Hip Structural Analysis (HSA) Program

(BMD and Structural Geometry Methodology)
As Used to Create NHANES III Dataset[1]

Octobert 29, 2002

Thomas J. Beck, ScD
Johns Hopkins University, School of Medicine
The Russell H. Morgan Department of Radiology and Radiological Sciences
601 North Caroline Street
Baltimore, MD 21287-0849

[1] ***Versions of the HSA program developed after the NHANES III data were processed contain additional features***

Note to NHANES III Hip Geometry Data Users:

Extremely high and low values have been verified whenever possible, and values that are obvious measurement errors (e.g., due to positioning errors, excessive anteversion, incomplete scans and other artifacts) have been deleted. However some errors may still remain; in addition, some high or low values may represent actual anatomic extremes. Therefore, users should examine the range and frequency of values before analyzing data.

Program Methodology

The Hip Structural Analysis (HSA) program measures not only the BMD of the hip bone but also structural geometry of cross-sections traversing the proximal femur at specific locations. The bone mass image is used directly from the DXA scan where pixel values are expressed in areal mass (g/cm^2). The method employs the principle that a line of pixel values across the bone axis correspond to a cut plane traversing the bone at that location and contain some of the information about the cross-section. The program analyzes the proximal femur at three locations as shown in Figure 1. The regions are: *Narrow Neck (NN)* across the narrowest diameter of the femoral neck, 2) *Intertrochanteric (IT)* along the bisector of the neck-shaft angle and 3) the *Shaft (S)*, 2 cm distal to the midpoint of the lesser trochanter. For each region the distribution of the bone mass across the bone is extracted then geometry properties are derived using formulae listed in Table 1. Note that widths of cross-sections are effectively broadened by averaging profile measurements along several parallel pixel lines at each region location. For the NHANES analysis 3 lines were averaged ~ 1 mm apart[2]. BMD is calculated in the conventional manner although these regions of interest do not have conventional counterparts in the standard Hologic BMD analysis, thus absolute BMD values differ from those obtained from the standard Hologic regions of interest.

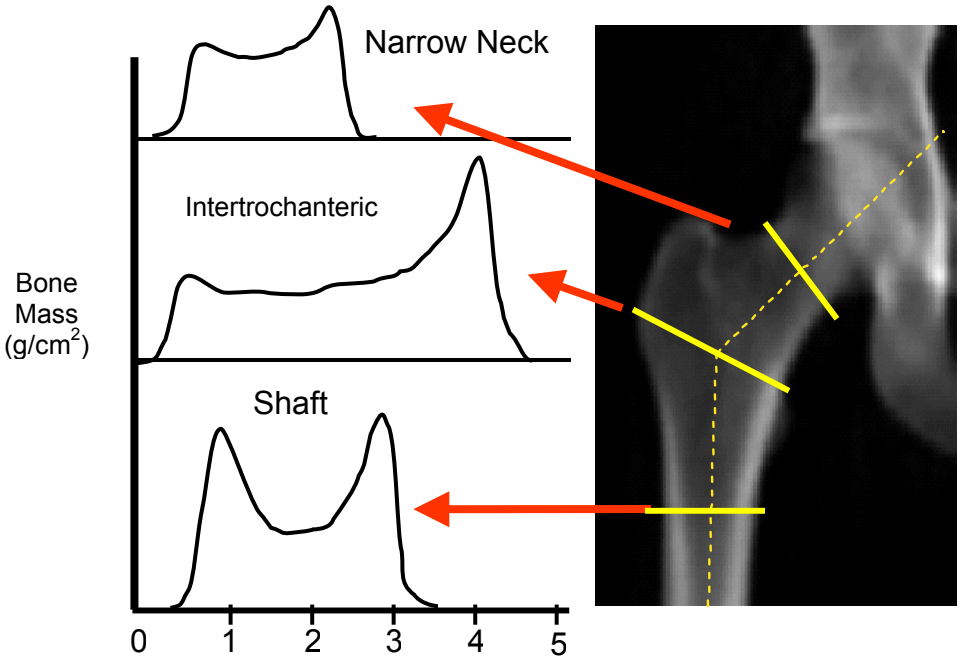

Figure 1: Hip image from a Hologic DXA scanner showing positions of thin analysis regions across the femur at the neck (NN region), intertrochanteric (IT) and shaft. On the left are shown typical bone mass profiles used in measurements of geometric properties.

The above measurements do not employ assumptions of shape, however it is often desirable to estimate cortical dimensions. The cross-sections are modeled as shown in Figure 2 in order to provide estimates of endocortical diameter, mean cortical thickness and buckling ratio. The buckling ratio is employed as a means for estimating stability of the cortex in thin-walled regions subjected to bending. The output for the NHANES III dataset consists of 34 variables on each scan data point for each subject. Table 1 provides a short explanation of each of the output variables as well as how it is calculated. A typical analysis sequence from an early version of the program follows Table 1.

[2] In versions of the HSA program developed after the NHANES III data were processed, 5 lines are averaged.

Figure 2: For estimates of endosteal diameter, cortical thickness and buckling ratio, models of the cross-sections using assumed shapes are necessary. The NN region and shaft regions are modeled as a circular annuli with 60/40 proportion of cortical/trabecular bone 100% cortical bone in the NN and shaft regions respectively. The IT region is modeled as an elliptical annulus that assumes 70/30 proportion of cortical/trabecular bone, with the anteroposterior diameter assumed to be the width of the shaft profile.

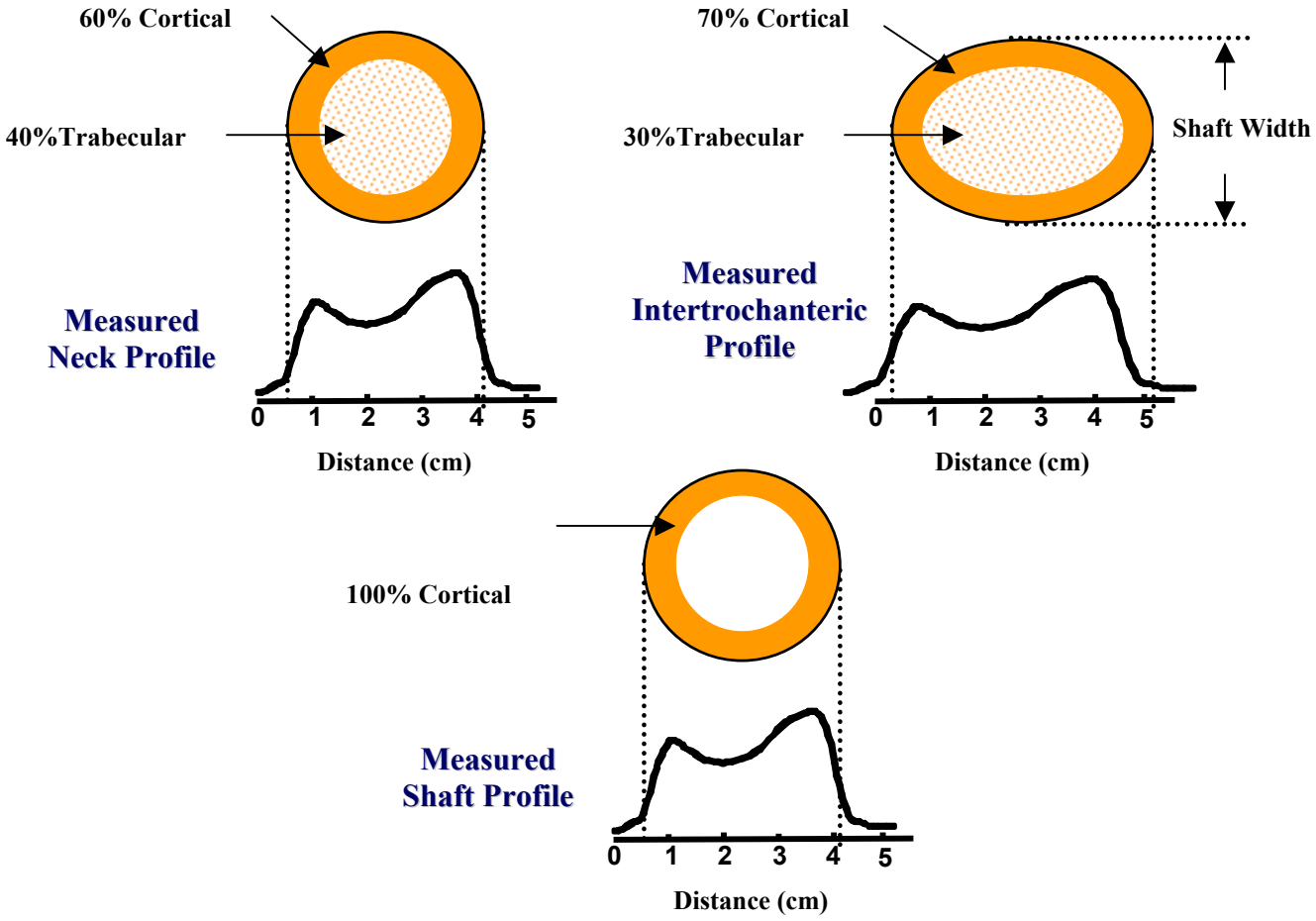

Table 1. Output variables in the NHANES III dataset obtained from the processing of hip scan files using the Hip Structural Analysis (HSA) Program.‡

Output Variable	Explanation of Variables
Hologic Femur Neck Width (cm)	This variable is not part of the HSA program. It was calculated from femur neck area output from conventional Hologic scan processing (BDPFNARE) as a convenience for users. In specific: FNWID=Hologic Femur neck area (BDPFNARE) / 1.5 This femur neck region differs from the Narrow Neck region measured in the HSA program in both size and location.
Neck Shaft Angle (degrees)	Angle between derived axes of neck and shaft
Neck Length (cm)	Distance from user defined center of femoral head to intersection of neck and shaft axes
Hip Axis Length (cm)	Distance from pelvic rim to outer margin of greater trochanter along neck axis
NN – Narrow Neck Region*	
NN Bone Mineral Density (g/cm^2)	Areal BMD calculated as: NN BMD = (NN CSA / NN Width) * 1.05†
NN Cross Sectional Area (cm^2)	Equivalent to the amount of (cortical equivalent) bone surface area in the cross-section after excluding all trabecular and soft tissue spaces. Computed as sum of pixel values in profile*(pixel spacing/1.05†)
NN Cross Sectional Moment of Inertia (cm^4)	For bending in the image plane from bone mass profile integral. Index of structural rigidity; reflects distribution of mass about the center of a structural element. Computed as (sum of pixel mass at each point in profile times square of its distance from profile center of mass) *(pixel spacing/1.05†)
NN Subperiosteal Width (cm)	Outer diameter of the bone computed as the blur-corrected width of the mass profile.
NN Endocortical Diameter (cm)	Estimate of inside diameter of cortex. Calculated as: NN ED = 2*((NN Width / 2)**2 - (0.6 * NN CSA / *pi*))**0.5
NN Average Cortical Thickness (cm)	Estimate of mean cortical thickness Calculated as: (NN Width – NN ED) / 2
NN Profile Center Distance (cm)	Distance from profile center of mass to medial margin of cortex
NN Center of Mass Position (dimensionless)	Fraction of neck width of location of center of mass of neck cross-section from medial cortical margin. Calculated as: NN Ctr = NN Profile Center Distance / NN Width

NN Section Modulus (cm^3)	Indicator of bending strength for maximum bending stress in the image plane.
	Calculated as follows: CSMI / (maximum distance between the center of mass and outer cortex), e.g.,
	If NN Ctr >= 0.5 then
	NN Sect Mod = NN CSMI / (NN Profile center distance);
	else
	NN Sect Mod = NN CSMI / (NN width – NN Profile center distance)

NN Buckling ratio	Relative thickness of NN cortex as an estimate of cortical stability in buckling. Calculated as: (Maximum distance between center of mass and outer cortex) / cortical thickness, e.g. NN BR = (NN CSMI / NN Sect Mod) / NN Avg Cort

IT – Intertrochanter Region*	
IT Bone Mineral Density (g/cm^2)	Areal BMD calculated as: IT BMD = (IT CSA / IT Width) * 1.05†
IT Cross Sectional Area (cm^2)	Equivalent to the amount of (cortical equivalent) bone surface area in the cross-section after excluding all trabecular and soft tissue spaces. Computed as (sum of pixel values in profile)*(pixel spacing/1.05†)
IT Cross Sectional Moment of Inertia (cm^4)	For bending in the image plane from bone mass profile integral. Index of structural rigidity; reflects distribution of mass about the center of a structural element. Computed as (sum of pixel mass at each point in profile times square of its distance from profile center of mass)*(pixel spacing/1.05†)
IT Subperiosteal Width (cm)	Outer diameter of the bone computed as the blur-corrected width of the mass profile.
IT Endocortical Diameter (cm)	Estimate of inside diameter of cortex. (This region assumes an elliptical cross-section for this measurement, with anteroposterior diameter as S Width) Calculated as: K = (((IT Width*S Width)*pi / 4 –0.7*IT CSA)/ (IT Width*S Width*pi / 4))**0.5 IT ED = K*IT Width,
IT Average Cortical Thickness (cm)	Estimate of mean cortical thickness Calculated as: (IT Width – IT ED) / 2
IT Profile Center Distance (cm)	Distance from profile center of mass to medial margin of cortex
IT Center of Mass Position (dimensionless)	Distance from center of mass to medial margin / bone subperiosteal width. Calculated as: IT Ctr = IT Profile center distance / IT Width
IT Section Modulus (cm^3)	Indicator of bending strength - for maximum bending stress in the image plane. Calculated as follows: CSMI / (maximum distance between the center of mass and outer cortex), e.g., IT Sect Mod = IT CSMI / (IT Width – IT Profile center distance) Assumed here that max distance was always IT Profile center distance for this region
IT Buckling ratio	Relative thickness of IT cortex as an estimate of cortical stability in buckling. Calculated as: (Maximum distance between center of mass and outer cortex) / cortical thickness,

	e.g. IT BR = (IT CSMI/ IT Sect Mod) / IT Avg Cort
	FS – Femur Shaft Region
FS Bone Mineral Density (g/cm^2)	Areal BMD calculated as: FS BMD = (FS CSA / FS Width) * 1.05†
FS Cross Sectional Area (cm^2)	Equivalent to the amount of (cortical equivalent) bone surface area in the cross-section after excluding all trabecular and soft tissue spaces. Computed as sum of pixel values in profile*(pixel spacing along profile/1.05†)
FS Cross Sectional Moment of Inertia (cm^4)	For bending in the image plane from bone mass profile integral. Index of structural rigidity; reflects distribution of mass about the center of a structural element. Computed as (sum of pixel mass at each point in profile times square of its distance from profile center of mass)*(pixel spacing along profile /1.05†)
FS Width (cm)	Outer diameter of the bone computed as the blur-corrected width of the mass profile.
FS Endocortical Diameter (cm)	Estimate of inside diameter of cortex. Calculated as: FS End Dia = 2*((FS Width/2)**2 – FS CSA/*pi*)**0.5
FS Average Cortical Thickness (cm)	Estimate of mean cortical thickness Calculated as: (FS Width – FS ED) / 2
FS Profile Center Distance (cm)	Distance from profile center of mass to medial margin of cortex
FS Center of Mass Position (cm)	Distance from center of mass to medial margin / bone subperiosteal width. Calculated as: FS Ctr = FS Profile center distance / FS Width

FS Section Modulus (cm^3)	Indicator of bending strength - for maximum bending stress in the image plane.
	
	Calculated as follows: CSMI / (maximum distance between the center of mass and outer cortex), e.g.,
	if FS Ctr >= 0.5 then
	FS Sect Mod = FS CSMI / FS Profile center distance;
	else
	FS Sect Mod = FS CSMI / (FS Width –FS Profile center distance)

FS Buckling ratio	Relative thickness of S cortex as index of cortical stability in buckling. Calculated as: (Maximum distance between center of mass and outer cortex) / cortical thickness, e.g. FS BR = (FS CSMI / FS Sect Mod) / FS Avg Cort

** Earlier versions of output define Neck region as "*Nrw*" and Intertrochanteric region as "*T*"
†Mineral density value taken from Martin RB, Burr DB. J Biomechanics 1984;17:195-201. In specific, it assumes density of mineral is ~ 3 gm/cm^2 and that mineral occupies ~35% of fully mineralized bone; thus mineral density = 0.35 x 3.0 = 1.05.
‡Other variables may be available in later versions of HSA program

Hip Structural Analysis (HSA) Program

The program is automated in that the user chooses actions by using the mouse. The analysis of each scan employs a number of steps. Listed below are figures showing the analysis of a hip scan for each step of the program. The illustrations show an early version of the program as used on NHANES III, later versions differ in a number of ways.

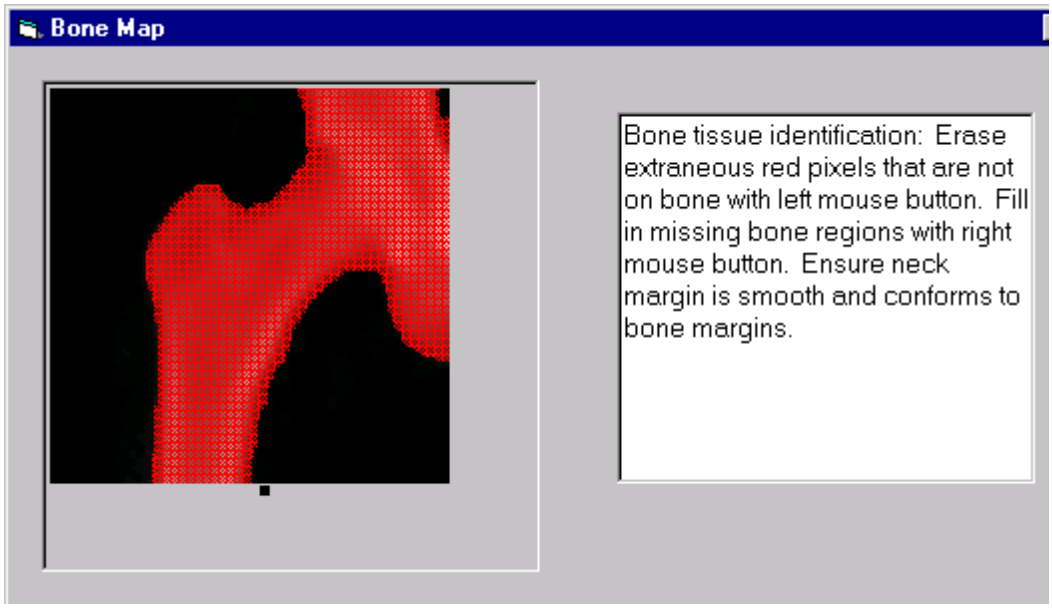

Figure 3. Bone Tissue Identification with Overlay

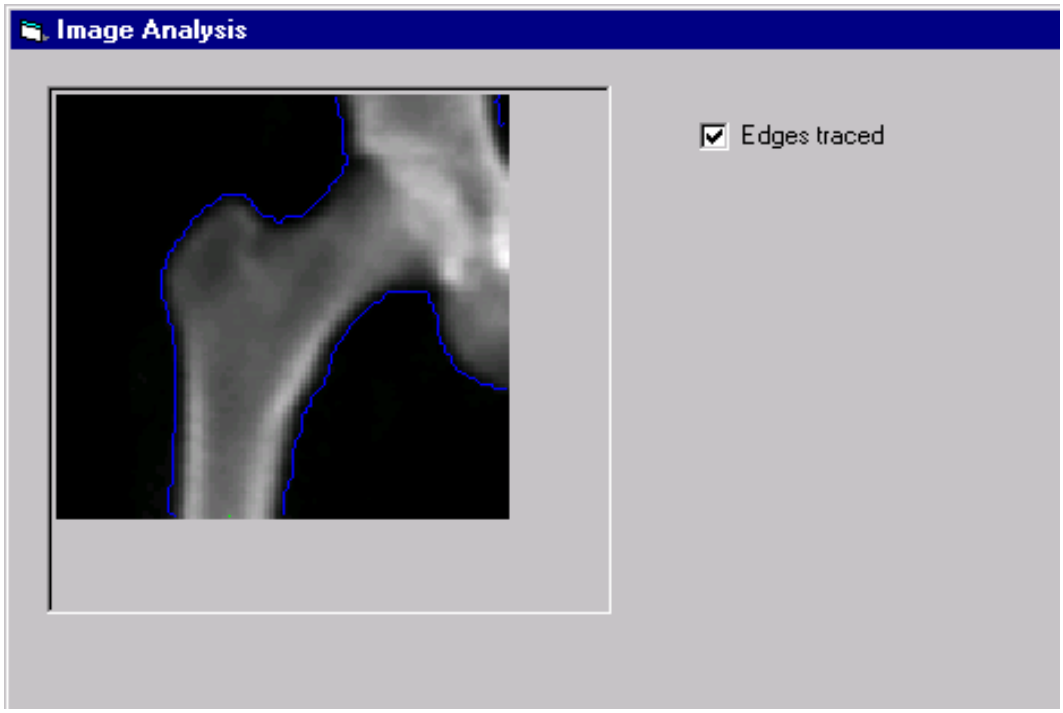

Figure 4. Bone Image Traced with Outline

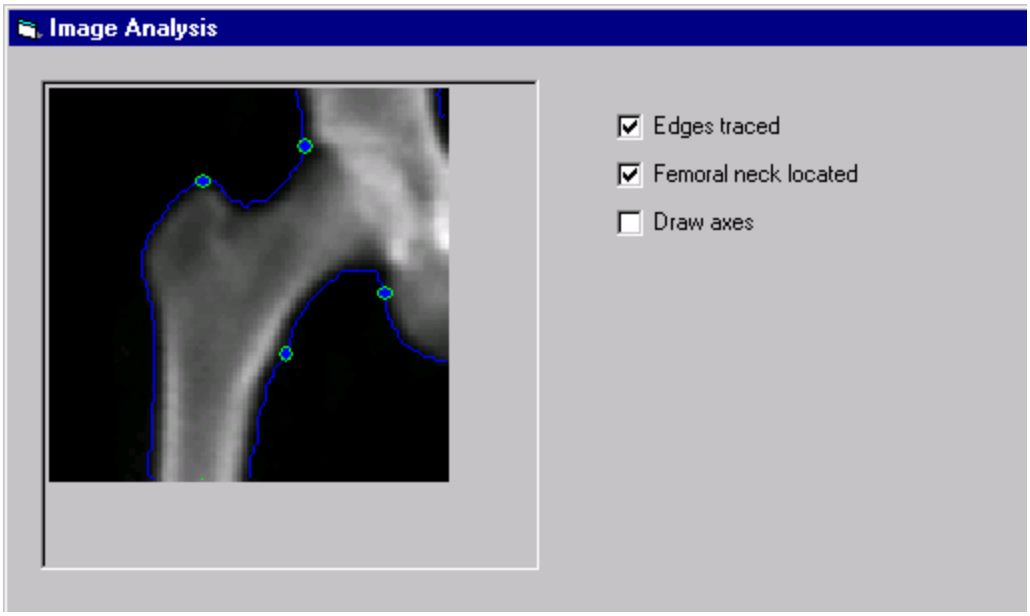

Figure 5. Location of the Femoral Neck

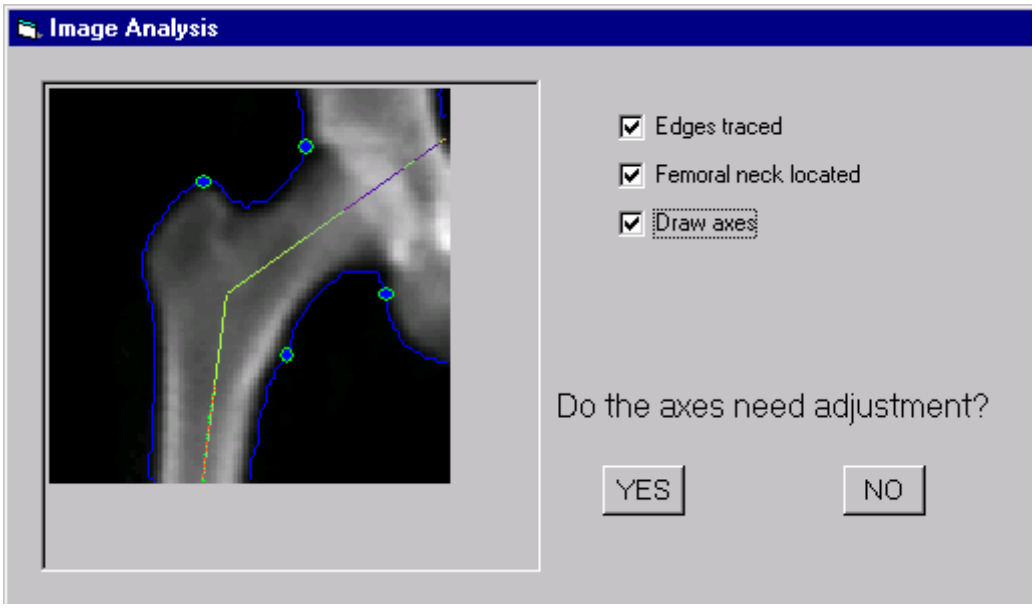

Figure 6. Neck and shaft Axes drawn for calculation of geometry parameters

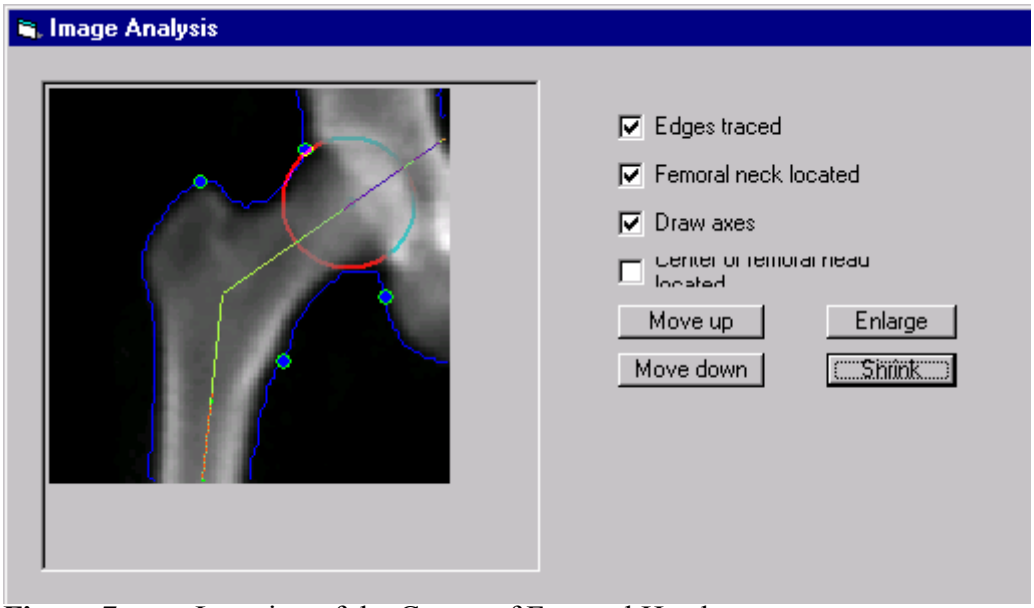

Figure 7. Location of the Center of Femoral Head

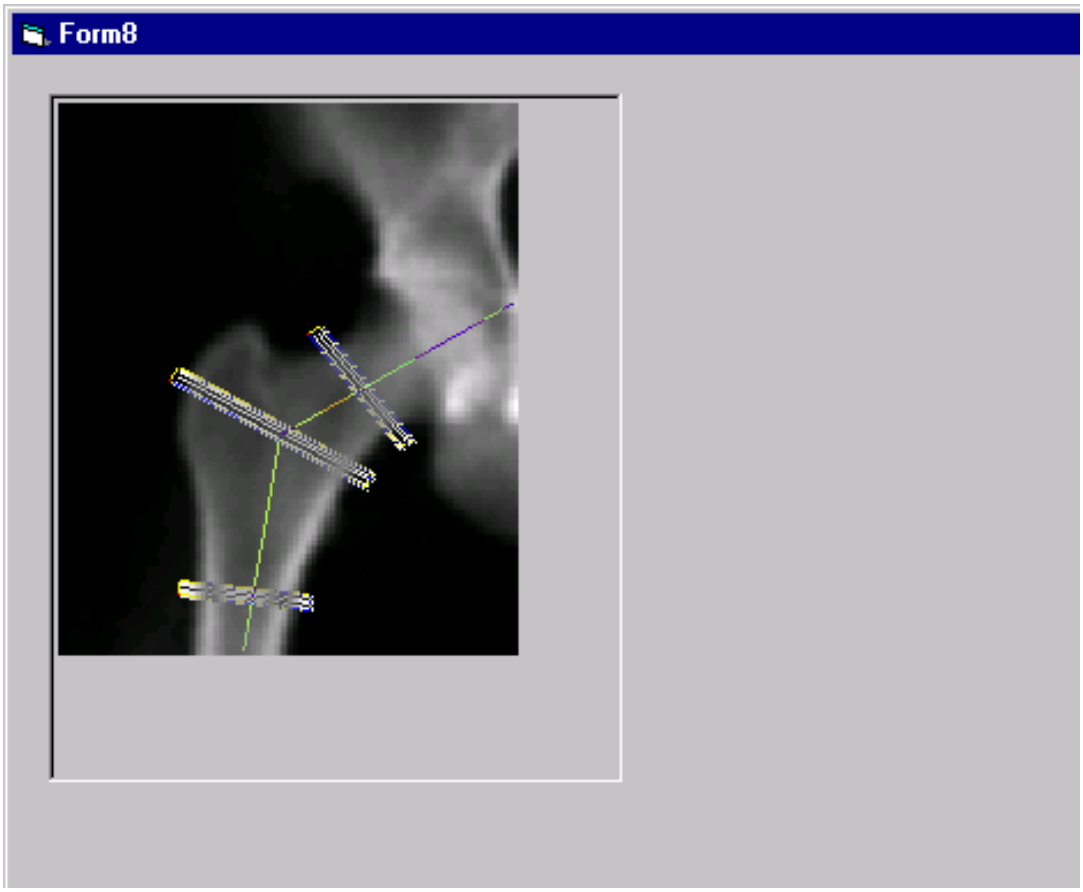

Figure 8. Calculation of Geometry Parameters for Neck (NN), Shaft (S) and Intertrochanteric (IT) Regions