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Review Article



# An Analogy between Gray Values of Cone Beam Computed Tomography and Hounsfield Units of CT: A Systematic Review and Meta-Analysis

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## Abstract

**Background:** This study was conducted to determine and compare the efficacy of Hounsfield Units (HU) of Computed Tomography (CT) and Gray Values (GV) of Cone Beam Computed Tomography (CBCT) in assessing bone Mineral density.

**Methods:** Literature search was carried out using electronic databases including PubMed, Google scholar, Scopus. *In vivo*, *in vitro* and animal studies that analyzed the comparison between the GV of CBCT and HU of CT were included. This review adheres to the Prisma guidelines, and QUADAS-2 tool for risk of bias assessment was performed.

**Results:** A Total of 4760 studies were roped in for this systematic review, of which 22 articles were included and 8 articles were selected for the meta-analysis. The odds ratio of 8 included articles showed a strong positive correlation between CT and CBCT and the overall classification of 89.86% was obtained. 19 studies had low risk of bias and 4 studies had high risk. Some of the included studies indicated quite low and limited reliability, advocating the need for clinical studies with diagnostic capacity to support the use.

**Conclusion:** The existing evidence suggests that GVs of CBCT and HUs of CT had a strong positive correlation and the standard formula for the conversion between the two parameters (Gray values and Hounsfield units) need to be derived in future studies with clinical correlation.

**Keywords:** Animals, Bone density, Cone-beam computed tomography, Laboratory, Reproducibility of results, Search engine, Spiral cone-beam computed tomography, Tomography, X-Ray computed

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## Introduction

Bone is a connective tissue which alters constantly in living beings (1). Bone constitutes 40% inorganic components, 35% organic components and 25% water (2). Bone remodeling occurs through continuous process of bone resorption and formation, where the net quantity of bone is retained (1). Bone quantity is associated with its mechanical strength, since patients cannot be put through mechanical testing, many non-invasive methodologies have been introduced. Computed Tomography (CT) has been widely used to assess bone density and provides measurement in the form of Hounsfield Units (HU) (3). With the advent of Cone Beam Computed Tomography (CBCT), which provides lesser radiation dose and exposure time along with higher image resolution than conventional CT for evaluating morphologic information. In addition, CBCT has been widely used to determine the Bone density estimation (1). The standard unit for measuring Bone Mineral Density (BMD) in CT is HU. The CT image is displayed as matrix of individual blocks called voxels and each square is called pixel. Each pixel is assigned a CT number which determines the x-ray beam attenuation representing tissue density in the form of arbitrary scale called HU, whereas the ability of CBCT imaging to display differences in photon attenuation is related to the ability of the detector to reveal subtle contrast differences. This parameter is called the bit depth of the system and determines the number of shades of gray available to display the attenuation in the form of Grayscale Values (GV) (4). The main objective of this systematic review is to convert HU to GV and *vice versa* in measuring bone mineral density and assessing its accuracy in doing so.

## Materials and Methods

This systematic review is focused on analyzing the relationship between gray values of CBCT and HU of CT. It follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The PICO guidelines were formatted with: Population such as animal studies, *in vivo* and *in vitro* studies. Intervention used are gray values of CBCT, comparison was done with HU of CT, and the expected outcomes were reliability and analogy between the two parameters.

Inclusion criteria:

- Animal, *in vitro*, *in vivo* studies were taken for the review.
- Studies involving both CT and CBCT imaging modalities were included.
- Only full-text articles in English were included for the study.
- Studies in which correlation coefficient and regression analysis performed were taken for the systematic review.

Exclusion criteria:

- Reviews, personal opinions, studies without reference standards, letters, and conference papers were excluded.
- Articles including other imaging modalities like Dual energy x-ray absorptiometry, Ultrasonography (USG), Magnetic Resonance Imaging (MRI), and Micro CT were excluded.
- Only abstracts, articles with either CT OR CBCT, and other language articles were excluded.
- Studies which lack correlation coefficient, regression analysis were excluded.

The review process involves Study selection, Data extraction, Qualitative assessment, (QUADAS 2), Meta analysis.

### *Literature search*

A literature search was performed using specific strategies in manual and electronic database search using PubMed, ScienceDirect, Google Scholar, and Scopus to identify studies. The Mesh terms used were Multislice Computed Tomography (MSCT) OR Multidetector Computed Tomography (MDCT) AND Cone Beam Computed Tomography OR CBCT AND Correlation AND *in vitro* studies AND *in vivo* studies AND animal studies.

### *Study selection*

All the articles were individually reviewed for title and abstract to remove the irrelevant and statistically insignificant ones. Later, full-text articles were retrieved based on the inclusion criteria.

### *Data extraction*

All the retrieved articles were reviewed individually and data were extracted from each article such as first author name, year, study design, samples used,

imaging modality, conversion equations based on the inclusion and exclusion criteria.

### *Quality assessment*

The Quality of studies included in the review were subjected to a risk of bias assessment with the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) checklist. The QUADAS-2 tool comprises 4 domains: patient selection, index test, reference standard, and flow and timing, under which signaling questions were included to determine the risk of bias. The results for each item were categorized as yes (Y), unclear (U), or no (N). The summary risk of bias for each study was categorized as low (A), unclear (B), or high (C).

## Results

### *Selection of literature*

4760 articles were identified through database and manual search. After removing statistically irrelevant, non- correlated studies and articles involving other imaging modalities 51 articles were screened by reading the abstracts. Ultimately 22 full-text articles were included based on the inclusion and exclusion criteria among which 8 were included for meta-analysis as mentioned in PRISMA Flowchart figure 1.

### *Study characteristics*

Out of 22 studies included, only 4 were *in vivo* studies, in which 3 studies were carried out in humans and 1 in rabbits. The remaining 18 were *in vitro* studies. All 22 studies were done in CT and CBCT. 7 Studies included conversion equation. All the studies evaluated the correlation between CT and CBCT as shown in table 1.

### *Qualitative assessment*

The studies were subjected for risk of bias assessment with the help of QUADAS-2 tool. It comprises 4 domains such as patient selection, index test, reference standard, and flow and timing, with 9 signaling questions which helps to judge the study in terms of high, low and unclear risk of bias. For risk of bias assessment, 15 studies (Bujtar *et al* (5), Bastami *et al* (6), Cassetta *et al* (7), Varshowsaz *et al* (8), Parsa

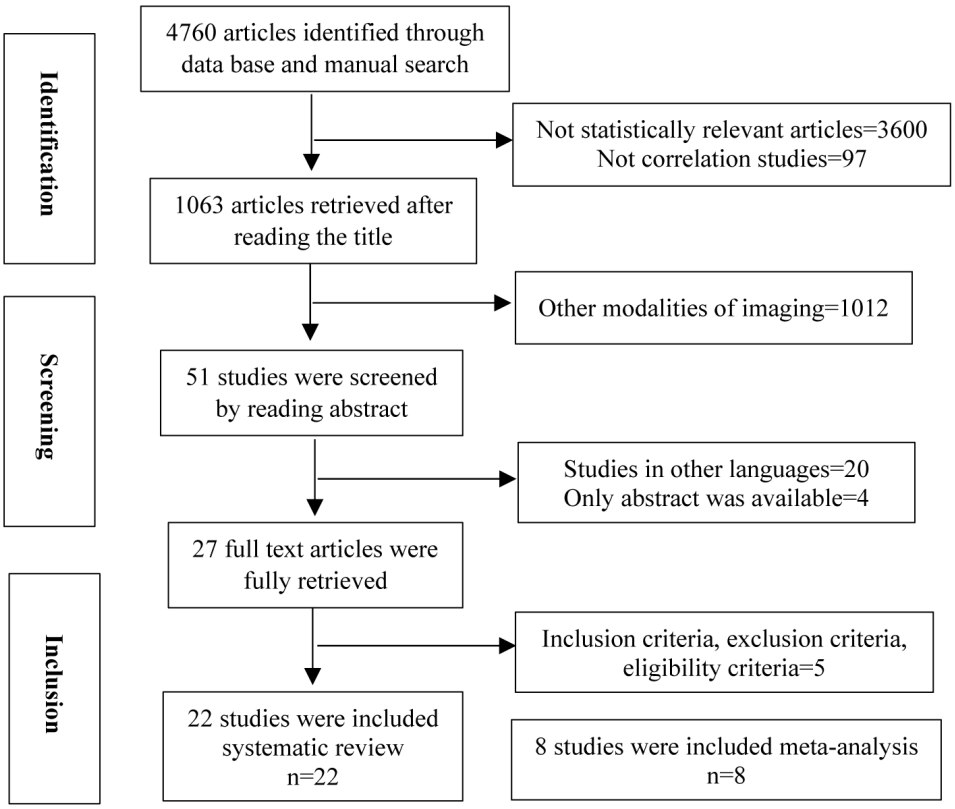


**Figure 1.** PRISMA Flowchart.

**Table 1.** Studies included & its characteristics

| Author & Year | Study design | Sample type | Imaging modality | Conversion equation |
|---|---|---|---|---|
| Magil *et al* 2017 | *In-vitro* study | Phantom | CT, CBCT | HVL = $\frac{\ln (2)}{\text{Aluminium}}$<br>HU material = $\frac{(\text{material} - \text{water})}{\text{water}} \times 1000$ |
| Nomura *et al* 2010 | *In-vitro* study | Phantom | MSCT, CBCT | $y=0.03669x^2+3.602x-350.3$ (x: voxel value, y: BMD mg/cm3 HA) |
| Bastami *et al* 2017 | *In-vivo* study | 5 rabbits-calvaria | CT, CBCT | 100 unit increase in GV=112.2 unit increase on HU |
| Varshowsaz *et al* 2016 | *In-vitro* study | Phantom | CT, CBCT | NA |
| Parsa *et al* 2013 | *In-vitro* study | Human jaws-20 | MSCT, CBCT | NA |
| Chindasombatjaroen *et al* 2011 | *In-vitro* study | Phantom | MDCT, CBCT | y = 2.0175x + 584.62;<br>x = pixel value in CBCT; y = CT value in MDCT |
| Naitoh *et al* 2009 | *In-vivo* study | 16 patients | CT, CBCT | NA |
| cassetta *et al* 2013 | *In-vitro* study | 20 dry mandibles | CT, CBCT | 0.7 X Values of CBCT = Values of CT |
| Patrick *et al* 2017 | *In-vitro* study | 20 dry mandibles | MSCT, CBCT | NA |
| bujtar *et al* 2014 | *In-vitro* study | human cadaver | CBCT, MSCT | CBCT GV = A X MSCT HU +B<br>A,B= correlation coefficients |
| Shokri *et al* 2018 | *In-vitro* study | Phantom | MDCT, CBCT | NA |
| Razi *et al* 2014 | *In-vitro* study | Sheep Head | CT, CBCT | HU=14.621+1.088×gray scale<br>HU= -24.052+1.146×gray scale<br>HU= -61.098+1.178×gray scale |
| Silva *et al* 2012 | *In-vitro* study | 20 mandibles | CBCT, MSCT | NA |
| sedeek *et al* 2019 | *In-vitro* study | Phantom | CBCT, MSCT | y=0.682(x)-161<br>y=BMD,x=CBCT GV |
| Khavid*et al* 2021 | *In-vitro* study | Phantom 52 specimens, cow rib bone | MDCT, CBCT | NA |
| Razi *et al* 2019 | *In-vivo* study | 21 patients | CT, CBCT | CBCT=126.92+0.93*CT |
| Arisan *et al* 2012 | *In-vivo* study | 18 patients | CBCT, MSCT | NA |
| Gaur *et al* 2022 | *In-vitro* study | 20 goat heads | CT, CBCT | CT mean= 82.3+0.4927CBCT mean |
| Azeredo *et al* 2013 | *In-vitro* study | Phantom | CT, CBCT | NA |
| Dings *et al* 2019 | *In-vitro* study | 5 human dry skulls | MDCT, CBCT | NA |
| Lee *et al* 2021 | *In-vitro* study | A dry mandible | CBCT, MSCT | NA |
| sedeek *et al* 2019 | *In-vitro* study | Phantom | CBCT, MSCT | y=0.682(x)-161<br>y=BMD,x=CBCT GV |

*et al* (9), Chindasombatjaroen *et al* (10), Mah *et al* (11), Razi *et al* (12), Patrick *et al* (13), Shokri *et al* (14), Nomura *et al* (15), Sedeek *et al* (16), Gaur *et al* (17), Dings *et al* (18), Razi *et al* (19) had low risk of bias, 4 studies [Silva *et al* (20), Arisan *et al* (21), Khavid *et al* (22), and Lee *et al* (23)] had high risk of bias, 3 studies [Naitoh *et al* (24), Azeredo *et al* (250, Magill *et al* (26)] had unclear risk of bias.

### *Meta-analysis*

Among 22 studies, 8 studies were included for meta-analysis due to heterogeneity of data in the remaining studies using RevMann software version 5.3. The forest plot analysis was produced between gray value of cone beam computed tomography and HU of computed tomograms (Table 2). Based on the analysis performed using random effects model with inverse variance method, summarized odds ratio was found out. The summarized odds ratio (OR) was 1.08 with a 95% confidence interval of 1.02-1.14 and this was found to be statistically significant as the test for overall effect shows a significance at $p<0.05$. Heterogeneity of the included eight studies was 0 (I2=0) which confirms the absence of notable variability between the studies. The effect sizes determined across cohorts were uniform in both size and direction as shown in figure 2.

The funnel plot indicates no potential publication bias. The Eggers' test does not support the presence of funnel plot asymmetry (intercept: -0.39, 95%CI: -1.22-0.43, t:-0.938, p-value: 0.384) as shown in figure 3.

The odds ratio indicated a strong positive correlation between CT and CBCT with an overall classification of 89.87%.

**Table 2.** Forest plot analysis showing Odds ratio

| | OR | UPPER 95%CI | LOWER 95%CI |
|---|---|---|---|
| Chindasombatjaroen *et al*, 2011 | 1.19 | 1.32 | 0.94 |
| Cassetta *et al*, 2013 | 1.08 | 1.23 | 0.96 |
| Parsa *et al*, 2013 | 1.04 | 1.25 | 0.83 |
| Razi *et al*, 2014 | 1.16 | 1.31 | 0.85 |
| Bujtar *et al*, 2014 | 1.02 | 1.19 | 0.96 |
| Bastami *et al*, 2017 | 1.16 | 1.34 | 0.8 |
| Razi *et al*, 2019 | 1.08 | 1.28 | 0.91 |
| Gaur *et al*, 2022 | 1.12 | 1.3 | 0.94 |

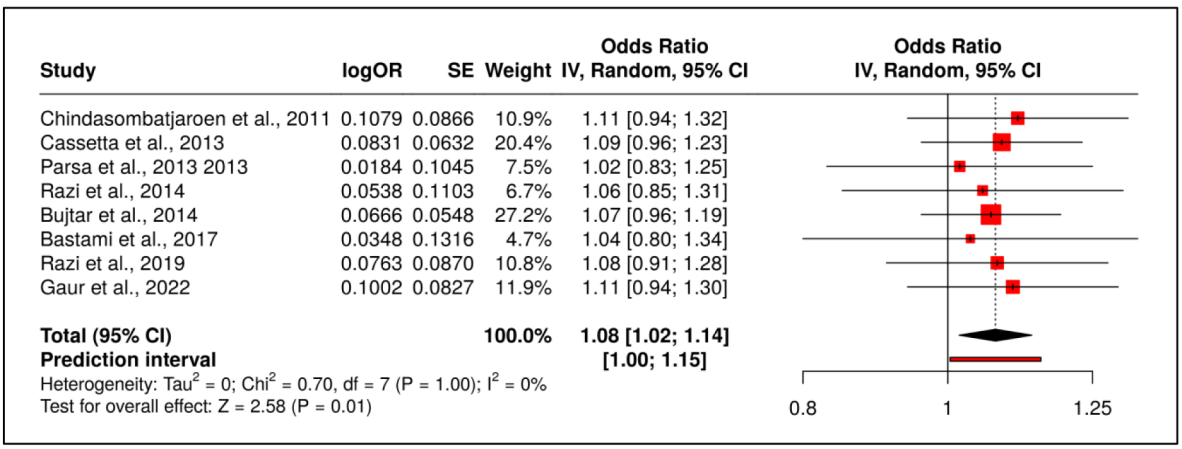


**Figure 2.** Forrest plot diagram.

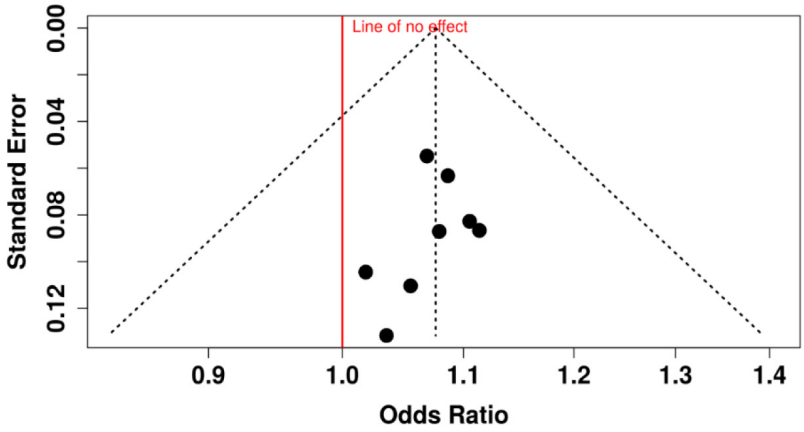


**Figure 3.** Funnel plot diagram.

## Discussion

Assessment of bone density serve multiple purposes in dental procedures, including the placement of dental implants and orthodontic micro implants. Additionally, this information proves beneficial in diagnosing conditions like tooth ankylosis, periodontal and endodontic lesions, and in predicting growth patterns and potential. While MSCT is indeed the appropriate instrument for gauging bone density, its widespread adoption in dentistry is hindered by its elevated cost and the substantial radiation dosage it entails (23).

In contrast, CBCT is favored in the dental field due to its lower radiation exposure, brief measurement time, cost-effectiveness, and the relatively high resolution of the images it produces (23). Making a direct comparison of gray density values derived from different CBCTs poses challenges. Unlike MSCT, the attenuation coefficient in CBCT lacks standardization. The gray density values among CBCT scanners are affected by technical variables, including the X-ray beam's hardening effect, radiation scatter, and the impacts associated with discontinuity in projection data (27).

According to Naitoh *et al* (24) in 2009 who has done a study with 16 patients, found a high level of correlation between CBCT & MSCT(r=0.965). Voxel values from Mandible cancellous bone was used for estimating BMD. Razi *et al* (12), performed a study with 21 patients (16 Males & 5 Females) totally in 25 soft and hard tissues, found strong correlation between CT & CBCT (R2 =0.85,0.74), respectively. According to Shokri *et al* (14), the size of FOV significantly changed mean gray values of bone substitutes, whereas CBCT with small FOV had significant correlation with MDCT results. Razi *et al* (19) performed a study comparing the GV of CBCT with HU of CT with 3 different types of CBCT scanners and 1 CT scanner and derived 3 linear regression equations which revealed a strong correlation between GV and HU.

A systematic review conducted by Eugren *et al* (28) in 2022 which included only 3 articles to conclude that GV of CBCT cannot be correlated to the HU of CT which was attributed to lack of clinical studies with diagnostic capacity. On the contrary, the current study, with 8 articles provided a strong positive correlation, in which Bujtar *et al* (5) and Parsa *et al* (9) showed the highest level of linear correlation.

### *Limitations and future perspectives*

Lack of homogeneity of data in the included studies is one of the major drawbacks of this systematic review. More clinical studies need to be incorporated to derive a standard conversion formula between HU and GV irrespective of the type of scanner used.

## Conclusion

This systematic review illustrated that converting GV to HU involves both qualitative and quantitative assessments. Thus, Gray values obtained can be used for estimation of bone mineral density with the proper conversion formula. However, standardization of equipment calibration, correlation methods, and conversion equations is necessary, regardless of the software utilized.

## Acknowledgement

The study has been approved by the Ethical committee of Meenakshi Ammal Dental College & Hospital, MAHER University, Chennai.

## Conflict of Interest

Authors declare no conflict of interest.

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