Original article

Evaluation of Hounsfield Unit in adult brain structures by CT

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Abstract
Introduction: The purpose of study was to evaluate the Hounsfield unit (HU) values in adult brain structures by computed tomography (CT). Hounsfield units (HU) describe relative densities of structures by CT. Different pathological process causes the change in attenuation by different tissues resulting in change of HU of the tissues so we should know the normal HU values to track the changes. These HU values are correlated with different clinical condition and different slice thickness.

Methods: A prospective study was done in 72 patients of age above 18 years. All CT scans were performed using 16 row multi-detector CT (Neusoft NewViz16). Two sets of images were reconstructed first one with 5 X 5 mm and second one with 3 X 3 mm slice thickness. For quantitative analysis, HU measurements were obtained by drawing elliptical/ circular region-of-interests (ROI) on various anatomical structures on both 5mm and 3mm slice images. Statistical analysis was done with t test,one way ANOVA and descriptive analysis.

Results: HU values for different anatomical area were: thalamus 34.50±1.92, caudate nucleus 36.64±2.01, internal capsule 31.40±2.16, pons 32.70± 2.39, dentate nucleus 30.70±2.22, cerebellar peduncle 30.90±2.37, hemisphere 39.62±2.38, vermis36.77±2.39, lateral ventricle 9.86±2.60, putamen 36.66±1.65, globus pallidus, 36.68±1.87, juxta 28.28±2.42, periventricular 29.18± 2.78, deep 27.13±2.06, cortex 34.26± 2.25, subcortical 27.36±2.49, corpus callosum 28.71±1.98. There was significant difference in HU values of genu of internal capsule, caudate nucleus, periventricular white matter,dentate nucleus, cerebellar peduncle & hemisphere for the 5mm and 3mm slice thickness.

Conclusion: HU of gray and white matter of brain were 34.54 ± 2.54 and 28.25 ±2.00 respectively.

Keywords: Attenuation, Brain, Computed Tomography, Hounsfield Unit, Slice thickness.

Introduction

Computed tomography (CT) also known as computed axial tomography which is an invaluable radiologic diagnostic imaging modality. CT has so far, the best contrast resolution for any x-ray modality.[1] Its application for various indications is growing rapidly. Single detector scanner was used in early days. Helical scanning technique was subsequently introduced in late 1980s and was followed by the development of multi-detector technology in late 1990s. Today MDCT technology with advanced computer and CT software is being used. Its application for different indication has grown exponentially over the years, rising from 3 million in 1980 to 67 million in 2006, an equivalent of a 600% increase from 1980 to 2006.[1-3] CT uses X-rays to generate cross-sectional, two-dimensional images of the body. Images are acquired by rapid rotation of the X-ray tube 360° around the patient. CT images are electronic images consisting of pixels. Each cell of information in image matrix is pixel (picture element). Each pixel of CT image is assigned a numerical value (CT number), which is the average of all the attenuation values obtained within the corresponding voxels. This number is compared to the attenuation value of water and displayed on a scale of arbitrary units named Hounsfield units (HU). Hounsfield units (HU) describe relative densities of structures by CT. Water, by convention, is 0 HU, dense bone is 1000 HU and air is -1000 HU. Brain has different variety of tissues having wide range of HU.[4]

Different pathological process causes the change in attenuation by different tissues resulting in change of HU of the tissues so we should know the normal HU values to track the changes.[6,7] HU values of different

cranial tissues are quoted in different text book but the method used to measure HU values are not given. To our knowledge no any studies have been done in Nepalese population to compare the HU values with the published one.

Methods

This was a prospective cross-sectional study carried out in the Department of Radiology and Imaging, Tribhuvan University Teaching Hospital, Kathmandu. A total of 72 cases were enrolled in this conducted fromJuly 2014 to December 2014. The study population consisted of those cases who underwent plain head CT scans for various clinical indications and showed normal finding of age >18 years. The exclusion criteria included Pediatric, Unco-operative, Non Nepalese patient and Patient having pathological findings.The study protocol was approved by the ethical committee and written informed consent were taken from each patient. All CT scans were performed using 16 row multi-detector CT (Neusoft NewViz16). Scanning was performed in helical mode from base of skull to vault with a 10- to 20-degree angulation of the gantry to the cantho-meatal line with acquisition parameters identical to the parameters used in our standard clinical protocol (16x1.5 mm collimation, 490.1 effective mAs, 120kVp, pitch=0.6713, 1Sec. rotation time, 512 X 512 Matrix).[16,17] Two sets of images were reconstructed one with 5x5mm and second with 3x3mm.[9,14,15] HU values were measured and entered in the predesigned proforma.Images were viewed in different window settings (WW40-120 and WL 30-40) for optimum visualization of interested anatomy.[18] For quantitative analysis, HU value measurements were obtained by drawing a elliptical/ circular region-of-interests (ROI) on each anatomy on both 5mm and 3mm slice images. The area of measurement (ROI) were approximately 20 mm^2 for thalamus, pons, dentate nucleus, cerebellar peduncle, cerebellar hemisphere, vermis, deep white matter; 10 mm^2 for lateral ventricles, caudate nucleus , genu and splenium of corpus callosum, 5mm^2 for anterior limb, genu, posterior limb of internal capsule with juxta and periventricular white matter and 1mm^2 for cortex and subcortical area. Data were measured on left hemispheric structures of brain. Statistical analysis was carried out with the help of SPSS version 20 and Microsoft Excel. Numerical data were presented as mean and SD and categorical variables are presented as percentage. The level of significance was kept at $p<0.05$. Means were compared using t-test for two variables and one way ANOVA for more than 2 variables.19

Results

The population consisted of 72 patients undergoing CT scan of Head. The age group ranged from 18 to 96 years. The mean age of the population was 40.58(18.17) years. More than 50% of the sample was in the age group of 25 to 45 years. The prevalence of diabetes, hypertension, smoking and alcoholism in the group was low. Sex distribution comprises of 38 (53%) Female and 34 (47%) Male.(Figure1)

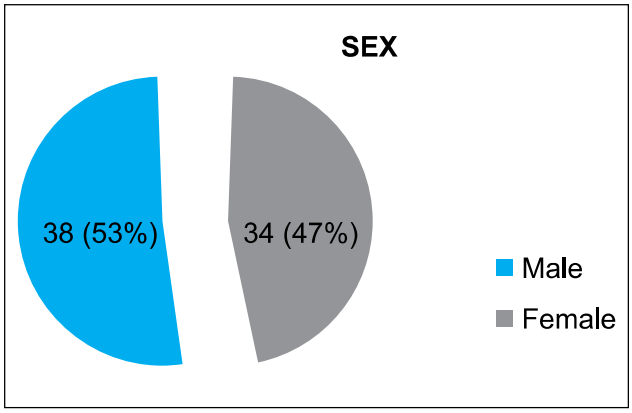

Figure 1. Sex distribution of Subjects

HU value of different area in brain

The HU value in internal capsule was lowest in posterior limb and highest in anterior limb with intermediate value in the genu region, HU value differed significantly between 5 mm and 3 mm cuts at genu of internal capsule however no significant difference was noted in anterior and posterior limbs of internal capsule. In Basal ganglia HU values in thalamus are slightly lower as compared to globus pallidus and caudated nucleus of basal ganglia region in both cuts. There is significant difference in HU values of caudate nucleus for 5mm and 3mm cuts. In Posterior fossa HU values of cerebellar hemisphere and vermis were found to be significantly higher than pons, dentate nucleus and cerebellar peduncle on both slice thicknesses. Significant difference in HU values of dentate nucleus, cerebellar peduncle and hemisphere were noted for both slice thickness. In Gray matter and white matter HU values for cortex were found approximately same on both the slice thickness without any significant difference. HU values calculated for various part of white matter and was also found similar except periventricular white matter having significant difference on both the slice thickness. In Lateral ventricle and corpus cal losumthere was no significant difference in HU values of lateral ventricle, genu and splenium of corpus callosum for both slice thickness (Table 1).

Table 1. HU values in different area of Brain on different slice thickness image. (n=72)

Area	Mean 5mm	SD.	Mean 3mm	SD	P-Value
Internal Capsule AL	31.40	2.16	31.56	1.93	0.39
Internal Capsule Genu	30.61	2.06	30.17	1.98	0.05
Internal Capsule PL	29.71	2.53	29.54	2.16	0.37
Putamen	36.66	1.65	36.74	1.87	0.25
Globus Pallidus	36.68	1.87	36.65	1.99	0.46
Thalamus	34.50	1.92	34.50	2.07	0.98
Caudate Nucleus	36.64	2.01	36.21	2.30	0.04
Pons	32.70	2.39	32.77	2.36	0.65
Dentate Nucleus	30.70	2.22	30.51	2.30	0.00
Cerebellar Peduncle	30.90	2.37	31.03	2.37	0.03
Hemisphere	39.62	2.38	39.82	2.32	0.02
Vermis	36.77	2.39	37.24	2.44	0.27
Cortex	34.26	2.25	33.66	4.39	0.64
Subcortical	27.36	2.49	27.34	2.39	0.85
Juxta	28.28	2.42	27.62	2.46	0.17
Periventricular	29.18	2.78	28.75	2.65	0.00
Deep	27.13	2.06	26.84	2.01	0.10
Lateral Ventricle	9.86	2.60	9.55	2.14	0.92
Corpus callosum Genu	28.71	1.98	28.93	1.99	0.11
Corpus callosum splenium	28.33	2.04	28.04	1.94	0.06

Male and female HU values comparis on

HU values were compared for different anatomical area for male and female group of participant. Significant differences in HU were found at posterior limb of internal capsule and periventricular white matter area among both groups. Rest of the anatomical area didn't reveal any significant difference (Table 2).

Table 2. Distribution of HU values of different anatomical areas according to gender. (n=72)

Area (5mm)	Male	Female	P-value
Thalamus	34.79 (1.98)	34.23 (1.84)	0.22
Caudate Nucleus	36.70 (1.64)	36.59 (2.31)	0.82
Internal Capsule AL	31.77 (2.32)	31.06 (1.98)	0.17
Internal Capsule Genu	30.73 (2.10)	30.50 (2.06)	0.64
Internal Capsule PL	30.32 (2.87)	29.16 (2.07)	0.05
Pons	33.25 (2.48)	32.21 (2.22)	0.06
Dentate Nucleus	30.93 (2.48)	30.50 (1.97)	0.42
Cerebellar Peduncle	31.17 (2.84)	30.67 (1.86)	0.37
Hemisphere	39.45 (2.82)	39.78 (1.94)	0.55
Vermis	36.82 (2.56)	36.73 (2.26)	0.87
Lateral Ventricle	9.57 (2.88)	10.11 (2.32)	0.39
Putamen	36.46 (1.62)	36.84 (1.67)	0.34
Globus Pallidus	36.71 (1.86)	36.65 (1.90)	0.89
Juxta	28.51 (2.90)	28.07 (1.92)	0.45
Periventricular	29.89 (2.87)	28.55 (2.58)	0.04
Deep	27.21 (1.99)	27.06 (2.14)	0.76
Cortex	34.54 (2.54)	34.01 (1.95)	0.32
Subcortical	27.41 (2.97)	27.32 (2.01)	0.88
Corpus callosum Genu	28.90 (2.40)	28.54 (1.53)	0.45
Corpus callosum splenium	28.36 (2.40)	28.31 (1.69)	0.91

Table3. HU values for diabetic patient of different anatomical area. (n=3)

Areas	Mean	(SD)	p-value
Thalamus	34.97	1.00	0.66
Caudate Nucleus	37.26	1.13	0.59
Internal Capsule AL	30.93	0.61	0.70
Internal Capsule Genu	30.44	0.18	0.89
Internal Capsule PL	30.51	1.02	0.58
Pons	33.17	0.17	0.73
Dentate Nucleus	31.85	0.59	0.36
Cerebellar Peduncle	32.54	1.79	0.22
Hemisphere	38.98	0.50	0.63
Vermis	36.47	0.38	0.83
Lateral Ventricle	8.78	0.85	0.47
Putamen	36.36	1.05	0.75
Globus Pallidus	35.92	1.32	0.48
Juxta	30.55	1.02	0.10
Periventricular	30.39	0.53	0.45
Deep	27.30	1.20	0.88
Cortex	34.51	1.89	0.85
Subcortical	27.46	0.29	0.95
Corpus callosum Genu	28.75	0.66	0.97
Corpus callosum splenium	29.07	0.32	0.52

Hypertension

The HU values of hypertensive group representing the 11(15.3%) of studied subjects showed significant difference at caudate nucleus and splenium of corpus callosum as compared to rest of the subjects (Table 4).

Table4. HU values for hypertensive patient of different anatomical area.(n=11)

Areas	Mean	(SD)	p-value
Thalamus	35.19	0.98	0.19
Caudate Nucleus	37.82	1.24	0.03
Internal Capsule AL	32.25	1.88	0.16
Internal Capsule Genu	30.91	1.10	0.60
Internal Capsule PL	30.11	1.18	0.57
Pons	32.84	1.75	0.83
Dentate Nucleus	30.54	1.71	0.80
Cerebellar Peduncle	32.01	2.12	0.09
Hemisphere	39.30	2.83	0.62
Vermis	37.00	1.72	0.74
Lateral Ventricle	9.87	3.66	0.98
Putamen	37.35	1.49	0.13
Globus Pallidus	36.87	1.66	0.71
Juxta	28.19	2.03	0.89
Periventricular	30.49	2.17	0.09
Deep	26.80	1.90	0.57
Cortex	33.37	2.27	0.15
Subcortical	27.69	2.40	0.64
Corpus callosum Genu	28.93	1.20	0.69
Corpus callosum splenium	29.49	1.62	0.04

Smoking

The HU values of smoking representing the 12(16.7%) of studied subjects didn't show any significant difference as compared to rest of the subjects (Table 5).

Table 5. HU values for smoking patient of different anatomical area.(n=12)

Areas	Mean	(SD)	p-value
Thalamus	35.19	1.94	.170
Caudate Nucleus	37.20	2.20	.298
Internal Capsule AL	32.72	2.53	.019
Internal Capsule Genu	31.55	2.79	.082
Internal Capsule PL	31.25	3.84	.019
Pons	33.35	2.00	.306
Dentate Nucleus	31.67	2.79	.098
Cerebellar Peduncle	31.52	2.61	.328
Hemisphere	39.33	3.30	.644
Vermis	37.05	2.75	.656
Lateral Ventricle	8.81	2.81	.129
Putamen	37.02	1.94	.415
Globus Pallidus	37.42	2.46	.134
Juxta	27.99	3.74	.650
Periventricular	29.62	2.98	.552
Deep	28.03	2.28	.097
Cortex	33.68	2.74	.336
Subcortical	27.97	2.93	.356
Corpus callosum Genu	29.74	2.91	.047
Corpus callosum splenium	29.26	2.20	.084

The mean HU Values of gray matter was 34.26 (2.25) and white matter was 27.99 (1.83).There was no significant difference in HU values of gray and white matter between male and female.The mean HU values were higher in gray matter than in white matter (Table 6).

Table 6. Summary of HU values according to gender

Areas	Male	Female	p-value
Grey matter	34.54 (2.54)	34.01 (1.95)	0.32
White matter	28.25(2.00)	27.75(1.66)	0.25
Difference	6.29	6.26	

Discussion

The population consisted of 72 patients undergoing CT scan of head. The age ranged from 18 to 96 years. The mean age of the population was 40.58 (18.17) years. Female were slightly predominant in the sample (53%). Mean HU value of different cranial structures: thalamus, caudate nucleus, internal capsule (anterior limb, genu and posterior limb), pons, dentate nucleus, cerebellar peduncle, hemisphere, Vermis, lateral ventricle, Putamen, Globus pallidus, white matter (Deep, Juxta and Periventricular), cortex, subcortical area and corpus callosum (genu and splenium) were measured in normal adult head CT images for 5x5mm slice and 3 x 3 mm axial slices with our MDCT scanner. Theoretically due to effect of volume averaging the HU values in 5 mm and 3 mm slices might differ.[2, 8, 14, 20] However our study showed significant difference of the HU values only in some areas namely genu of internal capsule 30.61±2.06, 30.17± 1.98 ($p<0.05$), caudate nucleus 36.64±2.01, 36.21±2.30 ($p<0.04$), periventricular white matter 29.18±2.78, 28.75±2.65($p<0.001$), dentate nucleus 30.70±2.22, 30.51±2.30 ($p<0.001$), cerebellar peduncle 30.90±2.37, 31.03±2.37 ($p<0.03$) cerebellar hemisphere 39.62±2.38, 39.82±2.32 ($p<0.02$) for the 5mm and 3mm slice thickness.

HU values of various brain regions were compared between diabetic and smokers and rest of the groups. No significant difference in HU values between these groups was found. Hypertensive patient representing 15.3% of studied subjects showed significant difference in HU values at caudate nucleus and splenium of corpus callosum as compared to rest of the population. Further investigation in large sample population is needed to confirm this finding. Finally HU values for gray matter (cortex) and white matter (average values of subcortical, deep, juxta and periventricular) were calculated for male and female group. HU values for gray matter in male and female were 34.54 ± 2.54 & 34.01 ±1.95 ($p=0.32$) and

for white matter it was found to be 28.25 ±2.00& 27.75 ±1.66 (p=0.25) respectively, it showed no significant statistical difference in HU values for male and female group. Difference between HU values of gray and white matter was 6.29 HU and 6.26 HU between male and female in our study. The cause of the lower attenuation in white matter is its myelin content. Myelin accounts for the whitish appearance, the high lipid content and the relatively low water content of white matter when compared with gray matter (72% versus 82%).[10, 12, 21] Weinstein MA, Duchesneau PM , Maci Ntyre WJ.(1977) performed a study to determine the HU values in cerebral white and gray matter and effect of intravenous contrast media on HU values of these areas. Without contrast material HU in the white matter in the parietal lobe measured from 25 to 34 units (mean 29) and the gray matter measured from 30 to 40 units (mean 35). After injection of contrast material, the white matter measured from 25 to 36 units (mean 29) and the gray matter measured from 32 to 43 units (mean 37).[11] This study was done with very earlier model of CT scanner (the Ohio Nuclear Delta 25 Head Scanner).[11,12] The difference seen between our study and study of Weinstein et al is probably due to the different parameters used on the machine. Weinstein et al used 130kV, 30 mA with 3 mm of aluminum filtration. The matrix size used was 256 X 256 with each matrix element of 0.98 mm square.Scan time were 2 minutes 10 seconds and 3 minutes and 5 seconds. Detectors used were Calcium fluoride. The machine they used was second generation CT scanner (translate-rotate configuration). We used 16x1.5 mm collimation, 490.1 effective mAs, 120kVp, pitch=0.6713, 1Sec.rotation time, 512 X 512 Matrix. Detector of our machine was Gadolinium oxysulfide.Lesley A. Cala et al. (1981) performed a similar type of study on 43 female and 50 male healthy volunteers of 15-40 years age. He found that HU values of gray matter in male and female were 33.2 ± 2.6, 33.0 ±3.3 respectively, while for white matter it was 29.8 ±3.3, 30.1 ±3.5. The difference of HU values in cerebral gray matter and white matter for male and female were 3.48 and 2.86 respectively. The narrow difference in gray matter and white matter HU can be explained by slice thickness they used for scanning. They used 9 mm thick sections and scanning parameter with 120kVp, only 33 mA and using matrix 160 X160 matrix[13]. Patient population was slightly different between our studies (we used 18-96 yrs), which might partially contributed for this difference.

Conclusion

Normal HU values for various anatomical regions were established. The mean HU value for gray matter was 34.26(2.25) and white matter was 27.99 (1.83). HU values calculated fordiabetic and smokers didn't show significant statistical difference with rest of population. Hypertensive group showed significant difference at caudate nucleus and splenium of corpus callosum as compared to rest of population.

Conflict of interest: None declared

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