

Acquisition and Analysis of Bone Mineral Density of the Distal Femur and Proximal Tibia

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The enclosed protocol was co-developed by **Craven BC, Moreno JC, Adachi JD and Webber CE** intended for use with a Hologic 4500 densitometer. Funding for this project was obtained from the Canadian Physiatry Research and Development Foundation (1998)

The rationale for the region of interest assignments were derived from QCT and validation of accuracy against ashed cadavers is contained September 2017 within JC Moreno's MSc thesis entitled, Bone Mineral Density of the Distal Femur and Proximal Tibia, McMaster University 2001.

This protocol is intended for use by an ISCD certified technologist, with a lower extremity positioner not recognized by the densitometer, and the normative data set for reporting of distal femur, and proximal tibia Z-scores and T-scores among patients with spinal cord injury.

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1 ACQUIRING THE KNEE SCAN

Under the **PERFORM EXAM** function button do the following:

- Click on the **AP Lumbar Spine** option within the Select Scan Type Window.
- Click the **NEXT** button.
- Increase the **SCAN LENGTH** to **9.1** in

1.1 Positioning the Patient



A custom made polycarbonate positioning device is used for the knee scan acquisition. The positioning device ensures 10° of hip internal rotation and 5° of knee flexion to provide optimal separation between the femur and tibia and reproducible positioning of the proximal fibula and patella. This device prevents movement artefacts in subjects with lower extremity spasticity and is not detected by the densitometer. A straight edge ruler will be needed to landmark the starting position for the scan.

1. Place the patient's right lower leg inside the polycarbonate positioning device. Rest their foot in the footplate.
2. Rotate the footplate medially and secure this position using the Velcro strap.
3. Place the polycarbonate arch in the popliteal fossa (behind the kneecap).
4. Make sure that the leg is parallel to the edge of the scanning table and the patella is perpendicular to the ceiling. Typically, the patella will sit superior to the joint line in this position.



1.2 Femur Scan

1. Using the C-Arm controls on the Control Panel, place the cross hair of the laser **5cm** below the **inferior** border of the patella and centred in the midline of the femur.
2. Click the **Start Scan** button.
3. As the image begins to appear in the Scan window look at the separation between the tibia and the fibula and the joint line between the tibia and the femur. If there is not a clear separation between the tibia and fibula **and/or** the joint line between the tibia and femur is not perpendicular to the long axis of the femur, stop the scan using the **Reposition Scan** button. Reposition the patient's leg to increase the separation between the tibia and fibula and/or straighten the joint line. Click the **Restart Scan** button.
4. The head of the femur should be centred in the middle of the scan window with even amounts of soft tissue on either side. The shaft of the femur should be straight. If the head is not centred and the shaft is not straight, click the **Reposition Scan** button.
5. Position the cursor over the knee image. Click and drag the image so that the head of the femur is centred in the scan window and the shaft of the femur is aligned with the blue vertical positioning line. If the shaft of the femur is not straight, reposition the patient's leg, being careful to maintain the position of the joint line.
6. When the femur is positioned correctly, click the **Restart Scan** button. Let the scan run until it runs the full scan length.
7. Proceed to scan analysis.

1.3 Tibia Scan

Acquiring the Tibia Scan only requires repositioning of the C-Arm, if steps 4 to 9 for acquiring the Femur Scan were carefully followed.

1. Using the C-Arm controls on the Control Panel, place the cross hair of the laser **22cm** below the **superior** border of the patella. Refer to the image of the tibia that appears in the Femur Scan to determine if the horizontal position of the C-Arm should be adjusted so that the head of the tibia will be centred in the scan window.
2. Click the **Start Scan** button.
3. The position of the tibia and fibula may be off center to allow for the head of the tibia to be centred in the scan window. The shaft of these bones should be straight.
4. If repositioning of the scan is necessary, use the **Reposition Scan** button.
5. Position the cursor over the image; click and drag it to the desired position. Or, if necessary move the patient's leg to the desired position. Movement of the patient's leg should not be necessary if an optimal position was achieved for the femur scan.
6. Click the **Restart Scan** button.
7. When you see the head of the femur appear, click the **Stop Scan** button.
8. Proceed to analysis.

2 Analysis of Distal Femur DXA Scans

(Using HOLOGIC Spine Software Version Apex 4.0.1)

2.1 Analyzing the Baseline Distal Femur Scan

1. Open the analysis screen of the software and select the scan to be analyzed.
2. Select **Compare to Previously Analyzed Scan** option.
3. Click **Scans of All Patients** tab.
4. Scroll down and select **ZZ Femur Knee Template** (This template will need to be installed).
5. Click the **NEXT** button.
6. The screen now shows two images, the template scan on the right and the newly acquired scan on the left.

2.1.1 Use the Region of Interest (ROI) box to measure the width of the Distal Femur

1. Click the **LINE MODE** tab on the left side of the screen.
2. Activate the left border of the ROI and move it until it touches the lateral aspect of the femur by dragging it with the mouse or using the arrow keys on the keyboard.
3. Activate the right border of the ROI and move it until it touches the medial aspect of the femur.
4. The width of the ROI box appears below the scan image. Record the number of pixels on the **Knee Analysis Worksheet**.
5. Click the **RESET** button on the bottom left side of the screen to restore the ROI box to its original width (116 pixels). **DO NOT** modify this width.
6. Click the **WHOLE MODE** tab on the left side of the screen. Move the ROI box until the bottom of it touches the most distal part of the femoral condyles.
7. Using the width recorded in step 4, find the corresponding ROI box length and the values for Line 1 and Line 2 in **Table 1 Knee Analysis - FEMUR**. Record them on the **Worksheet**. An example of using the epiphysis width to find the ROI

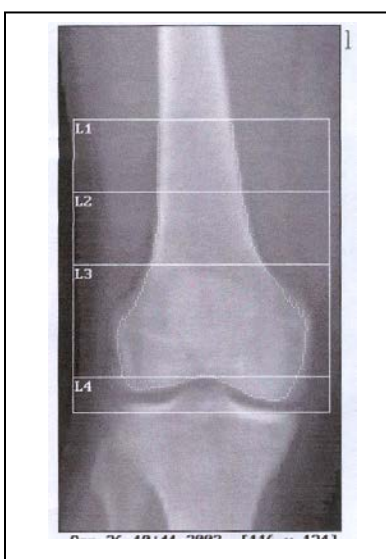
length and values for Lines 1 and 2 is provided below. [Line 3 is always set at the intercondylar notch (ICN) of the femoral head].

Example

Width	ROI Length	Line 1	Line 2	Line 3
71	95	76	49	ICN
72	96	77	50	ICN
73 →	98 ↙	78 ↙	51 ↙	ICN
74	99	79	51	ICN

2.1.2 Setting the ROI Box Length

1. Click the **LINE MODE** tab. Activate the top line of the ROI box. Move the line until the length of the ROI box is set to the value recorded in step 7.
2. Reactivate the bottom line of the ROI box and move it distally 3 pixels.
3. Click the **WHOLE MODE** button on the left side of the screen. Without changing the vertical position of the ROI box, use the arrow keys to move it horizontally until it is in the centre of the scan region. There should be sufficient space on either side of the ROI box to allow for horizontal movement of 4 pixels on either side of the femoral epiphysis.
4. When the ROI box is centred press the **END** key on the keyboard **twice**. The subregion of interest lines should be visible inside the ROI box.

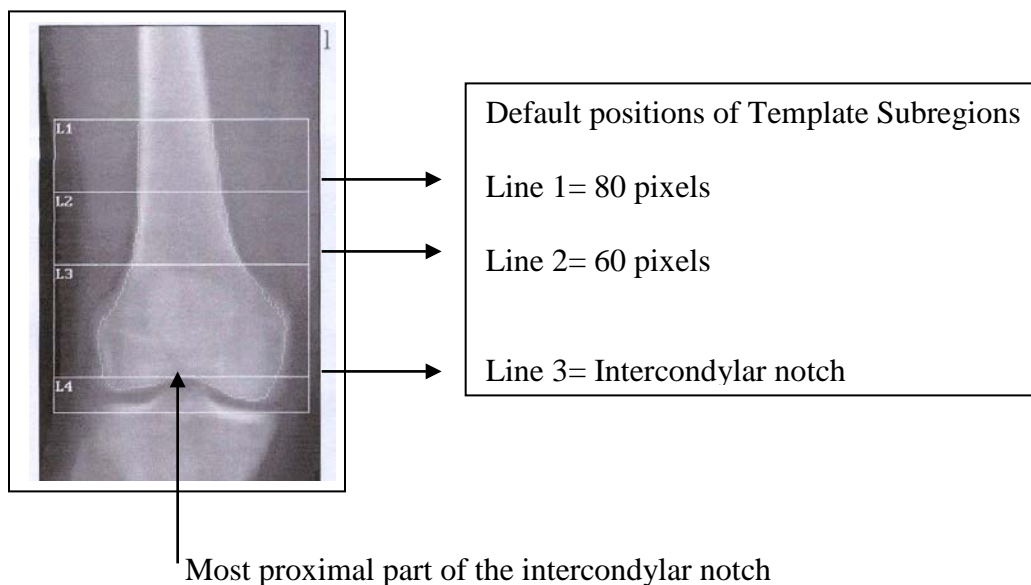


Note: The ROI box should include the knee joint. The femur epiphysis should be centered within the ROI box as shown.

2.1.3 Setting the Subregions Prior to Analysis

1. The 3 subregion lines inside the ROI box are set at default positions according to the template scan on the right side of the screen. The default positions are as follows:
 - a. Line 3= Intercondylar notch;
 - b. Line 2= 60 pixels; and
 - c. Line 1= 80 pixels.

Note: The values provided are pixels that correspond to the distances at which the lines should be placed as measured from the **bottom** of the Femur ROI box.



2. Activate the line closest to the bottom of the ROI box (Line 3) and move it, using the mouse or the arrow keys, to the most proximal part of the intercondylar notch. (See above).
3. Activate Line 2, and using the arrow keys move it up or down from the default position of 60 pixels until reaching the number recorded on the Worksheet.
4. Activate Line 1, and using the arrow keys move it up or down from the default position of 80 pixels until reaching the number recorded on the Worksheet.
5. Click the **END** key to move to the results screen. The values for Area, BMC, and BMD will appear.

2.1.4 *Horizontal Measurements*

1. Record the values for Total Area and Total BMD on the Worksheet in the row labelled Centre.
2. Click the **Global ROI** button. Use the arrow key to move the ROI box 1 pixel to the right. Press the **END** key once to reach the automatic bone map. Note if the bone map is satisfactory, but **DO NOT** make any modifications to it. Press the **END** key **twice** more to reach the **RESULTS** screen.
3. Record the values for **Area** and **BMD** on the **Worksheet** in the row labelled **1R**.
4. Repeat steps 2 and 3 four times, moving the ROI box 1 pixel further to the right each time and recording the values in the corresponding row of the **Worksheet**.
5. Return the ROI box to the centre position (4 pixels to the left).
8. Repeat steps 2 and 3 four times, moving the ROI box to the left.
9. Nine different measurements should be recorded on the **Worksheet**. Select the measurement that gives you the lowest **BMD** value (assuming a satisfactory bone map) with highest **Area** value or an area value that is within 2.5 cm² of the highest recorded area value. Move the ROI box to that position.

2.1.5 *Editing the Automatic Bone Map*

1. If the automatic bone map has included areas that are not bone, use the **Edit** function and activate the **Delete Bone** option. Remove any mapping that does not represent femoral bone using the mouse or the arrow keys.
2. If the automatic bone map omitted portions of femoral bone use the **Edit** function and activate the **Add Bone** option. Apply mapping to omitted areas using the mouse or the arrow keys.
3. Once a satisfactory bone map of the distal femur has been achieved press the **End** key to move to the **RESULTS** screen.
4. Print the results.

2.2 **Analyzing a Follow-Up Distal Femur Scan**

1. Click the **Compare to Previously Analyzed Scan** mode to analyze follow-up scans.
2. Select the patient's baseline femur scan.

3. Using the baseline scan as a guide, place the bottom of the ROI box in the position that matches as closely as possible the position of the bottom of the ROI box of the baseline scan.
4. **Do not** change the vertical position of the ROI box, but move it horizontally until it is centred. Press the **End** key **three** times to reach the **RESULTS** screen. Record the values for **Area** and **BMD** on the **Worksheet** in the row labelled Centre.
5. Repeat steps 2 and 3 in the **2.1.4 Horizontal Measurements** four times to the right of centre and four times to the left.
6. Repeat steps **2.1.5 Editing the Automatic Bone Map** to finish the analysis.

3 Analysis of Proximal Tibia DXA Scans

(Using HOLOGIC Spine Software Version Apex 4.0.1)

3.1 Analyzing the Baseline Proximal Tibia Scan

1. Open the analysis screen of the software and select the scan to be analyzed.
2. Select **Compare to Previously Analyzed Scan** option.
3. Click the **NEXT** button.
4. Click **Scans of All Patients** tab.
5. Scroll down and select **ZZ Tibia Knee Template** (This template will need to be installed).
6. Click the **NEXT** button.
7. The screen now shows two images, the template scan on the right and the newly acquired scan on the left.

3.1.1 Use the Region of Interest (ROI) box to measure the Width of the Proximal Tibia

1. Move the ROI box up until it reaches the widest part of the tibia.
2. Click the **LINE MODE** tab on the left side of the screen.

3. Activate the left border of the ROI and move it until it touches the lateral aspect of the tibia by dragging it with the mouse or using the arrow keys on the keyboard.
4. Activate the right border of the ROI and move it until it touches the medial aspect of the tibia.
5. The width of the ROI box appears below the scan image. Record the number of pixels on the **Knee Analysis Worksheet**.
6. Click the **RESET** button on the bottom left side of the screen to restore the ROI box to its original width (116 pixels). **DO NOT** modify this width.
7. Click the **WHOLE MODE** tab on the left side of the screen. Move the ROI box until the bottom of it touches the most distal part of the intercondylar eminence of the tibia. (See picture below).
8. Using the width recorded in step 5, find the corresponding ROI box length and the values for Line 1, Line 2 and Line 3 in Table 2 Knee Analysis – TIBIA. Record them on the **Worksheet**. An example of using the width to find the ROI box length and values for Lines 1, 2 and 3 is provided below.

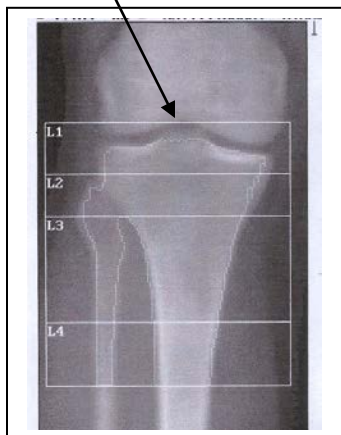
Example

Width	ROI Length	Line 1	Line 2	Line 3
71	99	16	33	72
72	100	17	33	73
73 →	102 ↘	17 ↘	34 ↘	75 ↘
74	103	17	34	76

3.1.2 Setting the ROI Box Length

1. Click the **LINE MODE** tab. Activate the bottom of the ROI box. Move the line up or down until the length of ROI box is set to the value recorded in step 8 of **3.1.1**.
2. Reactivate the top line of the ROI box and move it proximally 5 pixels.
3. Click the **WHOLE MODE** button on the left side of the screen and move the whole ROI box until the box is centred in the scan region.
4. When the ROI box is properly positioned press the **END** key on the keyboard **twice**.

Inter-condylar eminence

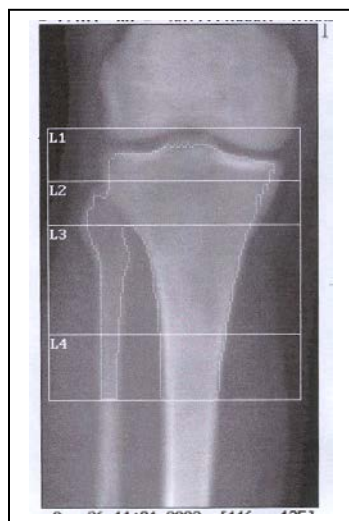


Note: The ROI box should include the knee joint line. The tibia should be centred within the ROI box as shown.

3.1.3 Setting the Subregions Prior to Analysis

1. The ROI box of the scan to be analyzed should have 3 lines inside that are set at default positions according to the template scan on the right side of the screen. Those default positions are as follows:
 - a. Line 1= 15 pixels;
 - b. Line 2= 30 pixels; and
 - c. Line 3= 80 pixels.

Note: The values provided are pixels that correspond to the distance at which the lines should be placed as measured from the **top** of the tibia ROI box.



Default Positions of Template Subregions

Line 1= 15 pixels
Line 2= 30 pixels

Line 3= 80 pixels

2. Activate the line closest to the top of the ROI box (Line 1), and move it using the arrow keys up or down from the default position of 15 pixels to the number recorded on the worksheet.

3. Activate Line 2, and move it using the arrow keys up or down from the default position of 30 pixels to the number recorded on the worksheet.
4. Activate Line 3 and move it, using the arrow keys, up or down from the default position of 80 pixels to the number recorded on the worksheet.
5. Click the **END** key to move to the **RESULTS** screen.

3.1.4 Horizontal Measurements

1. Record the values for **Area** and **BMD** in the row labelled **Centre** on the **Worksheet**.
2. Click the **Global ROI** button. Use the arrow key to move the ROI box 1 pixel to the right. Press the **END** key once to reach the automatic bone map. Note if the bone map is satisfactory, but **DO NOT** make any modifications to it. Press the **END** key **twice** more to reach the **RESULTS** screen.
3. Record the values for **Area** and **BMD** in the row labelled **1R**.
4. Repeat steps 2 and 3 four times, moving the ROI box 1 pixel further to the right each time and recording the values in the corresponding row on the **Worksheet**.
5. Return the ROI box to the centre position (4 pixels to the left).
6. Repeat steps 2 and 3 four times, moving the ROI box to the left 1 pixel each time.
7. Nine different measurements should be recorded on the **Worksheet**. Select the measurement that gives you the lowest **BMD** value (assuming a satisfactory bone map) with highest **Area** value or an area value that is within 2.5 cm² of the highest recorded area value. Move the ROI box to that position.

3.1.5 Editing the Automatic Bone Map

1. If the automatic bone map has included areas that are not strictly bone, use the **Edit** function and click the **Delete Bone** option. Remove any mapping that does not represent tibial bone using the mouse or the arrow keys.
2. If the automatic bone map omitted portions of tibia bone, use the **Edit** function and click on the **Add Bone** option. Apply mapping to omitted areas using the mouse or the arrow keys.
3. Once a satisfactory map of the proximal tibia has been achieved press the **End** key on the keyboard to move to the **RESULTS** screen.

4. Print the results.

3.2 Analyzing a Follow-Up Scan

1. Click the **Compare to Previously Analyzed Scan** mode to analyze follow-up scans.
2. Select the patient's baseline tibia scan.
3. Using the baseline scan as a guide, place the top of the ROI box in the position that matches as closely as possible the position of the top of the ROI box of the baseline scan.
4. **DO NOT** change the vertical position of the ROI box, but move it horizontally until it is centred. Press the **End** button **three** times to reach the **RESULTS** screen. Record the values for **Area** and **BMD**.
7. Repeat steps 2 and 3 in the **2.1.4 Horizontal Measurements** four times to the right of centre and four times to the left.
5. Repeat steps **2.1.5 Editing the Automatic Bone Map** to finish the analysis.

4 Knee Analysis Worksheet

FEMUR

Width	
ROI length	
Line 1	
Line 2	

Location	Area	BMD
Centre		
1 R		
2 R		
3 R		
4 R		
1 L		
2 L		
3 L		
4 L		

TIBIA

Width	
ROI length	
Line 1	
Line 2	
Line 3	

Location	Area	BMD
Centre		
1 R		
2 R		
3 R		
4 R		
1 L		
2 L		
3 L		
4 L		

5 Table 1 Knee Analysis – Femur

Width	ROI Length	Line1	Line 2	Line 3
60	80	64	42	ICN
61	82	65	42	ICN
62	83	66	43	ICN
63	84	67	44	ICN
64	86	68	45	ICN
65	87	70	45	ICN
66	88	71	46	ICN
67	90	72	47	ICN
68	91	73	47	ICN
69	92	74	48	ICN
70	94	75	49	ICN
71	95	76	49	ICN
72	96	77	50	ICN
73	98	78	51	ICN
74	99	79	51	ICN
75	100	80	52	ICN
76	102	81	53	ICN
77	103	82	54	ICN
78	104	83	54	ICN
79	106	85	55	ICN
80	107	86	56	ICN
81	108	87	56	ICN
82	110	88	57	ICN
83	111	89	58	ICN
84	112	90	58	ICN
85	114	91	59	ICN
86	115	92	60	ICN
87	116	93	61	ICN
88	118	94	61	ICN
89	119	95	62	ICN
90	120	96	63	ICN
91	122	97	63	ICN
92	123	98	64	ICN
93	124	100	65	ICN
94	126	101	65	ICN
95	127	102	66	ICN
96	128	103	67	ICN
97	130	104	67	ICN
98	131	105	68	ICN
99	132	106	69	ICN
100	134	107	70	ICN
101	135	108	70	ICN

102	136	109	71	ICN
103	138	110	72	ICN
104	139	111	72	ICN
105	140	112	73	ICN
106	142	113	74	ICN
107	143	114	74	ICN
108	144	116	75	ICN
109	146	117	76	ICN
110	147	118	77	ICN
111	148	119	77	ICN
112	150	120	78	ICN
113	151	121	79	ICN
114	152	122	79	ICN
115	154	123	80	ICN

6 Table 2 Knee Analysis - Tibia

Width	ROI Length	Line 1	Line 2	Line 3
55	77	13	26	56
56	78	13	26	57
57	79	13	26	58
58	81	13	27	59
59	82	14	27	60
60	84	14	28	61
61	85	14	28	62
62	86	14	29	63
63	88	15	29	64
64	89	15	30	65
65	90	15	30	66
66	92	15	31	67
67	93	16	31	68
68	95	16	32	69
69	96	16	32	70
70	97	16	32	71
71	99	16	33	72
72	100	17	33	73
73	102	17	34	75
74	103	17	34	76
75	104	17	35	77
76	106	18	35	78
77	107	18	36	79
78	109	18	36	80
79	110	18	37	81
80	111	19	37	82
81	113	19	38	83
82	114	19	38	84
83	116	19	39	85
84	117	19	39	86
85	118	20	39	87
86	120	20	40	88
87	121	20	40	89
88	122	20	41	90
89	124	21	41	91
90	125	21	42	92
91	127	21	42	93
92	128	21	43	94
93	129	22	43	95
94	131	22	44	96
95	132	22	44	97
96	134	22	45	98

97	135	23	45	99
98	136	23	45	100
99	138	23	46	101
100	139	23	46	102
101	141	23	47	103
102	142	24	47	104
103	143	24	48	105
104	145	24	48	106
105	146	24	49	107