Semi-Automated CT Based Analysis of Regional Bone-Density in Contra Lateral Total Hip Replacement

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Introduction:

Computer tomography (CT) is becoming the preferred imaging modality in monitoring osteolysis following total hip replacement. When compared to plain radiographs, CT provides more accurate information about the presence, location, and extent of osteolysis.[1-3]

While DEXA proved a reliable tool in measuring bone changes post total hip replacement, CT assisted osteodensitometry offers 3D volumetric measurements, analysis of separate views of the overall bone structure, and circumferential detections in the implant region.[4,5]

Posture and movement patterns acquired after surgery may change the load transfer within the pelvic region resulting in stress pattern changes within the pelvis.[6]

Even though the advantages of using CT to detect osteolysis are clear, the methodology of extracting and quantifying the osteolytic lesions may be time consuming and labor intensive.[7,8] We propose a semi-automatic method for measuring the bone densities starting at the apex and moving 16mm in the superior direction away from the prosthetic cup. This region is further divided into four angular and four positional zones, which reflect the complex geometry of the pelvis. While an initial segmentation of the cup is required, the zone segmentation is automatic, eliminating user variability. Once the 64 regions are constructed, the average and the standard deviation of the bone density can be recorded. Since osteolytic lesions are lower in density compared to healthy bone, this method offers a quick and standardized way of detecting lesions. Moreover, this method can be used in monitoring long term complications in total hip replacement.

Three subjects were randomly selected from the natural progression study sponsored by the NIH and conducted at University of Rochester. The prosthetic and contra lateral hips were scanned in 1mm axial slices using a GE CTi (Milwaukee, WI) scanner with 1mm collimation, a 1.5 pitch, and a 14 to 22cm FOV.

In what follows we present an explanation of our methodology of the developed zones as well as its application to the three selected subjects. A quantitative and qualitative analysis between the bone densities in the prosthetic and contra lateral hip is also investigated.

Methodology:

Steps taken to measure the acetabular bone density:

• An initial segmentation of the cup or the region immediate to the acetabulum is required. [Figure 1 (a) and (b)]

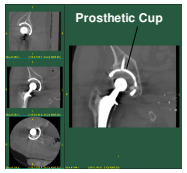


Fig. 1 (a)

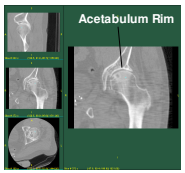


Fig. 1 (b)

• Either segmentation is fed to an algorithm, which fits a sphere around the outer surface of the identified object or region.

• The center of the sphere is computed and used in defining the four distance zones.

- Zone 1 represents the region 1mm away from the cup's surface.
- Zone 2 is defined by the region between 1 and 6mm from the same surface.
- Zone 3 and Zone 4 are defined by the region 6 to 11mm and 11 to 16mm, respectively.

• The distance zones were divided into four angular regions 15º, 30º, 45º, and 60º from the apex of the acetabular cup, defined by the center of the sphere and either of the four distance radii.

• The angular regions were divided into four positional zones: medial, lateral, anterior, and posterior, which are defined by four 45º quadrants.

• The bone-density is computed as the average density in HU measured from the CT scan using all the voxels within each of the 64 zones belonging to the prosthetic and the contra lateral hip. Figure 2 illustrates an example of the bone densities measured at 15º in all the positional and distance zones.

Subject	Distance Zone	Angular Regions (deg)	Mean	Sd	SE(Mean)	t	p	95% CI
1	1	15, 30, 45, 60	47.21	334.25	83.56	0.56	0.58	(-167.55, 261.97)
1	1	15, 30	55.85	263.53	93.17	0.60	0.57	(-183.61, 295.30)
1	2	15, 30, 45, 60	-98.15	277.34	69.33	-1.42	0.18	(-276.34, 80.04)
1	2	15, 30	-160.26	314.09	111.05	-1.44	0.19	(-445.66, 125.13)
1	3	15, 30, 45, 60	-38.79	231.02	57.75	-0.67	0.51	(-187.22, 109.64)
1	3	15, 30	-17.52	287.69	101.71	-0.17	0.87	(-278.92, 243.88)
1	4	15, 30, 45, 60	-47.76	199.27	49.82	-0.96	0.35	(-175.79, 80.27)
1	4	15, 30	-20.03	229.90	81.28	-0.25	0.81	(-228.92, 188.86)
2	1	15, 30, 45, 60	-89.68	258.48	64.62	-1.39	0.19	(-255.75, 76.39)
2	1	15, 30	-25.36	267.57	94.60	-0.27	0.80	(-268.49, 217.76)
2	2	15, 30, 45, 60	-8.88	139.41	34.85	-0.25	0.80	(-98.45, 80.69)
2	2	15, 30	27.74	158.98	56.21	0.49	0.64	(-116.71, 172.20)
2	3	15, 30, 45, 60	-1.37	131.84	32.96	-0.04	0.97	(-86.08, 83.34)
2	3	15, 30	66.28	155.17	54.86	1.21	0.27	(-74.71, 207.27)
2	4	15, 30, 45, 60	-176.56	280.11	70.03	-2.52	0.02	(-356.53, 3.42)
2	4	15, 30	-148.84	331.99	117.38	-1.27	0.25	(-450.50, 152.82)
3	1	15, 30, 45, 60	-208.93	307.51	76.88	-2.72	0.02	(-406.51, -11.36)
3	1	15, 30	-257.93	324.23	114.63	-2.25	0.06	(-552.53, 36.68)
3	2	15, 30, 45, 60	33.49	180.38	45.10	0.74	0.47	(-82.41, 149.39)
3	2	15, 30	127.08	133.62	47.24	2.69	0.03	(5.67, 248.50)
3	3	15, 30, 45, 60	14.66	229.21	57.30	0.26	0.80	(-132.61, 161.93)
3	3	15, 30	136.38	269.18	95.17	1.43	0.19	(-108.21, 380.96)
3	4	15, 30, 45, 60	19.20	184.63	46.16	0.42	0.68	(-99.43, 137.82)
3	4	15, 30	24.04	240.57	85.05	0.28	0.79	(-194.55, 242.63)

Table 1: Mean difference between bone densities in the prosthetic and contra lateral hip (includes all positional zones).

Subject	Angular Region (deg)	Positional Zone	Mean	Sd	SE(Mean)	t	p	95% CI
1	15	M,A,P,L	-47.87	141.35	70.67	-0.68	0.55	(-229.50, 133.76)
2	15	M,A,P,L	38.27	223.17	111.58	0.34	0.75	(-248.50, 325.04)
3	15	M,A,P,L	87.87	93.36	46.68	1.88	0.16	(-32.10, 207.84)

Table 2: Mean difference between bone densities in the prosthetic and contra lateral hip at 15º (includes all the positional zones and all distance zones).

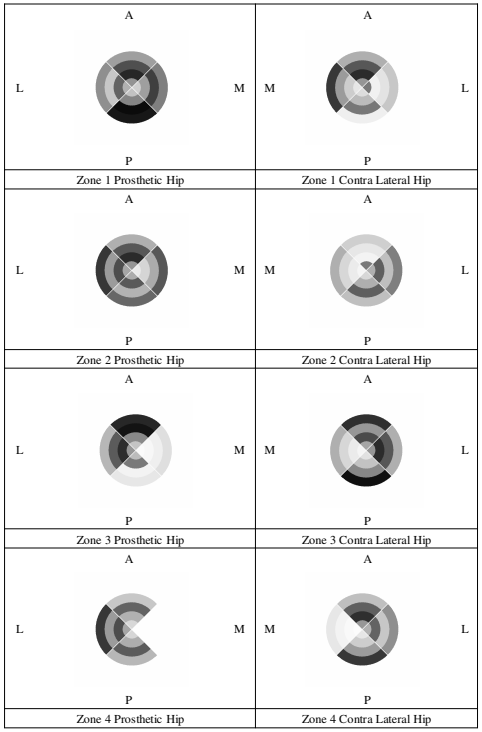


Fig. 2: Average bone density measurements for subject #1 (light regions represent low bone density values and dark regions represent high density values). Min = -70.98HU and Max. = 1399.46HU.

Results:

• Paired t test analysis, (**Table 1)** between the average bone densities measured in the prosthetic and contra lateral hips for each of the four distance zones reveal no statistic difference.

• To show loading trend, comparison of the average bone densities at 15º between prosthetic and contra lateral hips were considered, (**Table 2)**, where no statistical difference between the two hips for any subjects is found.

• Qualitative illustration of the average bone densities measured for subject #1's prosthetic and contra lateral hips are displayed in **Figure 2**. The low bone density values observed in the higher distance zones are attributed to muscle and other tissues found in the vicinity of the acetabulum.

• **Figure 3** illustrates a 3D rendering of the stem, cup and bone densities measured in the medial quadrant where all four angular and distance zones were included.

• Figure 4 (a) and (b) show differences in average bone density between positional zones in Zone 2 when the angular zone was fixed at 30º and 45º. Regardless of the angle, the bone densities between the two hips are very similar. This observation is true for the remaining 2 subjects.

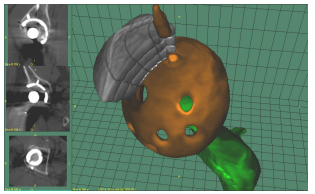
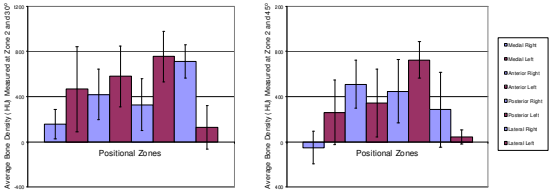


Fig 3: Subject #1, medial bone density quadrant showing Zones 1 through 4 at 60º, 45º, 30º, and 15º.



(a) (b)

Fig. 4: Comparison of prosthetic and contra lateral hip average bone densities at Zone 2 and 30º (a) and Zone 2 and 45º (b) in the medial, anterior, posterior, and lateral zones.

Discussion and Conclusion:

• A semi-automated method, which reflects the complex geometry of the pelvis, was established for measuring the bone density in prosthetic and contra lateral hips.

• The parameters, which define the positional, angular, and distance zones can be modified according to the specific application, keeping in mind constraints such as resolution of the CT scans.

• Similar to Kerner *et al.*[11], we hypothesized that the contra lateral bone represents the pre-operative state of the prosthetic hip in order to appraise the potential of our methodology. Until a larger subject set is considered, the observed similarities between prosthetic and contra lateral hips are questionable.

• Our methodology may be applicable to monitoring physical therapy treatment, observe osteolytic occurrences, and in cross validation and analyses of several types of prosthetic cups.

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