603	1,098	1,596
4	0,627	1,075	1,576
5	0,669	1,048	1,586
6	0,590	1,062	1,506
7	0,601	1,067	1,510
8	0,606	1,052	1,500
9	0,616	1,063	1,590
10	0,599	1,057	1,505
MEAN	0,615	1,072	1,557
up-limit	0,625	1,088	1,580
sub-limit	0,606	1,056	1,533
STD	0,022	0,020	0,045
CV	3,612	1,855	2,912

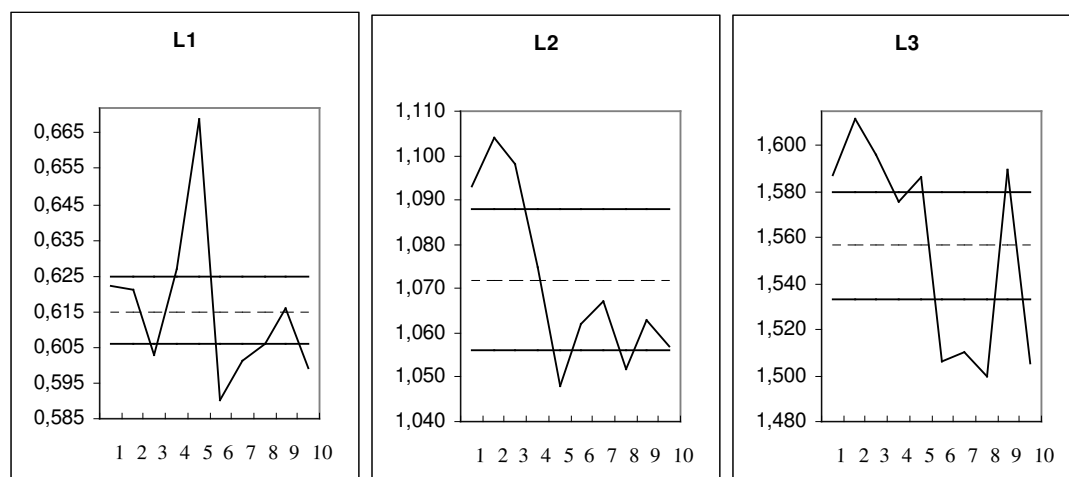
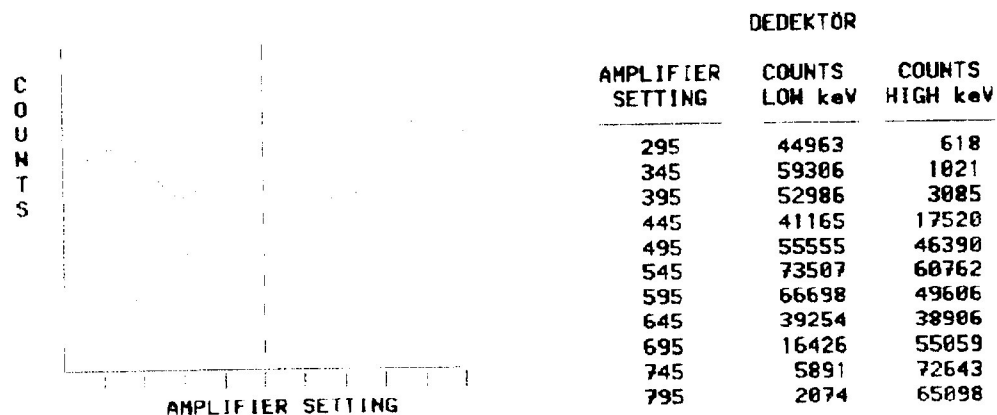


Figure A3 Center # 2 L1, L2 and L3 BMD (g/cm²) reproducibility control charts



PROSEDÜR	DEGER	DEGERLENDİRME
Lambalar	-	Kontrol
Peak Setting	545 ünite	Kontrol
Background (Low keV)	2 cps	
(High keV)	1 cps	Kontrol
Isin Durdurma	-	Kontrol
Isin Dağılım Yüzdesi	7.84 %	
Ki Kare	2	Kontrol
Hava Sayımı (Low keV)	774385 cps	Kontrol
(High keV)	414305 cps	Kontrol
Hava Oranı	0.54	Kontrol
Transvers Mekanik	12448/12449 adım	Kontrol
Longitudinal Mekanik	19719/19719 adım	Kontrol
Doku Değeri	1.308	Kontrol
Kolimasyon Oranı	3.932	Kontrol

	1	2	3	4	5	MEAN	SD	%CV
BÜYÜK BM	273.0	272.1	272.0	270.8	273.0	272.2	0.83	0.30
WIDTH	498	498	496	496	495	497	1.20	0.24
ORTA BM	203.8	203.1	204.9	203.2	206.1	204.2	1.12	0.55
WIDTH	430	433	433	432	432	432	1.10	0.25
KÜÇÜK BM	144.2	143.6	145.3	144.2	143.5	144.2	0.64	0.44
WIDTH	364	362	365	359	366	363	2.48	0.68

Figure A4 Center # 2 daily system test report

A.3. Center 3

Scanner Type: LUNAR DPX

Measurement date: 20/10/2004

Facility Type: Hospital

Table A 3
Center # 3 Measurement Results

Center # 3			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,578	1,049	1,496
2	0,586	1,066	1,515
3	0,589	1,077	1,534
4	0,609	1,042	1,542
5	0,595	1,032	1,551
6	0,587	1,053	1,530
7	0,591	1,055	1,545
8	0,586	1,076	1,526
9	0,593	1,062	1,550
10	0,594	1,078	1,571
MEAN	0,591	1,059	1,536
up-limit	0,600	1,075	1,559
sub-limit	0,582	1,043	1,513
STD	0,008	0,016	0,021
CV	1,372	1,477	1,363

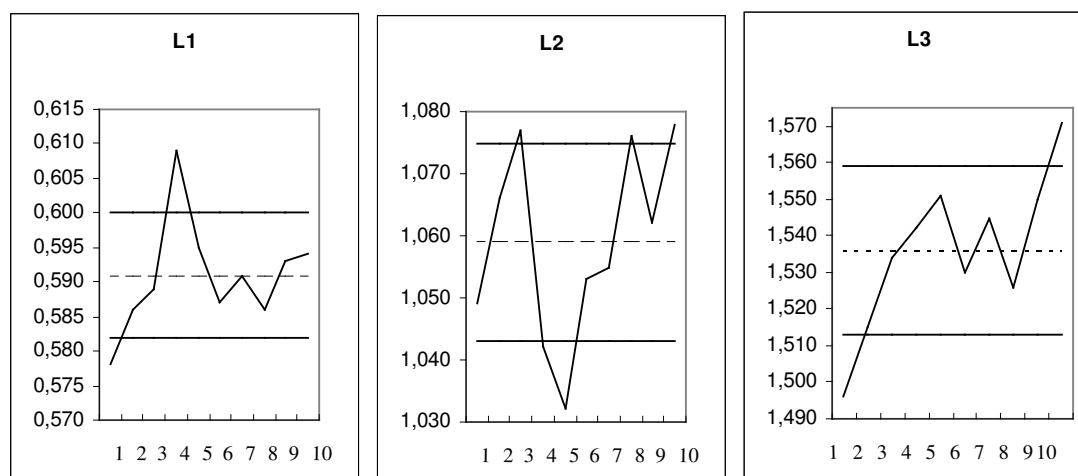


Figure A5 Center # 3 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

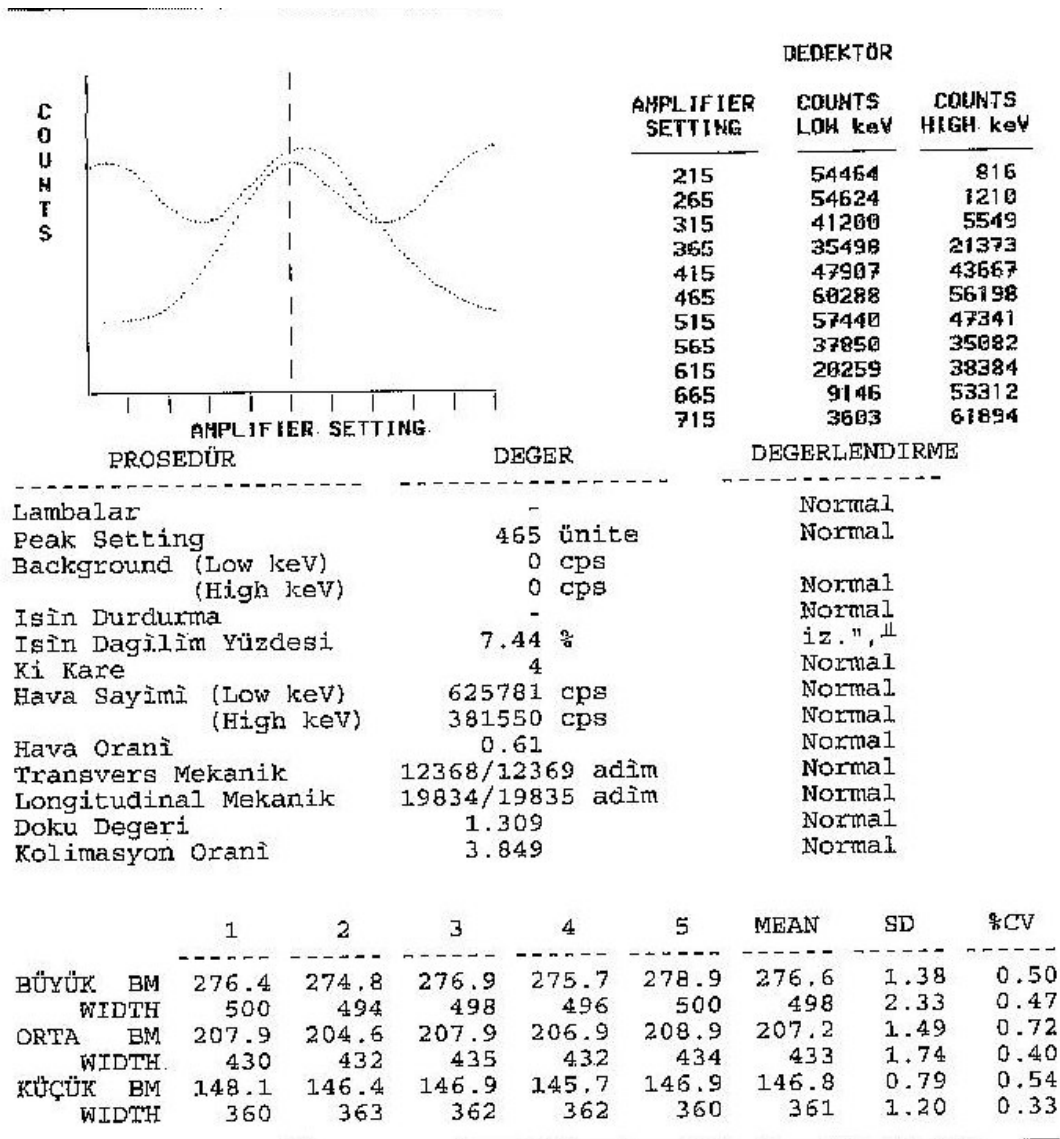


Figure A6 Center #3 daily system test report

A.4. Center 4

Scanner Type: Medilink Osteocore-3

Measurement date: 28/02/2005

Facility Type: Hospital

Table A 4
Center # 4 Measurement Results

Center # 4			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,498	0,954	1,479
2	0,510	0,996	1,495
3	0,506	0,957	1,456
4	0,513	0,964	1,506
5	0,493	0,976	1,479
6	0,500	0,956	1,494
7	0,501	0,964	1,439
8	0,513	0,965	1,445
9	0,512	1,004	1,432
10	0,513	0,965	1,445
MEAN	0,506	0,970	1,467
up-limit	0,513	0,985	1,489
sub-limit	0,498	0,956	1,445
STD	0,007	0,017	0,027
CV	1,463	1,756	1,821

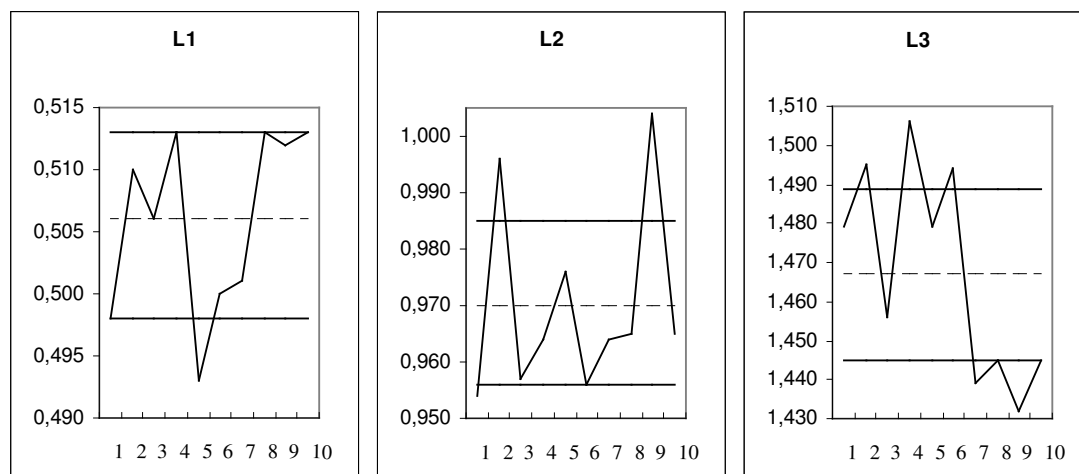


Figure A7 Center # 4 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.5. Center 5

Scanner Type: LUNAR DPX NT
 Measurement date: 26/10/2004
 Facility Type: University Hospital

Table A 5
 Center # 5 Measurement Results

Center # 5			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,585	1,026	1,512
2	0,597	1,030	1,512
3	0,585	1,033	1,519
4	0,587	1,057	1,486
5	0,590	1,042	1,476
6	0,592	1,039	1,505
7	0,598	1,031	1,525
8	0,593	1,040	1,492
9	0,591	1,029	1,491
10	0,597	1,039	1,527
MEAN	0,592	1,037	1,505
up-limit	0,600	1,052	1,527
sub-limit	0,583	1,021	1,482
STD	0,005	0,009	0,017
CV	0,821	0,867	1,160

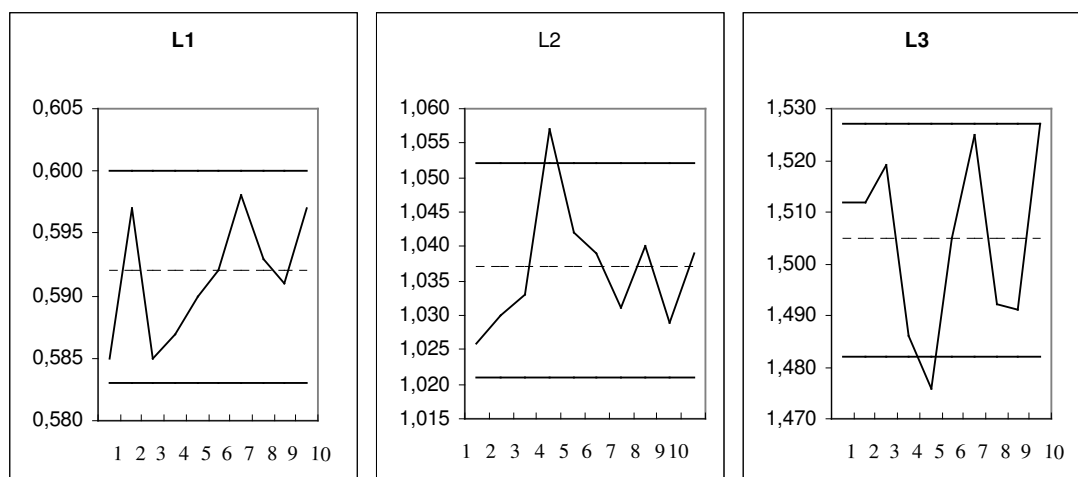
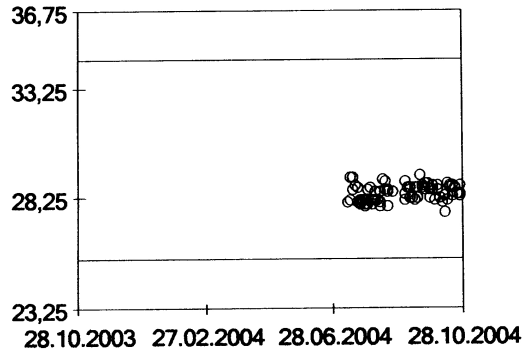


Figure A8 Center # 5 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

**Günlük ST Ölçümü**

Tarih 26.10.2004
 Zaman 08:35:24
 BMD Medium (1,500 mA) 0,989 g/cm²
 Deviasyon -0,05 %

Trend Özeti

Ortalama Current Ratio (0,050 mA) 28,52
 CV 1,27%
 Toplam Seanslar 83

Fonksiyonel Testler			Sekonder Kalibrasyon		
Test	Değer	Durum	Test	Ortalama	Durum
Peaking	2.732	Kontrol	BMD		
Beam Stop	3,33 / 1,58	Kontrol	Büyük	1,502	Kontrol
Mekanik Test			Medium	0,989	Kontrol
Transvers	620,70	Kontrol	Küçük	0,495	Kontrol
Longitudinal	1.959,25	Kontrol	Doku		
Spillover Test			Yumuşak	15,6%	Kontrol
Ortlama %	9,96%	Kontrol	Orta	37,4%	Kontrol
			Yağ	61,4%	Kontrol
Referans Hesaplamalar			kalibrasyon Durumu		Kontrol
Yüksek mA	242.706 / 273.084	Kontrol	Sistem Durumu		
Oran Yüksek mA'de	0,89	Kontrol	Kontrol		
Dedektör Durumu		Kontrol			

Figure A9 Center # 5 daily system test report

A.6. Center 6

Scanner Type: HOLOGIC QDR 4500W

Measurement date: 05/04/2005

Facility Type: Polyclinic

Table A 6
Center # 6 Measurement Results

Center # 6			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,536	0,936	1,380
2	0,537	0,920	1,341
3	0,543	0,916	1,300
4	0,539	0,940	1,413
5	0,525	0,939	1,375
6	0,530	0,931	1,406
7	0,538	0,945	1,438
8	0,543	0,956	1,426
9	0,542	0,941	1,416
10	0,548	0,954	1,398
MEAN	0,538	0,938	1,389
up-limit	0,546	0,952	1,410
sub-limit	0,530	0,924	1,368
STD	0,007	0,013	0,042
CV	1,246	1,378	3,030

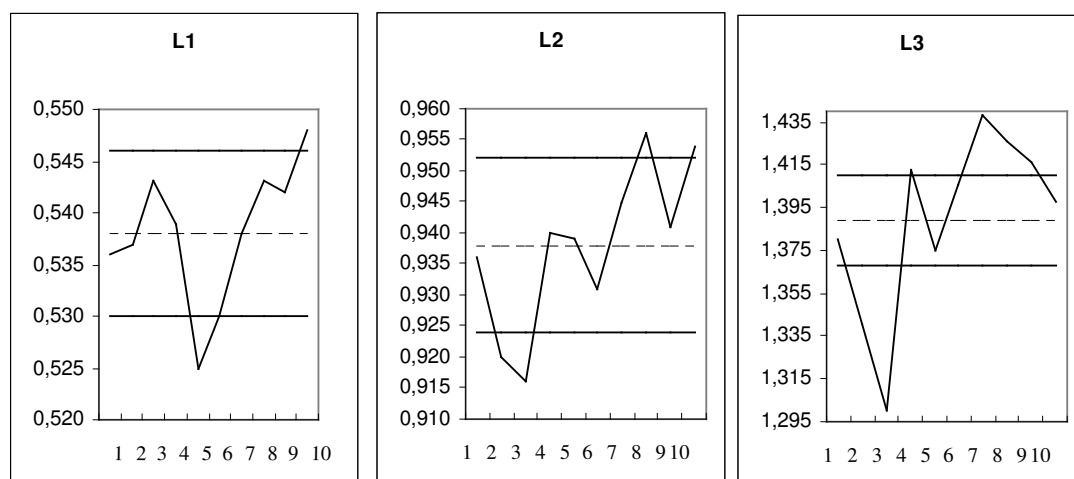


Figure A10 Center # 6 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.7. Center 7/ Densitometer # 1

Scanner Type: HOLOGIC QDR 4500W

Measurement date: 14/04/2005

Facility Type: University Hospital

Table A 7
Center # 7 Densitometer # 1 BMD results

Center # 7 Device #1			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,523	0,904	1,336
2	0,524	0,912	1,367
3	0,524	0,915	1,324
4	0,514	0,917	1,353
5	0,518	0,932	1,362
6	0,528	0,986	1,353
7	0,523	0,908	1,366
8	0,518	0,897	1,374
9	0,512	0,922	1,388
10	0,525	0,908	1,377
MEAN	0,521	0,920	1,360
up-limit	0,529	0,934	1,380
sub-limit	0,513	0,906	1,340
STD	0,005	0,025	0,019
CV	0,989	2,729	1,414

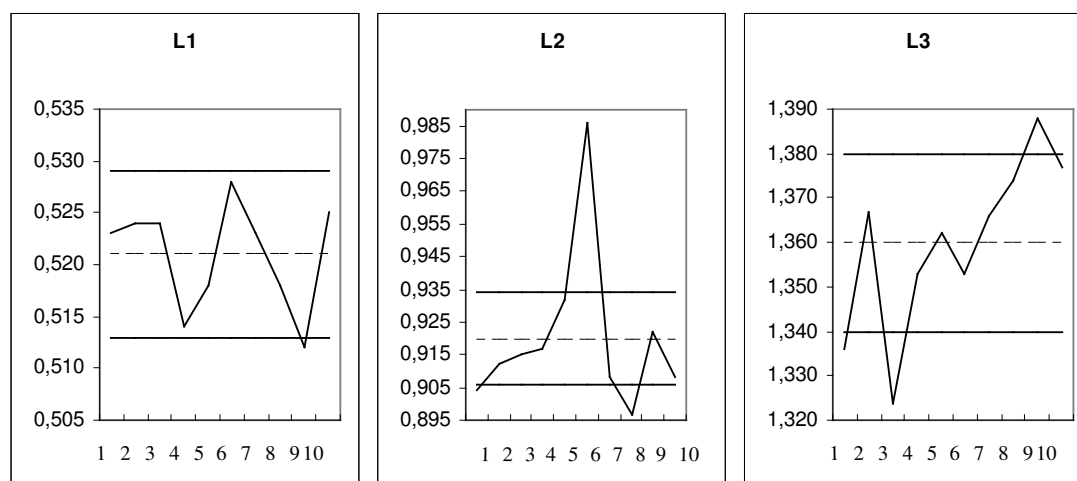


Figure 2 Center # 7 Densitometer #1
L1, L2 and L3 BMD (g/cm²) reproducibility control charts

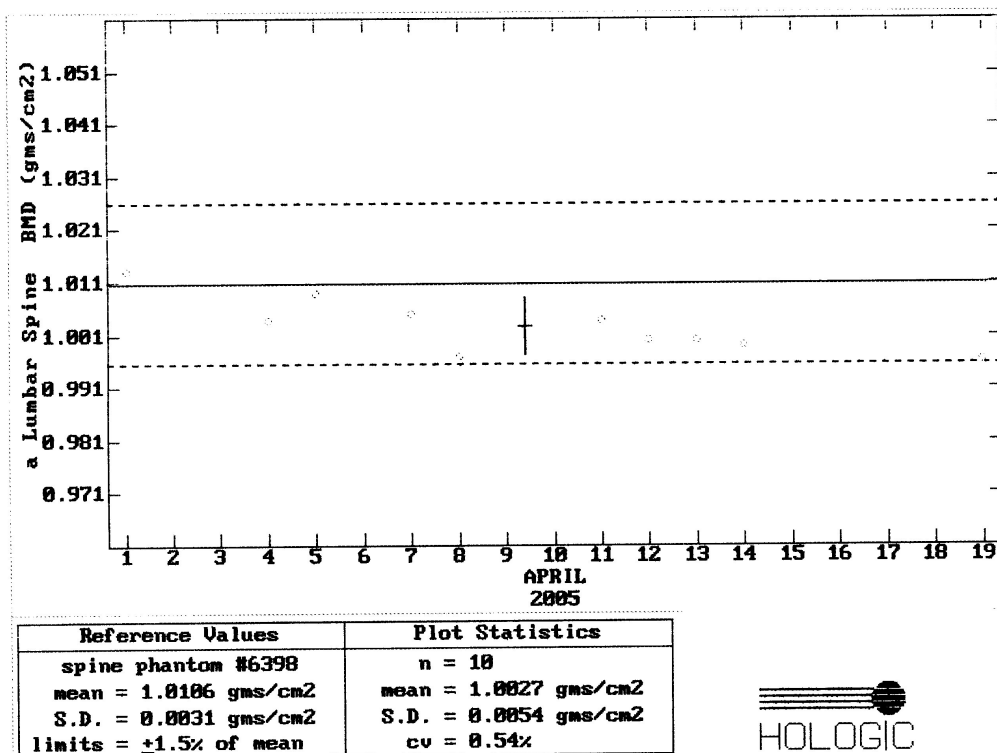


Figure A12 Center # 7 Densitometer # 1 daily system test report

A.8. Center 7/ Densitometer # 2

Scanner Type: HOLOGIC QDR 4500W

Measurement date: 14/04/2005

Facility Type: University Hospital

Table A 8
Center # 7 Densitometer #2 BMD results

Center # 7 Device #2			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,532	0,905	1,352
2	0,511	0,902	1,341
3	0,521	0,891	1,357
4	0,525	0,909	1,361
5	0,515	0,903	1,396
6	0,518	0,905	1,417
7	0,521	0,902	1,419
8	0,516	0,906	1,404
9	0,522	0,913	1,402
10	0,518	0,904	1,382
MEAN	0,520	0,904	1,383
up-limit	0,528	0,918	1,404
sub-limit	0,512	0,890	1,362
STD	0,006	0,006	0,028
CV	1,120	0,628	2,060

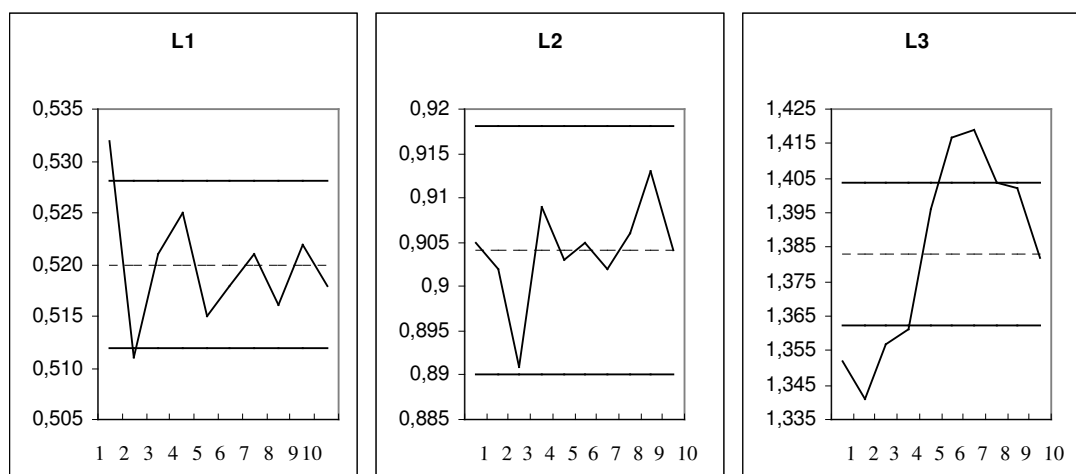
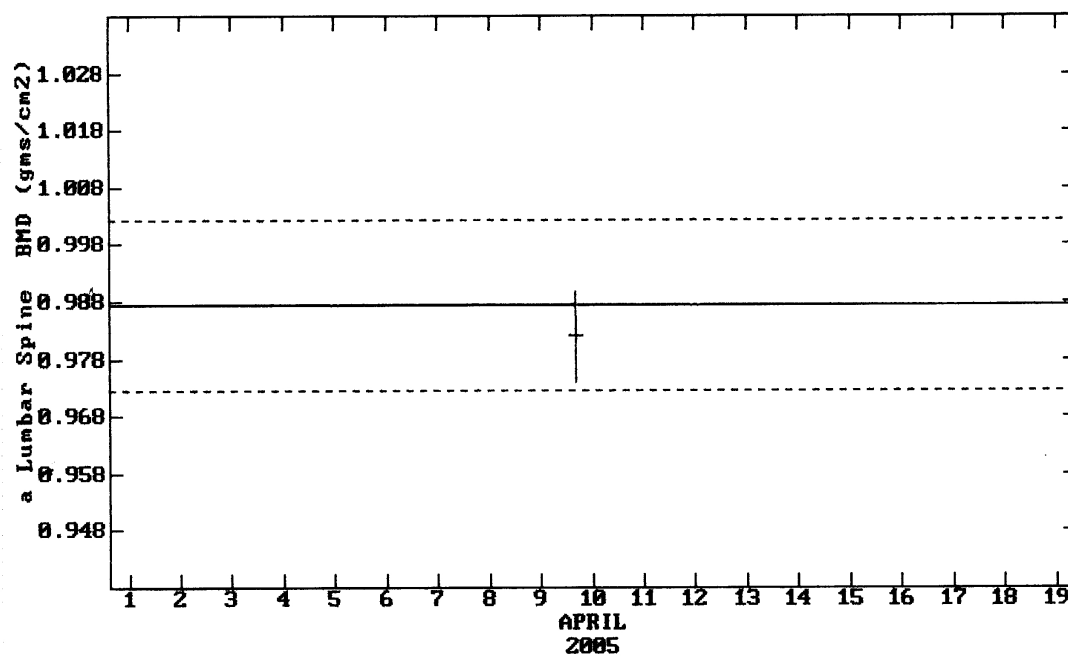


Figure A3 Center # 7 Densitometer #2 L1, L2 and L3 BMD (g/cm²) reproducibility control charts



Reference Values	Plot Statistics
spine phantom #5370	n = 13
mean = 0.9875 gms/cm2	mean = 0.9819 gms/cm2
S.D. = 0.0032 gms/cm2	S.D. = 0.0080 gms/cm2
limits = $\pm 1.5\%$ of mean	cv = 0.81%



Figure A14 Center # 7 Densitometer # 2 daily system test report

A.9. Center 8

Scanner Type: HOLOGIC QDR 4000

Measurement date: 13/04/2005

Facility Type: Medical Imaging Center

Table A 9
Center # 8 BMD results

Center # 8			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,505	0,878	1,277
2	0,508	0,873	1,298
3	0,502	0,878	1,292
4	0,498	0,872	1,294
5	0,504	0,872	1,298
6	0,511	0,888	1,297
7	0,501	0,868	1,294
8	0,490	0,864	1,301
9	0,487	0,876	1,256
10	0,502	0,862	1,265
MEAN	0,501	0,873	1,287
up-limit	0,508	0,886	1,307
sub-limit	0,493	0,860	1,268
STD	0,007	0,008	0,016
CV	1,491	0,865	1,216

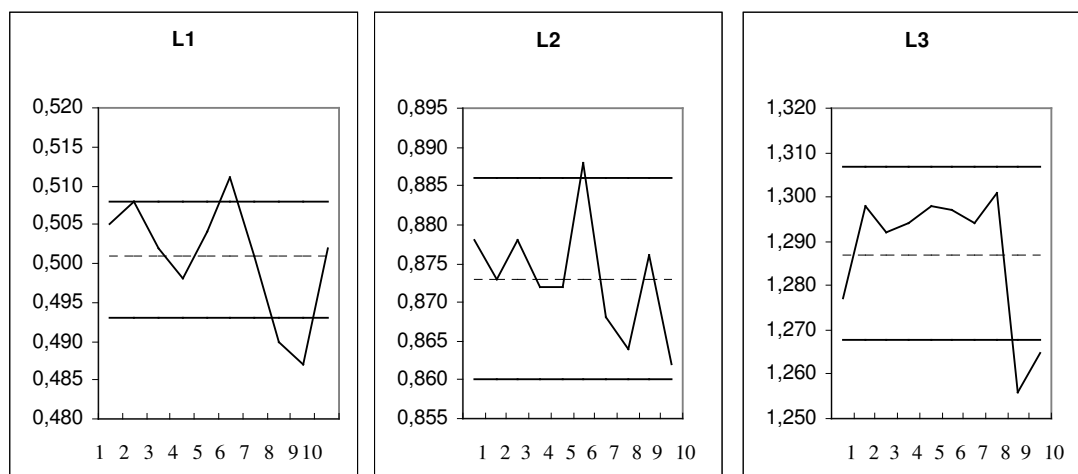
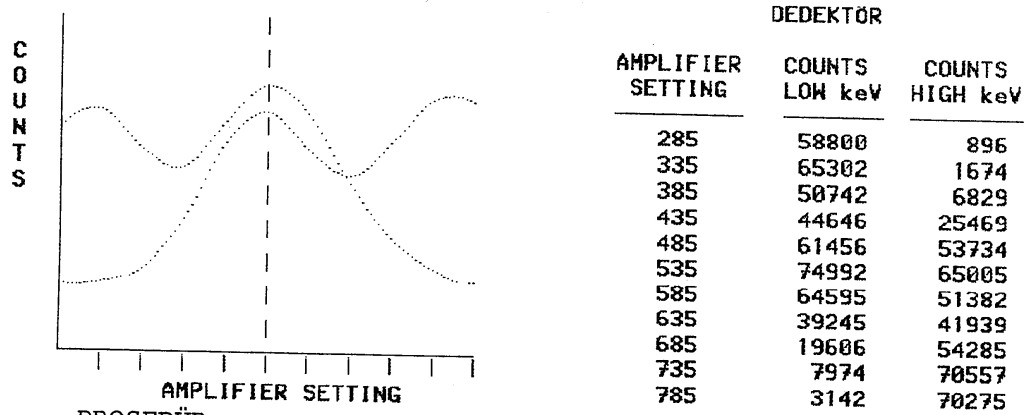


Figure A15 Center # 8 L1, L2 and L3 BMD (g/cm²) reproducibility control charts



PROSEDÜR	DEGER	DEGERLENDIRME
Lambalar	-	Kontrol
Peak Setting	535 ünite	Kontrol
Background (Low keV)	1 cps	
(High keV)	4 cps	Kontrol
Isin Durdurma	-	Kontrol
Isin Dagilim Yüzdesi	7.74 %	< 1
Ki Kare	4	Kontrol
Hava Sayimi (Low keV)	775669 cps	Kontrol
(High keV)	448205 cps	Kontrol
Hava Orani	0.58	Kontrol
Transvers Mekanik	12459/12460 adim	Kontrol
Longitudinal Mekanik	19774/19774 adim	Kontrol
Doku Degeri	1.307	Kontrol
Kolimasyon Orani	3.958	Kontrol

	1	2	3	4	5	MEAN	SD	%CV
BÜYÜK BM	266.3	266.3	267.8	267.5	266.9	267.0	0.62	0.23
WIDTH	503	499	499	501	498	500	1.79	0.36
ORTA BM	199.0	196.4	197.7	198.8	198.1	198.0	0.93	0.47
WIDTH	432	427	428	431	431	430	1.94	0.45
KÜÇÜK BM	140.8	141.4	141.6	141.1	143.8	141.7	1.06	0.75
WIDTH	364	362	363	364	364	363	0.80	0.22

Figure A16 Center # 8 daily system test report

A.10. Center 9

Scanner Type: LUNAR DPX

Measurement date: 27/05/2005

Facility Type: Hospital

Table A 10
Center # 9 BMD results

Center # 9			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,623	1,054	1,550
2	0,611	1,058	1,538
3	0,598	1,095	1,595
4	0,609	1,092	1,591
5	0,605	1,083	1,568
6	0,620	1,052	1,617
7	0,607	1,089	1,589
8	0,599	1,076	1,559
9	0,606	1,057	1,576
10	0,630	1,083	1,593
MEAN	0,611	1,074	1,578
up-limit	0,620	1,090	1,601
sub-limit	0,602	1,058	1,554
STD	0,010	0,017	0,024
CV	1,708	1,578	1,520

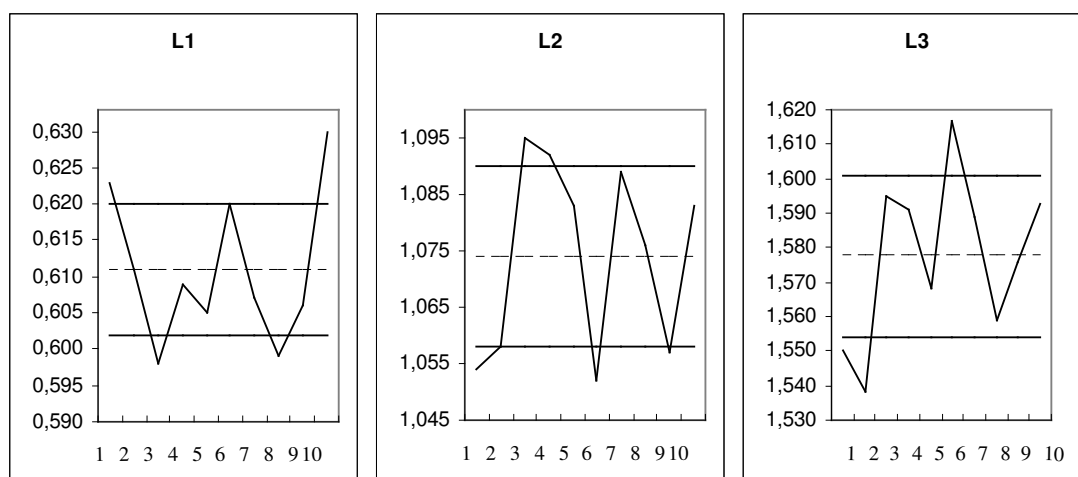


Figure A17 Center # 9 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

Center - 10

Scanner Type: HOLOGIC QDR4500A

Measurement date: 07/04/2005

Facility Type: Military University Hospital

Table A 11
Center # 10 BMD results

Center # 10			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,525	0,943	1,377
2	0,526	0,921	1,365
3	0,525	0,923	1,357
4	0,536	0,907	1,381
5	0,530	0,946	1,375
6	0,522	0,932	1,366
7	0,536	0,914	1,342
8	0,533	0,922	1,365
9	0,525	0,933	1,353
10	0,518	0,922	1,394
MEAN	0,528	0,926	1,368
up-limit	0,536	0,940	1,388
sub-limit	0,520	0,912	1,347
STD	0,006	0,012	0,015
CV	1,134	1,319	1,095

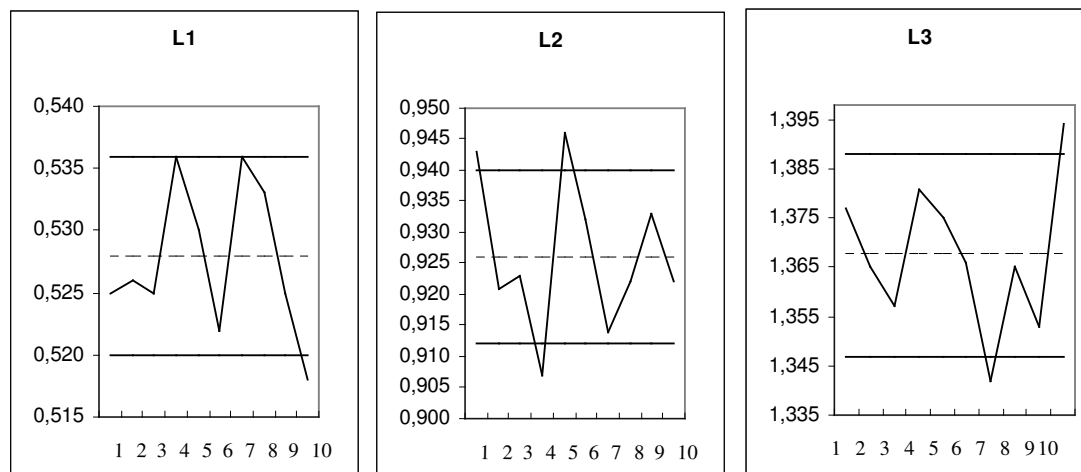


Figure A18 Center # 10 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.11. Center 11/ Densitometer # 1

Scanner Type: HOLOGIC QDR 4500C

Measurement date: 14/01/2005

Facility Type: University Hospital

Table A 12
Center # 11 Densitometer # 1 BMD results

Center # 4			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,517	0,912	1,360
2	0,526	0,898	1,352
3	0,516	0,912	1,338
4	0,531	0,908	1,335
5	0,516	0,908	1,344
6	0,519	0,927	1,339
7	0,532	0,910	1,344
8	0,525	0,902	1,345
9	0,508	0,910	1,337
10	0,514	0,911	1,338
MEAN	0,520	0,910	1,343
up-limit	0,528	0,923	1,363
sub-limit	0,513	0,896	1,323
STD	0,008	0,008	0,008
CV	1,497	0,830	0,578

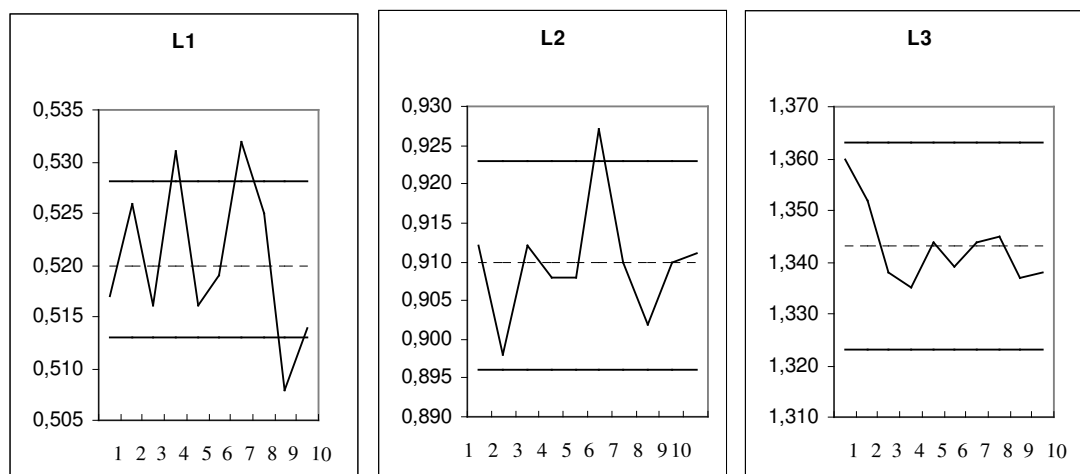


Figure A19 Center # 11 Densitometer #1 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.12. Center 11/ Densitometer # 2

Scanner Type: LUNAR DPX MD

Measurement date: 14/01/2005

Facility Type: University Hospital

Table A 13
Center # 11 Densitometer # 2 BMD results

Center # 11 Device # 2			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,598	1,033	1,499
2	0,595	1,020	1,529
3	0,600	1,034	1,507
4	0,595	1,059	1,495
5	0,596	1,061	1,500
6	0,594	1,039	1,504
7	0,614	1,045	1,514
8	0,595	1,041	1,524
9	0,581	1,042	1,517
10	0,593	1,035	1,508
MEAN	0,596	1,041	1,510
up-limit	0,605	1,057	1,532
sub-limit	0,587	1,025	1,487
STD	0,008	0,012	0,011
CV	1,352	1,170	0,738

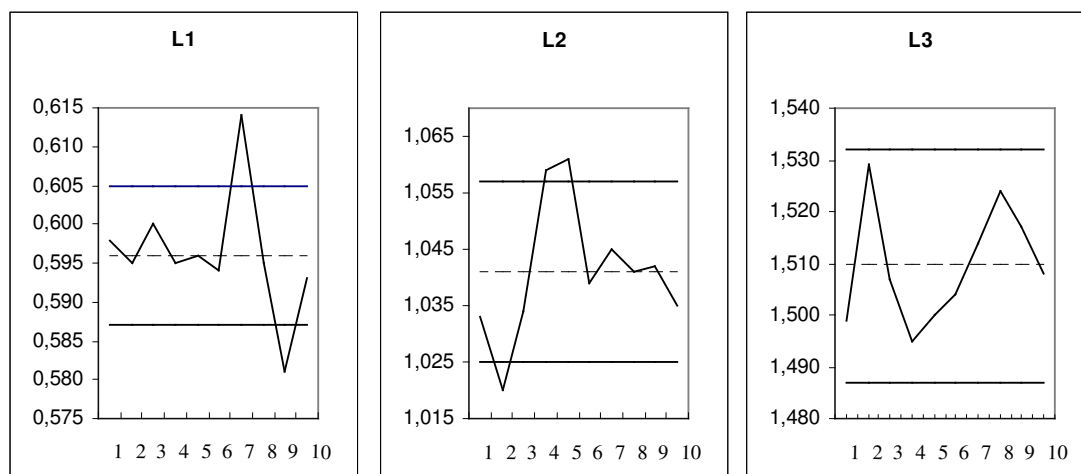


Figure A20 Center # 11 Densitometer # 2 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.13. Center 12

Scanner Type: LUNAR DPX

Measurement date: 12/03/2005

Facility Type: Hospital

Table A 14
Center # 12 BMD results

Center # 12			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,576	1,040	1,516
2	0,598	1,047	1,492
3	0,582	1,028	1,520
4	0,591	1,054	1,475
5	0,597	1,023	1,502
6	0,590	1,034	1,492
7	0,589	1,044	1,511
8	0,591	1,045	1,486
9	0,593	1,033	1,486
10	0,599	1,032	1,485
MEAN	0,591	1,038	1,497
up-limit	0,599	1,054	1,519
sub-limit	0,582	1,022	1,474
STD	0,007	0,010	0,015
CV	1,214	0,924	1,003

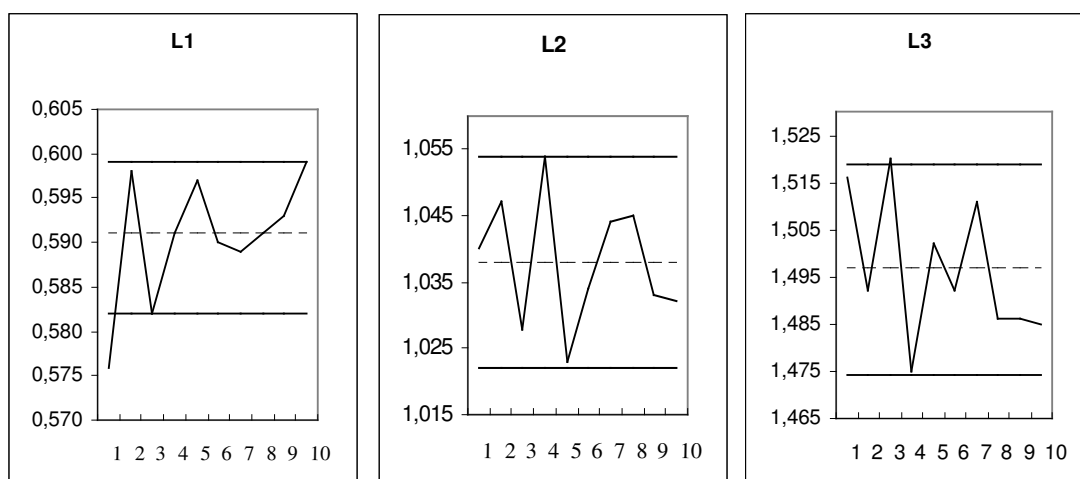


Figure A21 Center # 12 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.14. Center 13

Scanner Type: LUNAR DPX

Measurement date: 15/12/2004

Facility Type: Polyclinic

Table A 15
Center # 13 BMD results

Center # 13			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,566	1,090	1,548
2	0,568	1,048	1,557
3	0,608	1,074	1,555
4	0,588	1,060	1,540
5	0,592	1,061	1,549
6	0,587	1,074	1,572
7	0,567	1,062	1,534
8	0,567	1,060	1,557
9	0,599	1,075	1,567
10	0,583	1,039	1,529
MEAN	0,583	1,064	1,551
up-limit	0,591	1,080	1,574
sub-limit	0,574	1,048	1,528
STD	0,015	0,015	0,014
CV	2,576	1,373	0,884

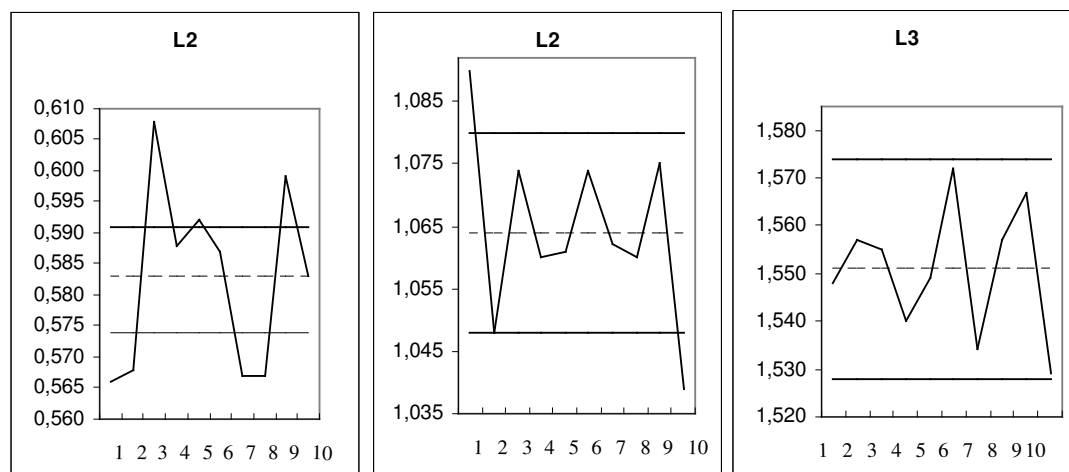
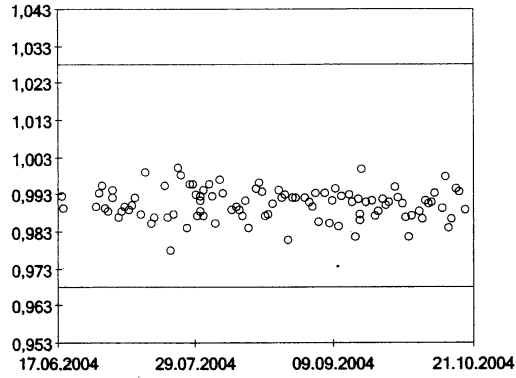


Figure A22 Center # 13 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

**Günlük ST Ölçümü**

Tarih	18.10.2004
Zaman	08:25:47
BMD Medium (1,500 mA)	0,989 g/cm ²
Deviasyon	-0,91 %

Trend Özeti

Ortalama BMD Medium (1,500 mA)	0,991 g/cm ²
CV	0,42%
Toplam Seanslar	102

Fonksiyonel Testler

Test	Değer	Durum
Peaking	2.256	Kontrol
Beam Stop	3,42 / 1,17	Kontrol
Mekanik Test		
Transvers	624,70	Kontrol
Longitudinal	1.960,30	Kontrol
Spillover Test		
Ortlama %	10,05%	Kontrol
Referans Hesaplamalar		
Yüksek mA	251.786 / 281.108	Kontrol
Oran Yüksek mA'de	0,90	Kontrol
Dedektör Durumu		Kontrol

Sekonder Kalibrasyon

Test	Ortalama	Durum
BMD		
Büyük	1,498	Kontrol
Medium	0,989	Kontrol
Küçük	0,493	Kontrol
Doku		
Yumuşak	15,9%	Kontrol
Orta	37,2%	Kontrol
Yağ	61,4%	Kontrol
Kalibrasyon Durumu		Kontrol

Sistem Durumu**Kontrol**

Figure A23 Center # 13 daily system test report

A.15. Center 14

Scanner Type: HOLOGIC QDR 1500

Measurement date: 28/10/2004

Facility Type: Imaging Center

Table A 16
Center # 14 BMD results

Center # 14			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,497	0,891	1,269
2	0,499	0,904	1,249
3	0,496	0,865	1,293
4	0,499	0,884	1,267
5	0,501	0,902	1,286
6	0,481	0,879	1,306
7	0,486	0,886	1,313
8	0,489	0,883	1,269
9	0,479	0,884	1,278
10	0,479	0,871	1,308
MEAN	0,491	0,885	1,284
up-limit	0,498	0,898	1,303
sub-limit	0,483	0,872	1,265
STD	0,009	0,012	0,021
CV	1,803	1,371	1,639

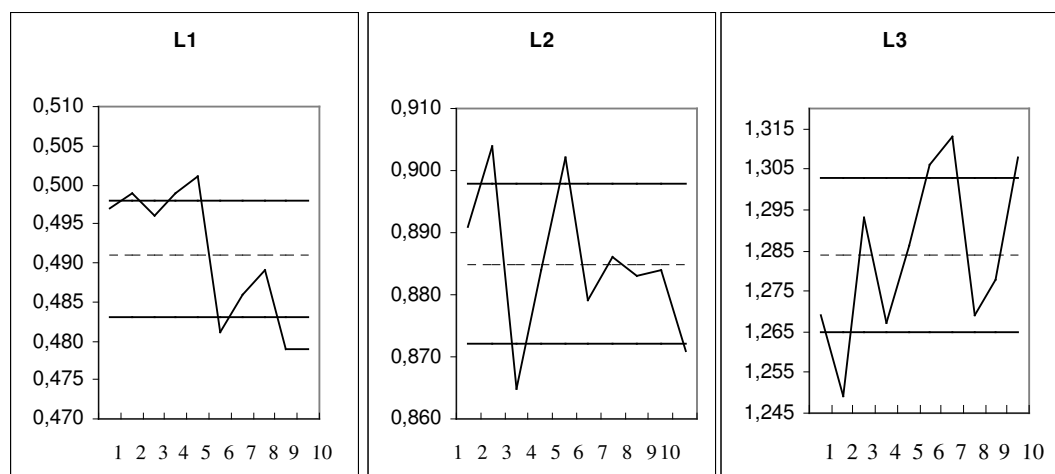


Figure A24 Center # 14 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.16. Center 15

Scanner Type: LUNAR DPX
 Measurement date: 18/10/2004
 Facility Type: Imaging Center

Table A 17
 Center # 15 BMD results

Center # 15			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,608	1,038	1,474
2	0,604	1,067	1,521
3	0,594	1,022	1,503
4	0,591	1,028	1,516
5	0,597	1,033	1,512
6	0,602	1,025	1,506
7	0,602	1,036	1,519
8	0,604	1,038	1,506
9	0,590	1,020	1,493
10	0,606	1,031	1,498
MEAN	0,600	1,034	1,505
up-limit	0,609	1,049	1,527
sub-limit	0,591	1,018	1,482
STD	0,006	0,013	0,014
CV	1,063	1,286	0,935

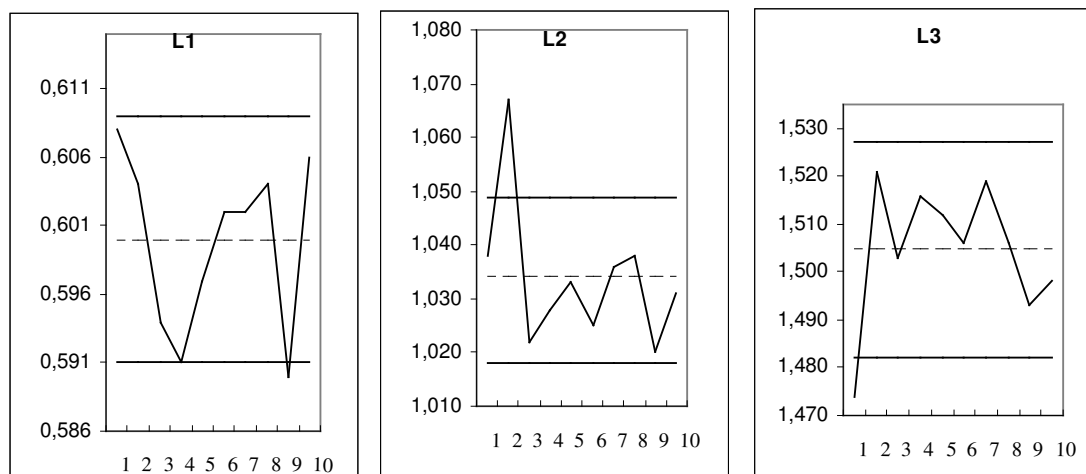


Figure A25 Center # 15 L1, L2 and L3 1,505 BMD (g/cm²) reproducibility control charts

A.17. Center 16

Scanner Type: HOLOGIC QDR 4500W

Measurement date: 26/10/2004

Facility Type: Polyclinic

Table A 18
Center # 16 BMD results

Center # 16			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,525	0,896	1,344
2	0,518	0,910	1,318
3	0,522	0,918	1,344
4	0,534	0,933	1,313
5	0,536	0,925	1,315
6	0,517	0,917	1,333
7	0,518	0,923	1,346
8	0,518	0,923	1,344
9	0,532	0,917	1,340
10	0,515	0,926	1,330
MEAN	0,524	0,919	1,333
up-limit	0,531	0,933	1,353
sub-limit	0,516	0,905	1,313
STD	0,008	0,010	0,013
CV	1,491	1,107	0,981

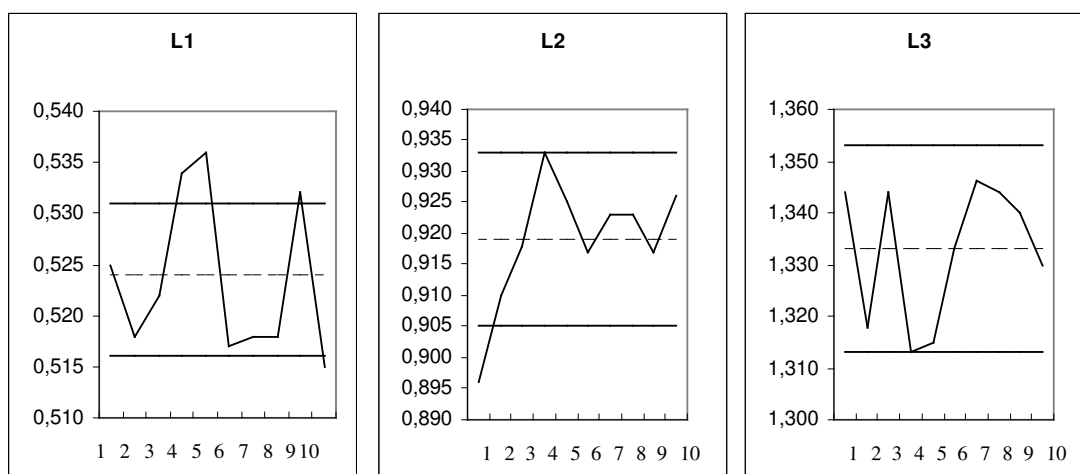


Figure A26 Center # 16 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.18. Center 17

Scanner Type: HOLOGIC QDR 4500A

Measurement date: 18/10/2004

Facility Type: Hospital

Table A 19
Center # 17 BMD results

Center # 17			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,520	0,927	1,372
2	0,512	0,918	1,370
3	0,520	0,923	1,356
4	0,517	0,918	1,346
5	0,521	0,924	1,359
6	0,519	0,913	1,383
7	0,524	0,939	1,352
8	0,522	0,922	1,398
9	0,525	0,944	1,361
10	0,521	0,917	1,378
MEAN	0,520	0,925	1,368
up-limit	0,528	0,938	1,388
sub-limit	0,512	0,911	1,347
STD	0,004	0,010	0,016
CV	0,705	1,069	1,158

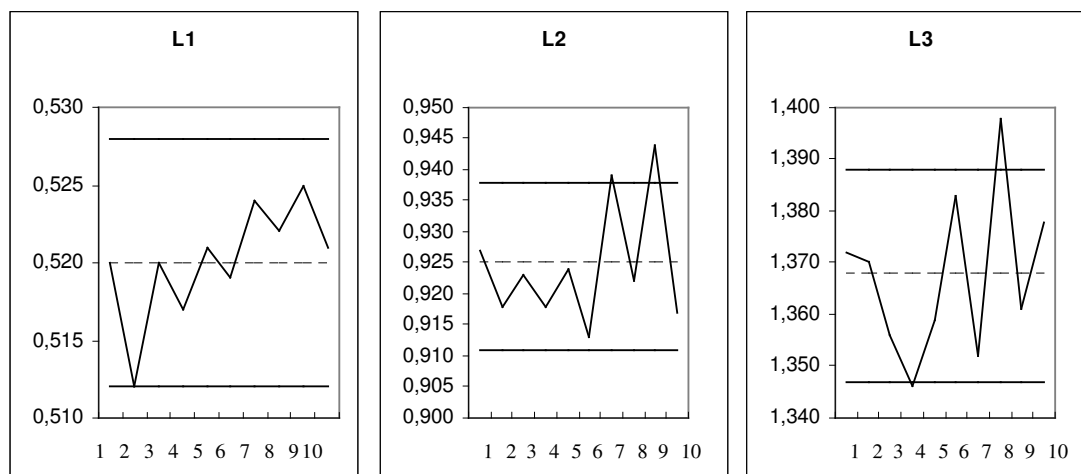


Figure A27 Center # 17 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.19. Center 18

Scanner Type: LUNAR DPXIQ

Measurement date: 07/04/2005

Facility Type: Hospital

Table A 20
Center # 18 BMD results

Center # 18			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,631	1,076	1,567
2	0,635	1,060	1,585
3	0,627	1,077	1,567
4	0,634	1,077	1,546
5	0,634	1,083	1,545
6	0,606	1,090	1,552
7	0,617	1,065	1,553
8	0,627	1,071	1,545
9	0,606	1,069	1,560
10	0,614	1,070	1,559
MEAN	0,623	1,074	1,558
up-limit	0,632	1,090	1,581
sub-limit	0,614	1,058	1,534
STD	0,011	0,009	0,013
CV	1,822	0,808	0,816

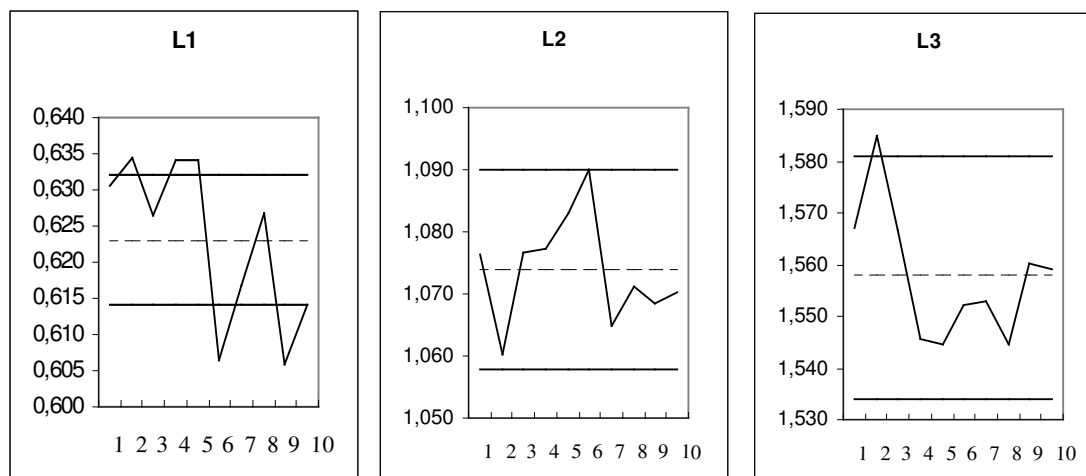


Figure A28 Center # 18 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.20. Center 19

Scanner Type: HOLOGIC QDR 1000P

Measurement date: 11/04/2005

Facility Type: Hospital

Table A 21
Center # 19 BMD results

Center # 19			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,489	0,912	1,296
2	0,496	0,879	1,287
3	0,487	0,899	1,293
4	0,500	0,887	1,274
5	0,502	0,883	1,322
6	0,494	0,887	1,285
7	0,493	0,868	1,359
8	0,489	0,897	1,304
9	0,509	0,863	1,346
10	0,501	0,894	1,301
MEAN	0,496	0,887	1,307
up-limit	0,503	0,900	1,326
sub-limit	0,489	0,874	1,287
STD	0,007	0,015	0,027
CV	1,406	1,653	2,101

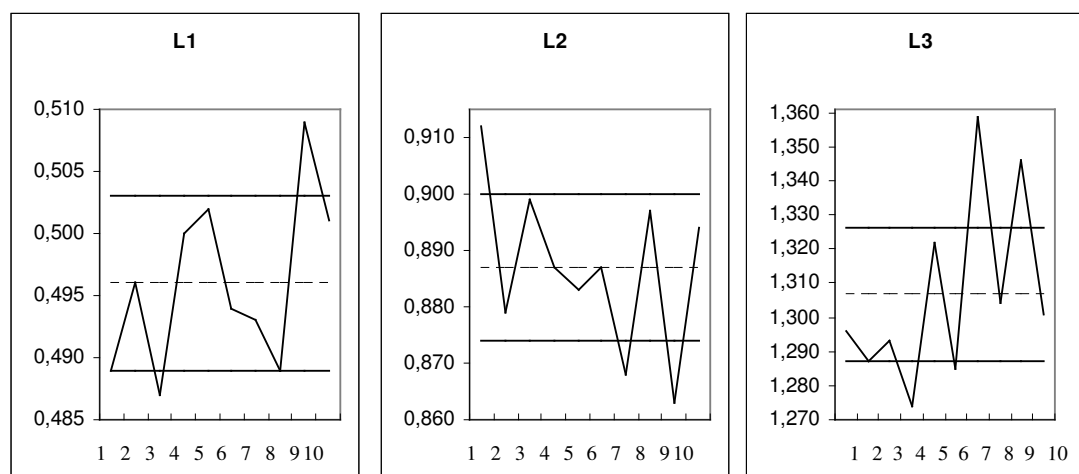


Figure A29 Center # 19 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

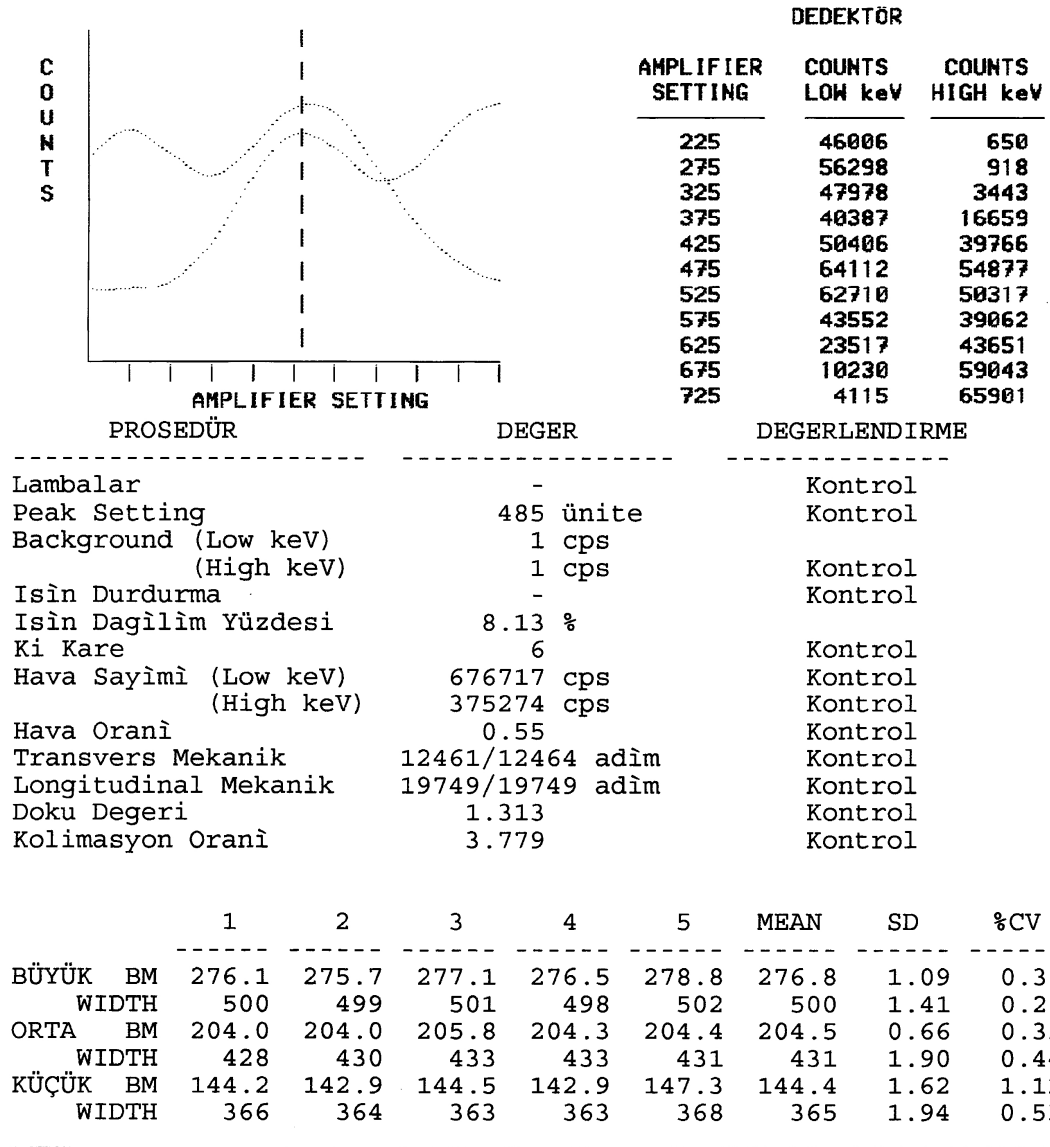


Figure A30 Center # 19 Densitometer daily system test report

A.21. Center 20

Scanner Type: HOLOGIC QDR 4000

Measurement date: 28/10/2004

Facility Type: Hospital

Table A 22
Center # 20 BMD results

Center # 20			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,490	0,860	1,290
2	0,490	0,900	1,290
3	0,500	0,900	1,270
4	0,490	0,870	1,350
5	0,500	0,880	1,300
6	0,500	0,870	1,340
7	0,490	0,870	1,290
8	0,490	0,870	1,300
9	0,500	0,870	1,260
10	0,500	0,870	1,260
MEAN	0,495	0,876	1,295
up-limit	0,502	0,889	1,314
sub-limit	0,488	0,863	1,276
STD	0,005	0,013	0,030
CV	1,065	1,541	2,338

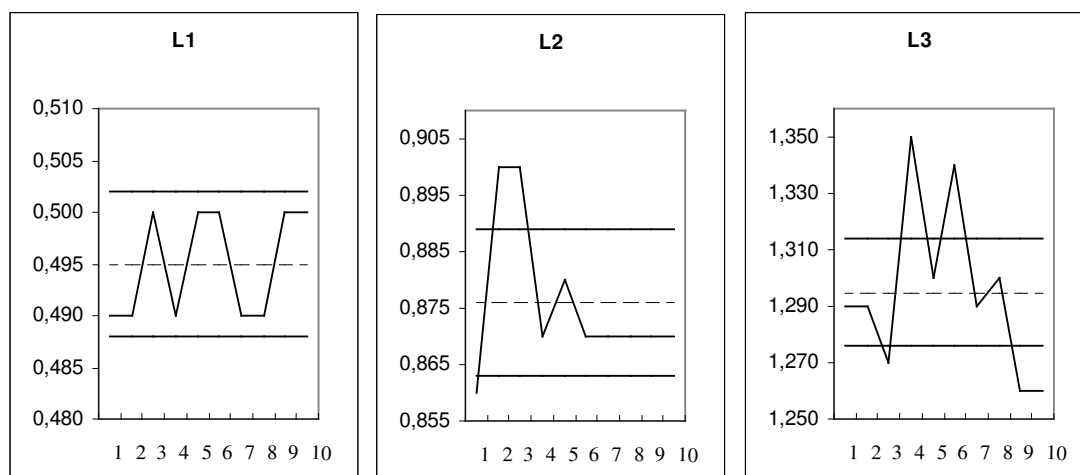


Figure A31 Center # 20 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.22. Center 21

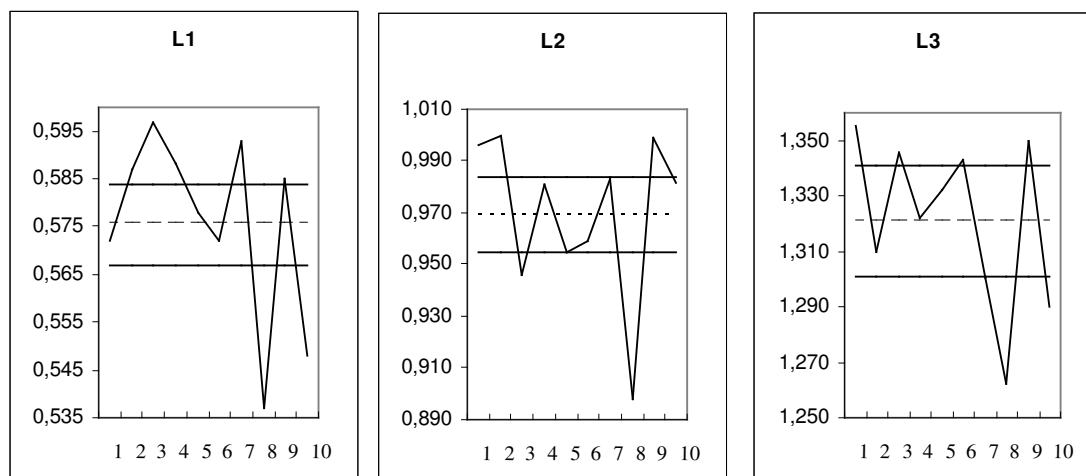
Scanner Type: MediLink Osteocore 2

Measurement date: 28/10/2004

Facility Type: Hospital

Table A 23
Center # 21 BMD results

Center # 21			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,572	0,996	1,355
2	0,587	1,000	1,310
3	0,597	0,946	1,346
4	0,588	0,981	1,322
5	0,578	0,955	1,332
6	0,572	0,959	1,343
7	0,593	0,983	1,300
8	0,537	0,898	1,262
9	0,585	0,999	1,350
10	0,548	0,982	1,290
MEAN	0,576	0,970	1,321
up-limit	0,584	0,984	1,341
sub-limit	0,567	0,955	1,301
STD	0,060	0,032	0,030
CV	10,813	3,253	2,289



FigureA32 Center # 21 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.23. Center 22

Scanner Type: LUNAR DPX IQ

Measurement date: 30/10/2004

Facility Type: Hospital

Table A 24
Center # 22 BMD results

Center # 22			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,613	1,063	1,546
2	0,604	1,044	1,524
3	0,627	1,051	1,513
4	0,611	1,061	1,539
5	0,619	1,058	1,484
6	0,643	1,061	1,539
7	0,631	1,087	1,529
8	0,608	1,075	1,520
9	0,612	1,075	1,527
10	0,606	1,062	1,537
MEAN	0,617	1,064	1,526
up-limit	0,627	1,080	1,549
sub-limit	0,608	1,048	1,503
STD	0,013	0,012	0,018
CV	2,036	1,172	1,165

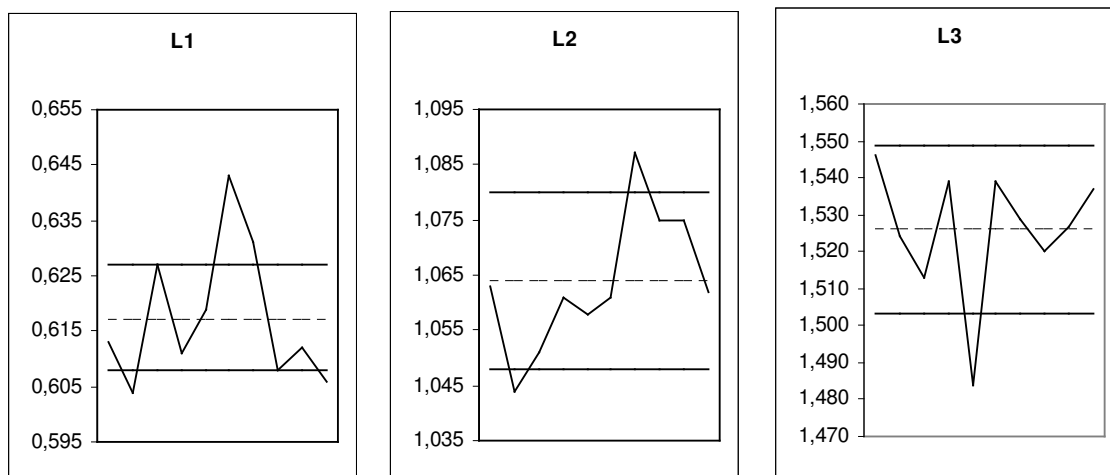


Figure A33 Center # 22 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.24. Center 23

Scanner Type: HOLOGIC QDR4000

Measurement date: 15/04/2004

Facility Type: Hospital

Table A 25
Center # 23 BMD results

Center # 23			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,501	0,880	1,259
2	0,489	0,890	1,282
3	0,491	0,868	1,264
4	0,502	0,867	1,307
5	0,490	0,876	1,297
6	0,496	0,861	1,318
7	0,492	0,875	1,350
8	0,503	0,870	1,330
9	0,494	0,887	1,323
10	0,492	0,873	1,325
MEAN	0,495	0,875	1,306
up-limit	0,502	0,888	1,325
sub-limit	0,488	0,862	1,286
STD	0,005	0,009	0,030
CV	1,056	1,036	2,274

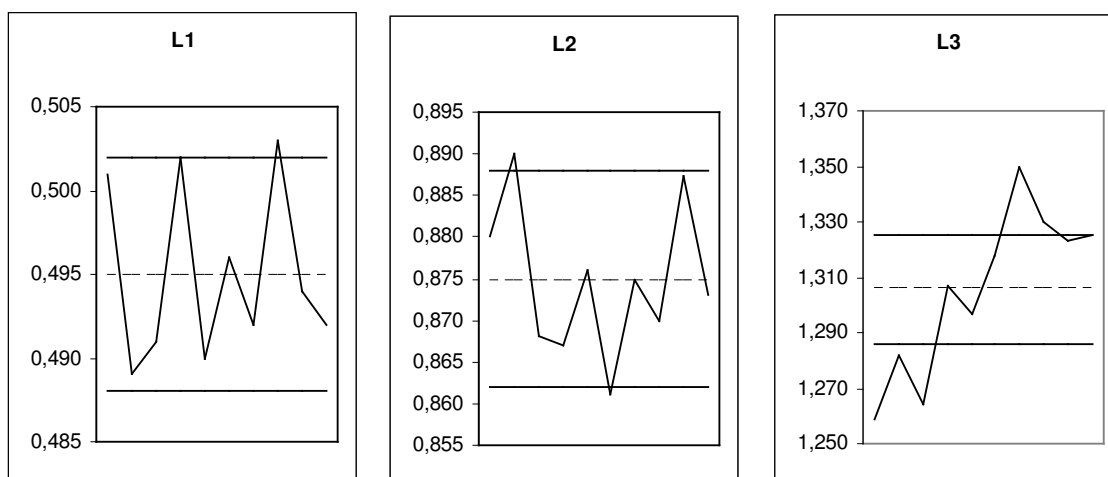


Figure A34 Center # 23 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.25. Center 24

Scanner Type: NORLAND XR

Measurement date: 09/04/2005

Facility Type: Polyclinic

Table A 26
Center # 24 BMD results

Center # 24			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,574	0,936	1,268
2	0,567	0,928	1,265
3	0,587	0,950	1,287
4	0,555	0,921	1,331
5	0,563	0,946	1,296
6	0,571	0,906	1,300
7	0,570	0,915	1,313
8	0,541	0,914	1,266
9	0,556	0,906	1,326
10	0,578	0,913	1,297
MEAN	0,566	0,923	1,295
up-limit	0,575	0,937	1,314
sub-limit	0,558	0,909	1,275
STD	0,013	0,016	0,024
CV	2,313	1,718	1,846

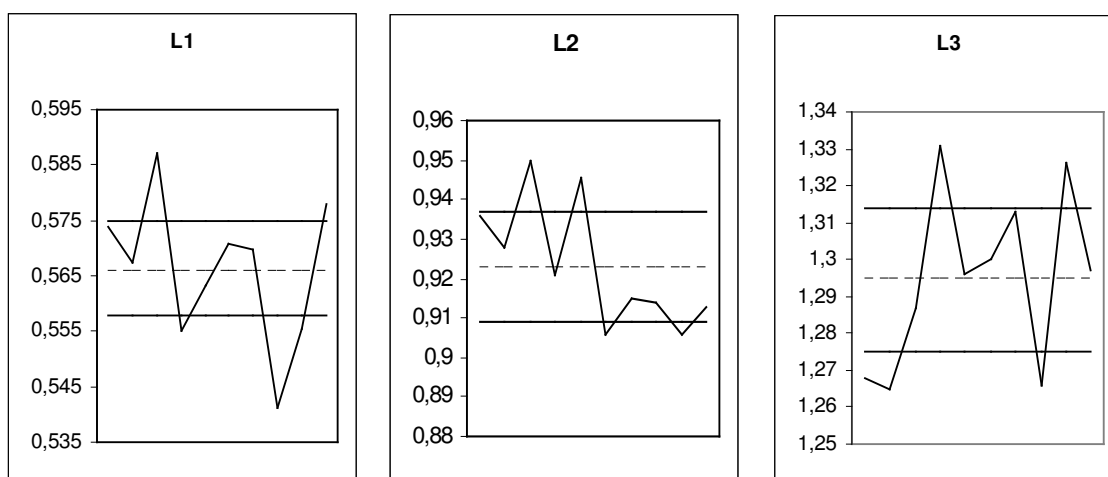


Figure A35 Center # 24 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.26. Center 25

Scanner Type: LUNAR DPX

Measurement date: 12/03/2005

Facility Type: Polyclinic

Table A 27
Center # 25 BMD results

Center # 25			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,598	1,055	1,520
2	0,597	1,051	1,538
3	0,595	1,059	1,541
4	0,597	1,062	1,541
5	0,593	1,051	1,543
6	0,603	1,047	1,553
7	0,599	1,055	1,546
8	0,600	1,059	1,546
9	0,596	1,057	1,529
10	0,588	1,058	1,533
MEAN	0,597	1,055	1,539
up-limit	0,606	1,071	1,562
sub-limit	0,588	1,039	1,516
STD	0,004	0,005	0,009
CV	0,684	0,435	0,608

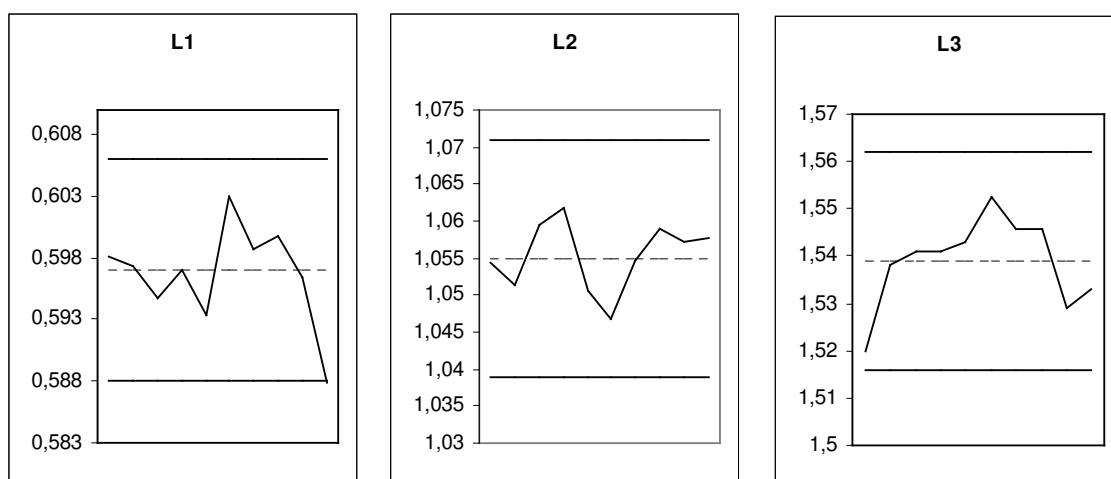


Figure A36 Center # 25 L1, L2 and L3 BMD (g/cm²) reproducibility control charts

A.27. Center 26

Scanner Type: LUNAR DPX IQ

Measurement date: 08/04/2005

Facility Type: Hospital

Table A 28
Center # 26 BMD results

Center # 26			
SCAN NO	L1 0.500g/cm ²	L2 1.000g/cm ²	L3 1.500g/cm ²
1	0,618	1,072	1,572
2	0,636	1,065	1,564
3	0,610	1,060	1,573
4	0,601	1,077	1,569
5	0,608	1,073	1,593
6	0,607	1,081	1,571
7	0,614	1,070	1,588
8	0,612	1,077	1,581
9	0,614	1,090	1,611
10	0,604	1,085	1,564
MEAN	0,612	1,075	1,579
up-limit	0,622	1,091	1,602
sub-limit	0,603	1,059	1,555
STD	0,010	0,009	0,015
CV	1,569	0,850	0,933

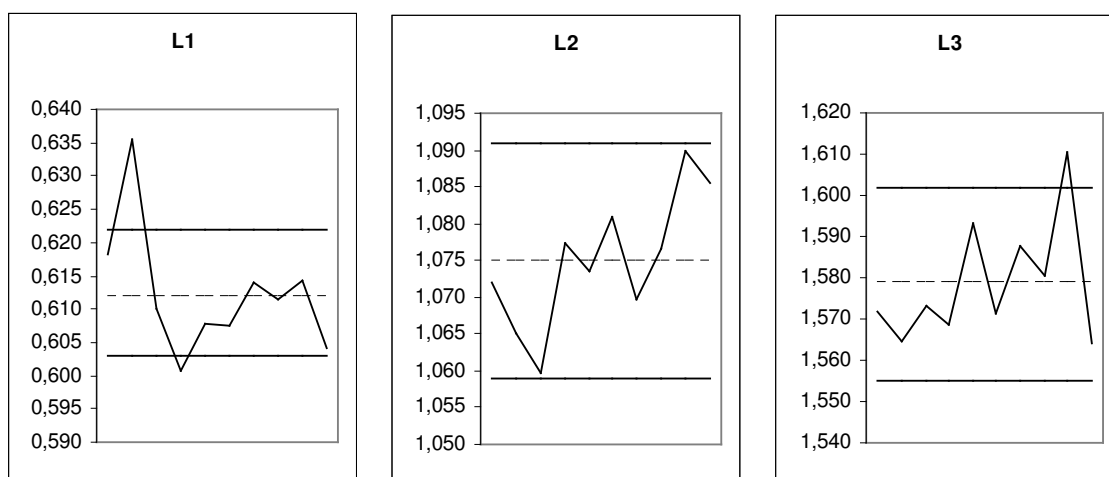


Figure A37 Center # 26 L1, L2 and L3 reproducibility acceptable ranges

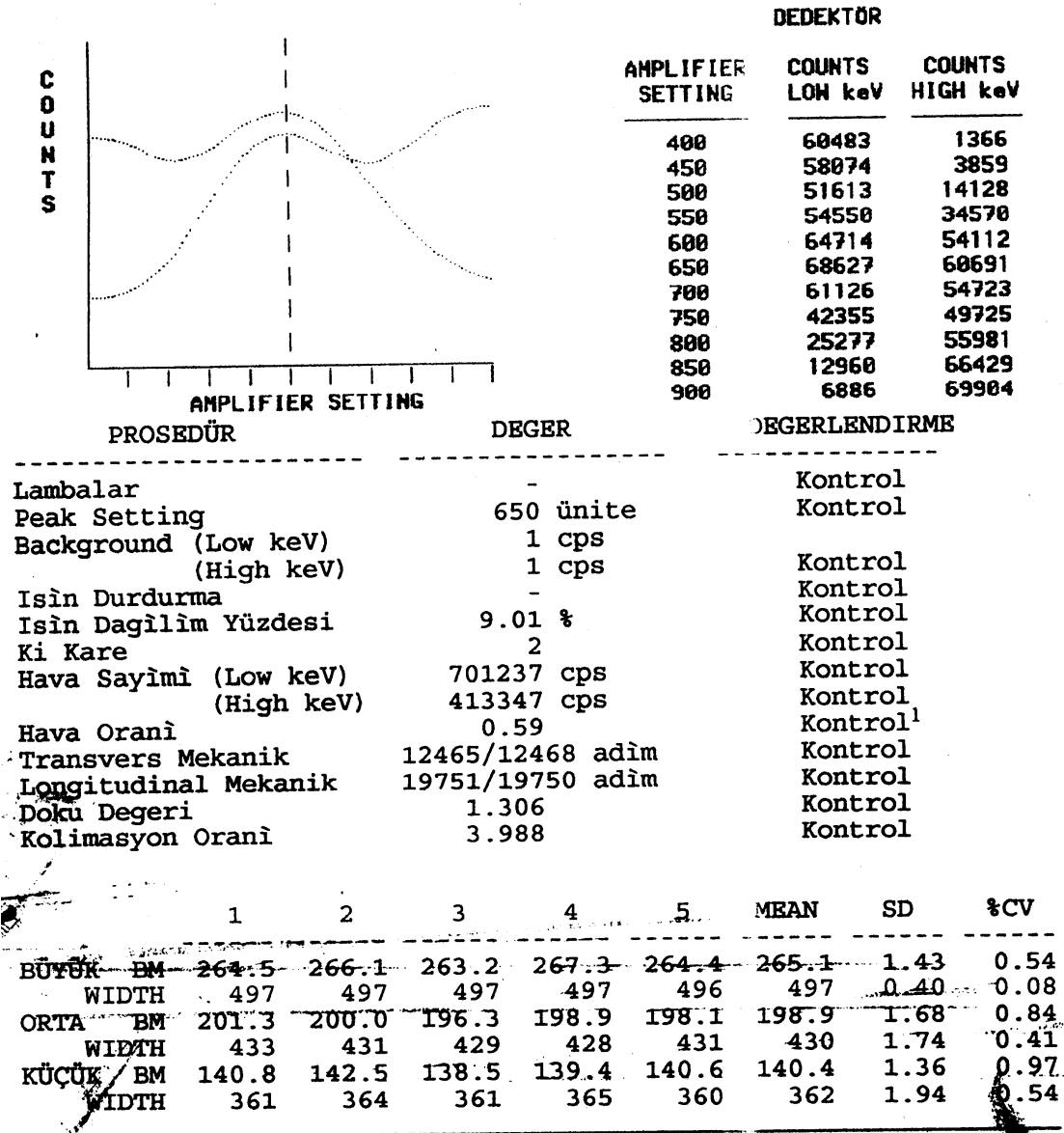


Figure A38 Center # 26 Densitometer daily system test report

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