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INFLUÊNCIA DA NORMALIZAÇÃO DOS NÍVEIS DE CINZA EM TOMOGRAFIAS COMPUTADORIZADAS CONE BEAM E MULTISLICE NA AVALIAÇÃO DA QUALIDADE ÓSSEA

DISSERTAÇÃO APRESENTADA COMO PARTE DOS REQUISITOS OBRIGATÓRIOS PARA A OBTENÇÃO DO TÍTULO DE MESTRE NA ÁREA DE PRÓTESE DENTÁRIA

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Ao inesquecível Dibi,

exemplo de superação, amizade, companheirismo, carinho e bondade.

Amor eterno. Saudade.

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Quando tudo nos parece dar errado
Acontecem coisas boas
Que não teriam acontecido
Se tudo tivesse dado certo

Renato Russo

RESUMO

INFLUÊNCIA DA NORMALIZAÇÃO DOS NÍVEIS DE CINZA EM TOMOGRAFIAS COMPUTADORIZADAS CONE BEAM E MULTISLICE NA AVALIAÇÃO DA QUALIDADE ÓSSEA

Este trabalho objetiva investigar a influência da normalização dos níveis de cinza em tomografias cone beam (CBCT) e multislice (MSCT). Imagens DICOM (Digital Imaging and Communications in Medicine) de 37 sítios ósseos (18 pacientes) foram analisadas. As tomografias CBCT foram realizadas em 5 diferentes aparelhos e as tomografias MSCT foram obtidas em um único tomógrafo. As medições dos níveis de cinza foram feitas em duas regiões de interesse; ROI_1 - osso alveolar (cortical e medular) e ROI_2 - osso medular separadamente, de 3 formas distintas: sem normalização (RAW), normalização de toda a imagem (ALL) e normalização da região de interesse apenas (ROI). Análise descritiva com coeficiente de variação (CV) e teste ANOVA seguido de Tukey foi realizado. Para as MSCT, a média dos níveis de cinza da ROI_1 aumentaram levemente de 121,9+-17,13 (RAW) para 125,0+-15,74 (ALL) ($p>0,05$) e reduziram para 104,8+-15,20 (ROI) ($p<0,0001$). O CV variou de 14,05%, para 12,59% and 14,50%, respectivamente. Na ROI_2 a média aumentou de 95,11+-13,96 (RAW) para 99,40+-13,62 (ALL) e 102,5+-17,86 (ROI) ($p=0,0678$). O CV foi de 14,67% para 13,71% e 17,43%, respectivamente. No grupo CBCT, a média de ROI_1 aumentou significativamente de 91,73+-32,17 (RAW) para 135,2+-36,06 (ALL) e 118,7+-18,65 (ROI) ($p<0,0001$), com o CV diminuindo de 35,06% para 26,68% e 15,71%, respectivamente. A média da ROI_2 foi 81,23+-34,36, 115,3+-28,53 and 109,4+-17,47, respectivamente ($p=0,0002$), com um CV reduzindo de 42,30% (RAW) para 24,74% (ALL) e 15,97% (ROI). Desta forma, foi demonstrada a redução das discrepâncias entre diferentes aparelhos e da variabilidade entre exames com a utilização da normalização de intensidade de exames CBCT e MSCT na avaliação da qualidade óssea para implantes dentais.

Palavras-chave: implantes dentais, densidade óssea, CBCT, Unidades Hounsfield, MSCT, níveis de cinza

ABSTRACT

INFLUENCE OF GREY LEVEL NORMALIZATION IN CONE BEAM AND MULTISLICE CT FOR BONE QUALITY ASSESSMENT

This paper aims to investigate the influence of normalization in cone beam computed tomography (CBCT) and multislice computed tomography (MSCT) grey level to assess bone quality of recipient sites for dental implants. DICOM (Digital Imaging and Communications in Medicine) images from 37 bone sites (18 patients) were analyzed. CBCT was performed with 5 different CBCT devices and MSCT in a single multislice CT scanner. Measurements of mean grey level were performed in two regions of interest; ROI_1 - alveolar bone (cortical and trabecular) and ROI_2 - cancellous bone separately with 3 tested forms: no normalization (RAW), normalization of the whole image (ALL) and normalization of the region of interest only (ROI). Descriptive analysis with coefficient of variation (CV) and one-way ANOVA followed by Tukey was performed. For MSCT, ROI_1 mean grey level slightly increased from 121.9+-17.13 (RAW) to 125.0+-15.74 (ALL) ($p>0.05$) and reduced to 104.8+-15.20 (ROI) ($p<0.0001$). CV varied from 14.05%, to 12.59% and 14.50%, respectively. ROI_2 increased from 95.11+-13.96 (RAW) to 99.40+-13.62 (ALL) and 102.5+-17.86 (ROI) ($p=0.0678$). CV was 14.67% to 13.71% and 17.43%, respectively. In CBCT group, ROI_1 meaningfully raise from 91.73+-32.17 (RAW) to 135.2+-36.06 (ALL) and 118.7+-18.65 (ROI) ($p<0.0001$), with CV decreasing from 35.06% to 26.68% and 15.71%, respectively. ROI_2 was 81.23+-34.36, 115.3+-28.53 and 109.4+-17.47, respectively ($p=0.0002$), with a CV reducing from 42.30% (RAW) to 24.74% (ALL) and 15.97% (ROI). Therefore, the use of intensity normalization of CBCT and MSCT examinations was demonstrated on reducing discrepancies between different scanners and inter-exams variability in bone quality assessment for dental implants.

Key Words: dental implants, bone density, CBCT, HU, MSCT, grey level

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1 INTRODUÇÃO

A reabilitação da estética e da função mastigatória com o uso de implantes dentários pode ser conseguida em diversas situações clínicas com segurança, dispondo de vários estudos longitudinais comprovando seu sucesso a longo prazo. [1-6] Entretanto, em situações desfavoráveis, com limitada quantidade óssea disponível e/ou baixa qualidade óssea, esta mesma previsibilidade nem sempre é conseguida. [7-10]

Diversos estudos têm demonstrado uma menor estabilidade primária em osso de baixa qualidade, havendo uma correlação direta entre a menor estabilidade primária em osso tipo IV e uma menor taxa de sucesso neste tipo de condição. [11-18] Desta forma, assim como acontece com a avaliação da quantidade de osso disponível para a instalação de implantes, seria importante poder prever a qualidade óssea com a mesma acuidade anteriormente à cirurgia para um melhor planejamento cirúrgico e protético, devido aos maiores cuidados necessários ao se trabalhar com osso de baixa qualidade, ainda mais se associada a pouca quantidade óssea. (19)

Esta mensuração da qualidade óssea de um potencial sítio receptor de um implante pré-cirurgicamente poderia ser realizada a partir dos mesmos exames tomográficos mais utilizados atualmente como rotina para o planejamento deste tipo de procedimento, as tomografias computadorizadas *cone beam* (CBCT) ou também das já consagradas tomografias computadorizadas *multislice* (MSCT). [20,21]

O termo qualidade óssea tem sido utilizado na literatura para descrever diferentes aspectos de características ósseas com definições variáveis dentro do contexto utilizado. Tanto para CBCT quanto MSCT, além de medições lineares, a mensuração da densidade óssea é a forma mais utilizada como medição da qualidade óssea pré-operatória. [22]

Tem sido sugerida a medição dos níveis de cinza da imagem, *grey level, em inglês* (GL), como método para medir a densidade óssea nas CBCT, uma vez que há uma forte correlação entre os tons de cinza em CBCT e a escala de Unidades

Hounsfield (HU) utilizada em tomografias médicas multislice (MSCT), já utilizada e validada. [23-26] Entretanto, a utilização de HU em exames CBCT apesar de utilizada em vários estudos não é a ideal. Mesmo quando da utilização do *grey level,* devido a alta variabilidade dos exames de CBCT, os valores medidos não são confiáveis, apresentando grandes discrepâncias entre exames, devido a influência do aparelho utilizado, parâmetros de regulagem e posicionamento do paciente, entre outros. [27,28]

Na CBCT, assim como em outros exames médicos, como a ressonância magnética, mamografia, ultrassom, angiografia e medicina nuclear, entre outros, esta variabilidade entre exames e o baixo contraste das imagens médicas necessitam ser resolvidos, havendo vários trabalhos na medicina sugerindo métodos de pós-processamento de imagem como alternativa para um melhor diagnóstico manual ou automático. [29-35]

O processamento digital de imagens tem como objetivo melhorar a qualidade da imagem para que o próprio observador consiga visualizar melhor a imagem, assim como detalhes relevantes dela difíceis ou até mesmo impossíveis de enxergar, e também preparar a imagem para que ela seja analisada pelo próprio computador de maneira adequada. [36]

Sob a ótica do processamento de imagem, o baixo contraste pode ser considerado como o resultado de uma má distribuição das intensidades de pixel dentro do espectro de visualização. Idealmente, para serem comparadas adequadamente, as imagens deveriam ter a mesmas propriedades de luminosidade e contraste a fim de permitir uma correta avaliação e medições mais confiáveis. Entretanto, raramente isto acontece. [32]

Isto sugere a possibilidade de aplicação da normalização *(contrast stretching ou histogram stretching)*, uma técnica conceitualmente simples utilizada na correção do contraste de imagens diferentes, nas mais variadas áreas do processamento digital de imagens, seja na área médica ou não. Com esta abordagem, uma função linear é aplicada a imagem, adequando a extensão de sua intensidade a um intervalo de distribuição desejado (*range)*, através de um processo padronizado. Em uma imagem em 8-bit, com 256 níveis de cinza, a normalização faz com que os valores de pixel de uma imagem com um *range* de 50 a 180, por exemplo, extendam-se de 0 a 255, fazendo com que as medições não dependam das propriedades tonais da imagem. [36]

O presente estudo objetiva avaliar os resultados da normalização em imagens de maxila e mandíbula, obtidas em diferentes *scanners* CBCT e MSCT. A hipótese do trabalho é que a normalização torna as imagens mais uniformes, e assim mais comparáveis, para uma melhor avaliação da qualidade óssea para implantes dentais.

2 ARTIGO SUBMETIDO AO JOURNAL OF DIGITAL IMAGING

INFLUENCE OF GREY LEVEL NORMALIZATION IN CONE BEAM AND MULTISLICE CT FOR BONE QUALITY ASSESSMENT

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This paper aims to investigate the influence of normalization in cone beam computed tomography (CBCT) and multislice computed tomography (MSCT) grey level to assess bone quality of recipient sites for dental implants. DICOM (Digital Imaging and Communications in Medicine) images from 37 bone sites (18 patients) were analyzed. CBCT was performed with 5 different CBCT devices and MSCT in a single multislice CT scanner. Measurements of mean grey level were performed in two regions of interest; ROI_1 - alveolar bone (cortical and trabecular) and ROI_2 - cancellous bone separately with 3 tested forms: no normalization (RAW), normalization of the whole image (ALL) and normalization of the region of interest only (ROI). Descriptive analysis with coefficient of variation (CV) and one-way ANOVA followed by Tukey was performed. For MSCT, ROI_1 mean grey level slightly increased from 121.9+-17.13 (RAW) to 125.0+-15.74 (ALL) ($p>0.05$) and reduced to 104.8+-15.20 (ROI) ($p<0.0001$). CV varied from 14.05%, to 12.59% and 14.50%, respectively. ROI_2 increased from 95.11+-13.96 (RAW) to 99.40+-13.62 (ALL) and 102.5+-17.86 (ROI) ($p=0.0678$). CV was 14.67% to 13.71% and 17.43%, respectively. In CBCT group, ROI_1 meaningfully raise from 91.73+-32.17 (RAW) to 135.2+-36.06 (ALL) and 118.7+-18.65 (ROI) ($p<0.0001$), with CV decreasing from 35.06% to 26.68% and 15.71%, respectively. ROI_2 was 81.23+-34.36, 115.3+-28.53 and 109.4+-17.47, respectively ($p=0.0002$), with a CV reducing from 42.30% (RAW) to 24.74% (ALL) and 15.97% (ROI). Therefore, the use of intensity normalization of CBCT and MSCT examinations was demonstrated on reducing discrepancies between different scanners and inter-exams variability in bone quality assessment for dental implants.

Key Words: dental implants, bone density, CBCT, HU, MSCT, grey level

INTRODUCTION

Bone density plays an essential role in the success of dental implant therapy. Several classification methods have been suggested for assessing the bone quality and predicting prognosis. (Turkyilmaz and McGlumphy, 2008) Lekholm and Zarb proposed the most popular and established method for bone quality assessment almost thirty years ago. (Lekholm and Zarb, 1985)

Computed tomography (CT) is one of the most useful medical imaging techniques for assessing not only the structure of the body tissue, but also its density. In multislice CT scans (MSCT) it is possible to use Housfield Units (HU) scale, based in the attenuation coefficient, to evaluate bone density at potential implant sites being a widely used and validated methodology. (Iwashita 2000, Norton and Gamble 2001, Shapurian et al 2006, Turkyilmaz et al 2007, Oliveira et al 2008, Fuh et al 2010)

However, the method of correlating bone density to HU values in cone beam computed tomography examinations (CBCT) although allowed, is not ideal, because CBCT data have a larger amount of scattered X-rays than conventional multislice CT, enhancing noise in reconstructed images and thus affecting the low-contrast detectability. Moreover, the scatter and artefacts in CBCT get even worse around inhomogenous tissues with reduced HU values. Because of beam hardening, the HU of certain structures such as soft tissue and bone alters. A non-uniform angular distribution of the X-ray beam intensity known as heel effect, leads to HU that have no uniformity. The relatively large amount of noise in CBCT may lead to inaccurate grey values in the medium-density range, and the limited field-of-view (FOV) diameter implies that the part of the scanned object outside the reconstructed volume can affect the grey values inside the FOV in a non-uniform way. These factors listed above confirm that the HU in CBCT is not a valid method for bone quality assessment. (Hua et al 2009, Pauwels et al 2013)

It has been suggested that the mean grey level measure could be used in an image region of interest for bone quality assessment. The reason for this would be in order to correct the deficiency in using HU in CBCT, since there is a strong correlation between mean grey level in CBCT and HU in MSCT. (Parsa et al., 2012; Valiyaparambil et al., 2012)

Nevertheless, CBCT scans present high variability, in which the pixel values are not reliable. This can be attributed to the influence of the device, image acquisition parameters, and patient positioning. These variables may present huge discrepancies using different CBCT equipment and when comparing CBCT and MSCT values. Even for images acquired through the same aquisition system, several factors may affect the acquisition process itself. (Nackaerts et al, 2011, Azeredo et al., 2013)

In CBCT, like other medical images such as MSCT, magnetic resonance imaging (MRI), mammography, ultrasound, angiography and nuclear medicine, low-contrast images need to be resolved and several papers suggest this approach for medical examinations. (Lu et al 1994, Lo and Puchalski 2008, Jagatheeswari et al 2009, Langarizadeh et al 2011, Matsopoulos 2012, Mohanapriya and Kalaavathi 2013, Shanmugavadivu and Balasubramanian 2014, El Zuki et al 2014)

To obtain higher contrast directly from the image device, it is almost always necessary increase time examination or radiation amount. For example, the low contrast in CT is only enhanced by raising the number of photons absorbed in each voxel, which is proportional to the x-ray dose. In these situations, digital post-processing can play a very important role. From an image processing point of view, low contrast can be considered as a result of bad distribution of pixel intensities over the dynamic range of the display device. (Lu et al., 1994) Ideally, the compared images should have the same luminosity and contrast properties in order to allow both manual and software-aided assessment. However, this is rarely the case. (Matsopoulos, 2012)

This suggests the application of contrast stretching, or normalization, a conceptually simple technique used to correct the contrast of images by fitting the range of their intensity to a desired interval of distribution. A linear function is applied on the pixels of the subject image in order to achieve the correction within the desired full range. The normalization process is a universally and widely used correction technique, due to its simplicity and fast executing performance. (Gonzalez and Woods, 2002)

The present study aims to determine the influence of intensity normalization process, also called contrast stretching or histogram stretching. This process extends the pixel values range and makes the images of different CBCT and MSCT scanners more uniform and comparable between them in the assessment of bone quality for dental implants.

MATERIAL AND METHODS

We analyzed 37 CT scans from posterior regions (maxilla and mandible) with an indication of single short implants in 18 patients (11 women and 7 men, aged between 25 and 76 years) included in a prospective clinical trial.

CT scans of 17 implant sites were performed in 9 patients and 5 CBCT scanners were used: i-CAT CBCT (Imaging Sciences International, Hatfield, PA), Xoran CAT CBCT (Xoran Technologies, Ann Arbor, MI) and Instrumentarium OP300 CBCT (Instrumentarium Dental, Tuusula, Finland). The Xoran CAT was made in 3 different radiology services and considered three distinct scanners. CT scans for 20 implants in 9 other patients were obtained in the same multislice scanner Elscint CT Twin II (Elscint, Haifa, Israel).

Obtaining tomographic slices and delineation of regions of interest

Using ImageJ freeware (ImageJ version 1.47v for Mac, National Institutes of Health, MD, USA) a DICOM sequence for each implant region was imported, reconstructed and then converted to 8-bit. Then, with the use of measurements made in immediate postoperative radiographs, straight reference lines were traced from the distal surface of nearest tooth at bone level to the implant center for defining the regions of interest (ROIs) location. Two regions of interest were manually delineated by a single operator (with the agreement of a second): ROI_1 - which corresponded with the alveolar bone, including cortical and cancellous bone; and ROI_2 comprised only of the trabecular bone separately. This was done in the axial, coronal and sagittal planes, totaling 6 ROIs per site of implantation. (Figure 1)

All the straight reference lines and ROIs were coded for patient, implant, orientation plane, and slice number, and then saved for later use with the ROI manager tool, as well as for future studies, in a standardized, systematic, and reproducible way.

Image preprocessing and measurements

For each implant recipient site, a DICOM sequence was reconstructed in ImageJ, the ROIs were imported to ROI Manager and the 8-bit image grey levels were measured for ROI_1 and ROI_2 in axial, coronal and sagittal planes, first with no contrast stretching (RAW). The mean of the three planes were computed for analysis.

Thereafter, grey level measurements of the same ROIs on bone site were performed with a previous normalization of the whole image. ROI_1 and ROI_2 mean grey values for the three orientation planes were averaged the same way. The DICOM sequence was then closed and reopened.

With the DICOM sequence converted to 8-bit resolution, ROI_1 was selected, and the normalization of the region of interest was performed. Mean grey level was measured, saved and the image was closed and reopened one more time. After 8-bit conversion, the ROI_2 was selected, normalized and averaged by the same manner.

Mean grey level of the three planes was averaged for each ROI, ROI_1 and ROI_2; and for each group CBCT and MSCT, and submitted for statistical analysis. Descriptive analysis with coefficient of variation measure (CV) and repeated measures ANOVA followed by Tukey's post hoc test ($p \leq 0.05$) was performed using GraphPad Prism (version 6.00 for Mac, GraphPad Software, La Jolla California USA).

RESULTS

In MSCT group, alveolar bone (ROI_1) grey values ranged from 91.61 to 157.0 with no normalization (RAW), 93.17 to 157.1 for normalization of the entire image (ALL) and 75.4 to 137.7 for normalization of the region of interest only (ROI). Cancellous bone (ROI_2) measures ranged from 72.48 to 134.0 (RAW), 78.38 to 134.1 (ALL) and 76.25 to 133.0 (ROI).

In CBCT group, ROI_1 (alveolar bone) grey values ranged from 53.12 to 170.4 with no normalization (RAW), 53.34 to 175.7 for normalization of the entire image (ALL) and 61.97 to 148.2 for normalization of the region of interest only (ROI). Cancellous bone (ROI_2) measures ranged from 32.94 to 153.7 (RAW), 48.38 to 152.9 (ALL) and 62.37 to 138.5 (ROI).

For MSCT examinations, ROI_1 mean grey level slightly increased from 121.9+-17.13 (RAW) to 125.0+-15.74 (ALL) ($p>0.05$) and then reduced to 104.8+-15.20 for ROI ($F=24.70$; $p<0.0001$). The Coefficient of Variation (CV) presents a reduction from 14.05% (RAW), to 12.59% (ALL), and then to 14.50% (ROI). Measures for ROI_2 were increased at the same pattern, from 95.11+-13.96 (RAW) to 99.40+-13.62 (ALL) and 102.5+-17.86 (ROI)(F= 3.271; p=0.0678), with CV decreasing from 14.67% (RAW) to 13.71% (ALL) and raising to 17.43% (ROI). (Table 1)

Unlike MSCT, CBCT examinations demonstrated a statistic meaningful increase after normalization. ROI_1 mean grey level in CBCT group rose from 91.73+-32.17 (RAW) to 135.2+-36.06 when normalized (ALL) (F=21.21; p<0.0001) and reduced to 118.7+-18.65 (ROI)(p=0.0004), with a coefficient of variation (CV) decreasing from 35.06% (RAW) to 26.68% (ALL) and 15.71% (ROI), respectively. ROI_2 mean value was increased from 81.23+-34.36 (RAW) to 115.3+-28.53 (ALL) (F=13.05; p=0.0002) and 109.4+-17.47 for ROI normalization (p=0.0016), with a CV reducing from 42.30% (RAW) to 24.74% (ALL) and 15.97% (ROI). (Table 2)

DISCUSSION

Several studies have found that bone quality is equally or more important to treatment outcome than the quantity of bone for dental implants. (Turkyilmaz, 2007) Many papers stated that the use of MSCT through HU scale is possible to assess bone density with reliability prior to implant placement enabling better treatment planning and predictability. (Iwashita 2000, Norton and Gamble 2001, Shapurian et al 2006, Turkyilmaz et al 2007, de Oliveira et al 2008, Fuh et al 2010) Indeed, the MSCT has a higher radiation exposure, higher cost and is difficult to access. These facts allowed the CBCT to increase development and present an evolutionary arm to CT imaging. (Angelopoulos et al., 2012)

Despite all limitations in the use of HU in CBCT for bone density related in the literature (Hua et al 2009, Nackaerts et al 2011), many studies have employed HU to assess bone quality in CBCT examinations. (Fuster-Torres et al 2011, Isoda et al 2012, Kaya et al 2012, Pagliani et al 2013) Another approach suggested is the utilization of grey values in CBCT to infer the bone density of implant sites. (Parsa et al 2012, Valiyaparambil et al 2012)

The critical issue using grey values in CBCT is its variability. In the CBCT the dimensional accuracy is also comparable with CT, but in contrast to the CT, the grey density values of the CBCT images (voxel value [VV]) are not absolute. (Casseta el al., 2012) Nackaerts et al (2011) evaluated the variability of intensity values in CBCT imaging compared with MSCT HU units in order to assess the reliability of density assessments using CBCT images and concluded that the use of intensity values in CBCT images are not reliable, because the values are influenced by device, imaging parameters and positioning. For Pauwels et al (2012) even though most CBCT devices showed a good overall correlation with CT numbers, large errors can be seen when using the grey values in a quantitative way. Although it could be possible to obtain pseudo-Hounsfield units from certain CBCTs, alternative methods of assessing bone tissue should be further investigated. Even the time between examinations caused large discrepancies in voxel value distribution in CBCT images, with the variation randomly distributed. (Spin-Neto, 2014)

In this study, this variability was minimized through contrast stretching, often called intensity normalization. The results showed that even for MSCT examinations, the normalization could improve the image similarity, demonstrated with the reduction of Coefficient of Variation (CV). Horwood et al (2001) concluded that image normalization is a prerequisite for computer-based diagnosis of CT pulmonary images after observing great irregularities in greyscale distribution between datasets of MSCT thoracic examinations and even for one slice between another in a particular dataset. Figures 2, 3, 4 and 5 show the relatively stable behavior of no preprocessing MSCT after normalization for ROI_1 and ROI_2.

CBCT examinations demonstrated a meaningful increase after normalization, with an important CV decrease for ROI_1 and ROI_2. Contrast enhancement approaches as utilized for us are often used in MRI examinations because of the huge variability observed in this modality of image diagnosis, as well as CBCT. (Nyúl and Udupa 1999, Collewet et al 2004, Loizou et al, 2013) In fact, this is not an exclusivity of MRI or CBCT. Most part of medical images have this contrast problem that need to be resolved and many papers suggest image postprocessing to correct this deficiency and to improve manual and automatic diagnosis. (Lu et al 1994, Lo and Puchalski 2008, Jagatheeswari et al 2009, Langarizadeh et al 2011, Matsopoulos 2012, Mohanapriya and Kalaavathi 2013, Shanmugavadivu and Balasubramanian 2014, El Zuki et al 2014)

Ideally, the compared images should have the same brightness and contrast properties in order to allow both manual and software-aided assessment.

(Matsopoulos, 2012) Visually, the normalized CBCT images (ALL) were comparable with the MSCT (RAW and ALL). (Figure 6) The mean grey values suggest the same, as shown in tables 1 and 2, with an approximation of the CBCT values after normalization (ALL and ROI) and MSCT (RAW and ALL). But these results must be seen carefully.

One of the limitations of our study was the sample size. The examinations were obtained from patients included in a clinical prospective research, with severe inclusion criteria. Additionally, most of these patients had been evaluated before by other professionals and came with the examinations already performed less than six months earlier. For ethical reasons, it was impossible to repeat the examinations with the same CBCT scanner or same modality (CT and CBCT scans). Furthermore, the parameters and acquisition protocols were not possible to standardize, because they were arising from different radiologic services.

One of the most relevant contributions of this study, regarding image post processing, is that we could avoid these negative issues by obtaining CT images with optimal contrast. These issues include higher radiation dose, higher cost and higher examination time (Lu et al 1994). The possibility to diminish the inter-exams variability and improve the bone quality assessment prior to implant placement enhancing treatment planning and predictability should also be highlighted.

Although this methodology is well known and established in digital image processing field, the use of contrast stretching on standardization of CBCT and MSCT for dental purpose has not been reported.

Further in vitro studies, initially, with even more controlled variables are needed to better assess and validate this methodology. As a suggestion, it is possible to correlate the corrected numbers with many clinical parameters, such as primary stability, tactile and visual assessments, and texture analysis features for example.

In conclusion, the use of intensity normalization of CBCT and MSCT examinations was demonstrated in reducing discrepancies between different scanners and inter-exams variability in bone quality assessment for dental implants.

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Table 1. Mean grey level before and after normalization in MSCT scans for ROI_1 and ROI_2

MSCT	ROI_1			ROI_2		
n=20	RAW	ALL	ROI	RAW	ALL	ROI
Mean	121.9[a]	125.0[a]	104.8[b]	95.11	99.4	102.5
Std. Dev.	17.13	15.74	15.20	13.96	13.62	17.86
Std. error	3.831	3.519	3.399	3.121	3.046	3.994
Coef. variation	14.05%	12.59%	14.50%	14.67%	13.71%	17.43%
P<0.0001				P=0.0678		

Table 2. Mean grey level before and after normalization in CBCT scans for ROI_1 and ROI_2

CBCT	ROI_1			ROI_2		
n=17	RAW	ALL	ROI	RAW	ALL	ROI
Mean	91.73[a]	135.2[b]	118.7[c]	81.23[a]	115.3[b]	109.4[b]
Std. Dev.	32.17	36.06	18.65	34.36	28.53	17.47
Std. error	7.801	8.745	4.522	8.334	6.920	4.237
Coef. variation	35.06%	26.68%	15.71%	42.30%	24.74%	15.97%
P<0.0001				P=0.0002		

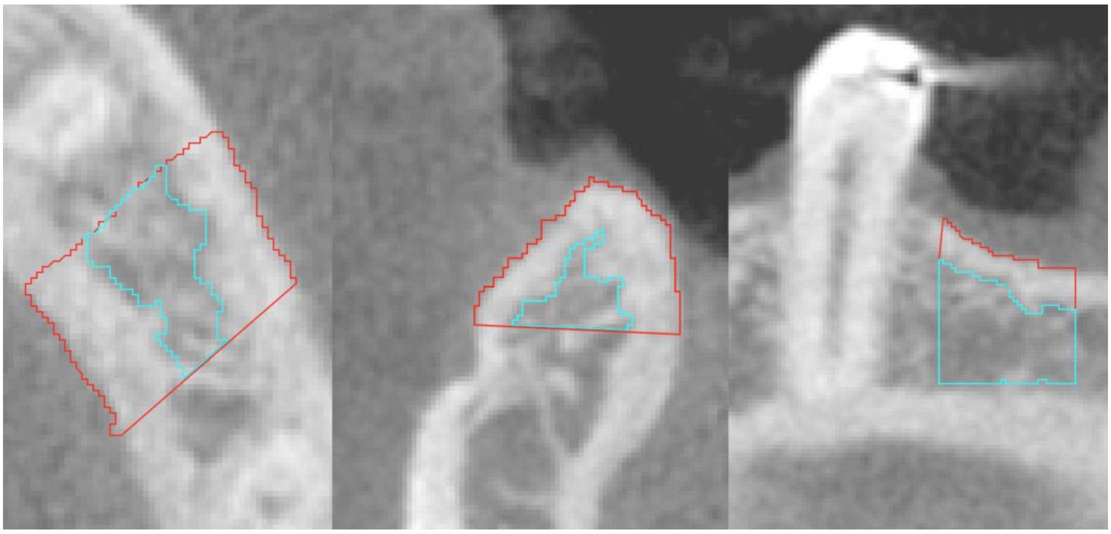
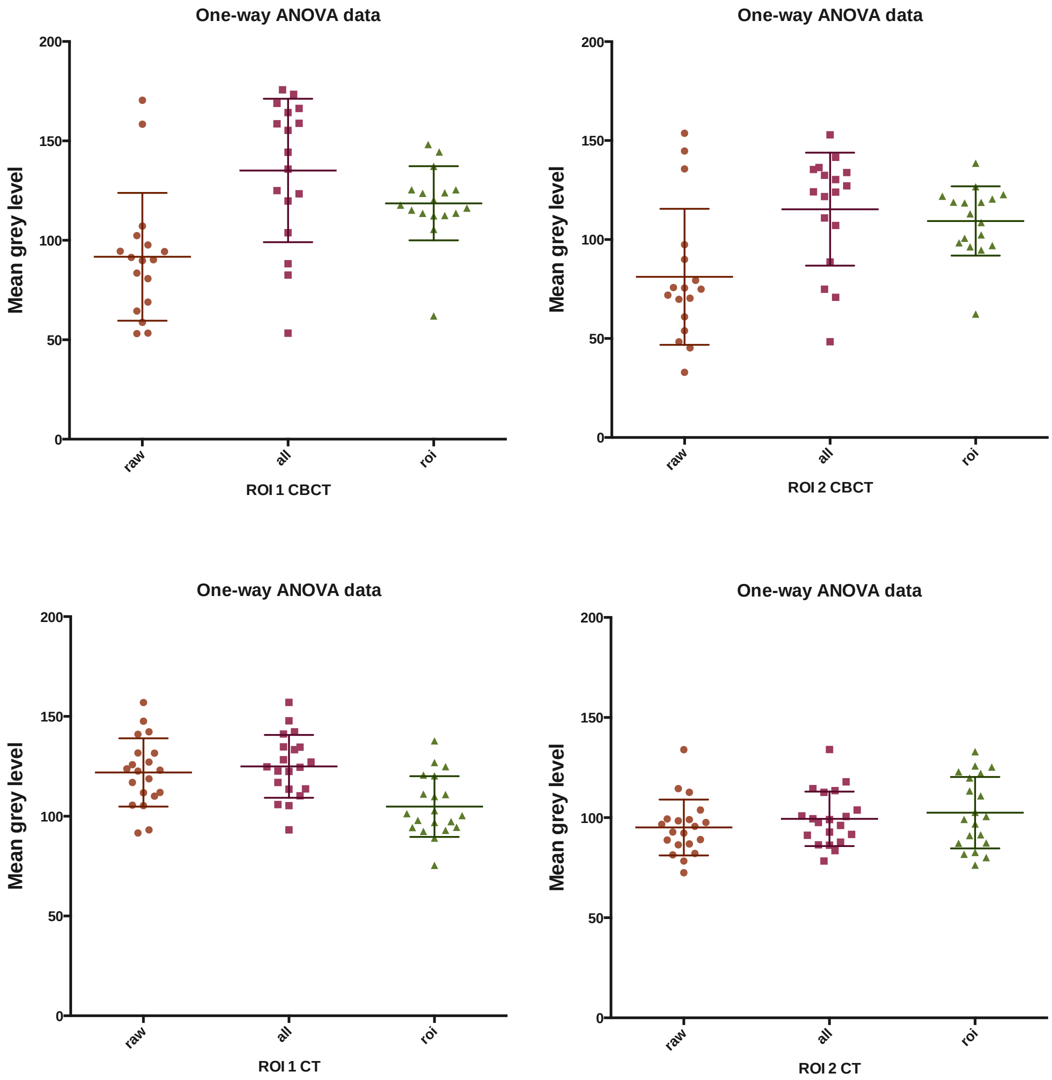


Figure 1. ROI_1 (alveolar bone, cortical and trabecular included, in red) and ROI_2 (cancellous bone only, in blue) in axial, coronal and sagittal planes.



Figures 2, 3, 4 and 5. Intensity values distribuition in CBCT (up) and MSCT (down) groups before and after normalization

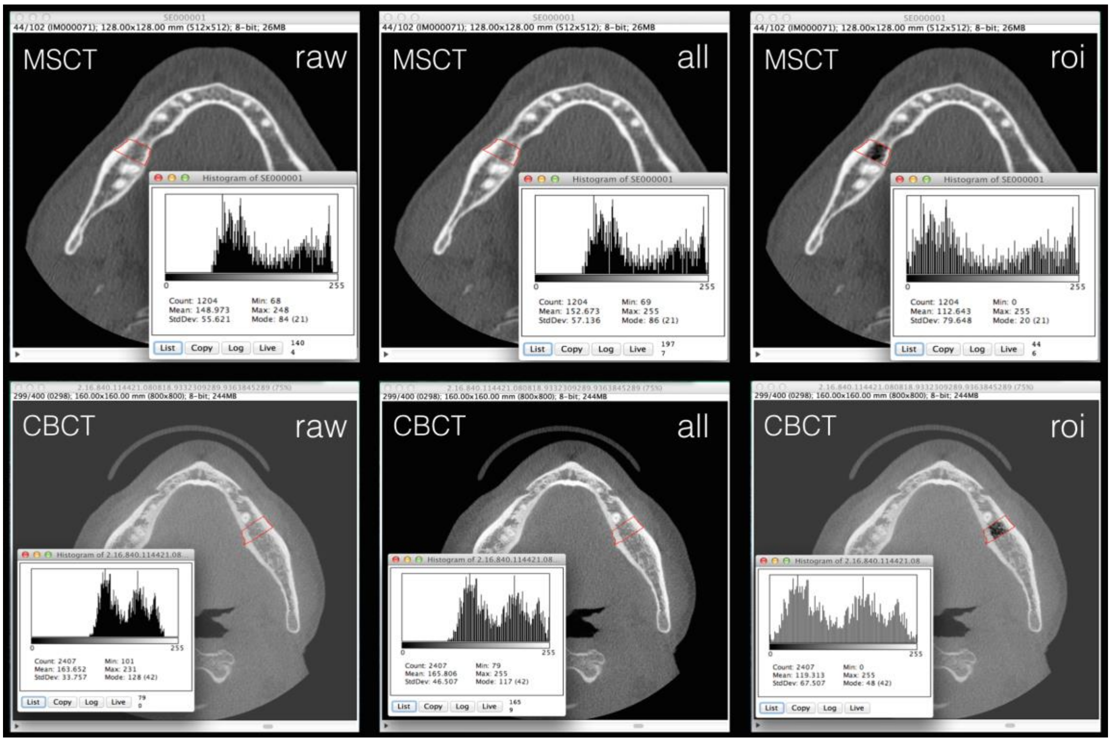


Figure 6. Effect of normalization in MSCT (up) and CBCT (down) scans. No normalization (RAW, left column), normalization of the whole image (ALL, middle) and normalization of the ROI_1 only (ROI, right column).

3 DISCUSSÃO

Os estudos sobre qualidade óssea em tomografias MSCT e CBCT estão normalmente concentrados na densidade óssea. [23, 37, 38] Para isso, a MSCT é uma modalidade clinicamente estabelecida na qual as Unidades Hounsfield (HU) podem ser convertidas em densidade óssea (BMD - *bone mineral density*) de maneira bastante acurada. [39,40] Por sua vez, a CBCT apresenta uma confiabilidade controversa na avaliação da qualidade óssea, especialmente em relação aos seus valores de intensidade de cinza - *grey level, em inglês* (GL) - mesmo que estes apresentem alta correlação com HU em alguns trabalhos. [23, 24, 26, 41-44]

Os valores de pixel/voxel de um exame CBCT são altamente influenciados por inúmeros fatores, desde o modelo do aparelho, parâmetros de regulagem, posicionamento do paciente e da região de interesse dentro do campo de visão - *field of view, em inglês* (FOV), tecidos e materiais escaneados fora do FOV, tamanho de pixel/voxel e resolução, contraste, tamanho do FOV, artefatos, e até mesmo pela variação decorrida da aquisição em momentos diferentes. [27, 28]

Neste estudo, foram analisados exames de vários tomógrafos e serviços radiológicos diferentes, inclusive com tecnologia diferente (CBCT e MSCT). Os tamanhos de voxel variaram de de 0.2mm a 1mm, com tamanhos de FOV variados. Normalmente, a escala de cinza que os aparelhos de tomografia computadorizada trabalham varia de 8 a 16-bit. [45] Para que houvesse uma padronização da escala de cinza na medição, todos os exames foram padronizados em 8-bit, já que encontramos exames com escala de cinza de 12, 14 e 16-bit. Isto fez com que a comparação com outros estudos se tornasse inviável, pois seriam necessários cálculos de conversão da escala em 256 níveis de cinza para Unidades Hounsfield ou para uma escala radiográfica específica para cada resolução.

Devido a estas inconsistências inerentes a própria modalidade de exame e a falta de um padrão técnico nas CBCT, além do fato de utilizarmos exames também tomografias MSCT, é que este estudo sugeriu um método de otimização das imagens tomográficas através da normalização, para uma melhor distribuição dos níveis de cinza dentro do seu espectro, melhorando também a sua relação de contraste, tornando os exames de diferentes momentos, pacientes, aparelhos, regulagens e modalidades mais comparáveis. Esta heterogeneidade de exames e serviços nos aproxima de uma realidade clínica, aumentando a validade externa de nosso trabalho.

Neste estudo, a variabilidade interexames foi minimizada e os resultados mostraram que mesmo para tomografias MSCT a normalização pode aumentar a similaridade ocasionalmente, o que foi demonstrado com a diminuição do Coeficiente de Variação (CV). (Tabela 1) Horwood e colaboradores [46] após observarem grandes irregularidades na distribuição dos níveis de cinza entre exames tomográficos torácicos, e mesmo entre cortes diferentes, concluiram que a normalização é um pré-requisito para o diagnóstico auxiliado por computador em imagens pulmonares MSCT.

No nosso caso, percebe-se na Figura 2 o comportamento consideravelmente estável das MSCT após normalização, especialmente de RAW para ALL, tanto na análise do osso alveolar como um todo (ROI_1) quanto do osso medular separadamente (ROI_2).

Já as CBCT demonstraram um aumento considerável no *grey level* após normalização, de RAW para ALL, para ROI_1 e ROI_2, na grande maioria dos exames, com um importante decréscimo no Coeficiente de Variação. (Tabela 2) A mesma abordagem é freqüentemente utilizada em exames de ressonância magnética, onde a variabilidade também é bastante significativa, assim como nas CBCT. Estas limitações não são exclusividade da ressonância ou da CBCT, sendo encontrados também em outros exames médicos como a própria MSCT, mamografia, angiografia, medicina nuclear, entre outros. A normalização já foi sugerida para o processamento destas imagens médicas de baixo-contraste de forma semelhante em outros estudos, com metodologias variadas. [29-35]

Idealmente, as imagens comparadas deveriam ter as mesmas propriedades, tonais, de brilho e contraste, permitindo um melhor diagnóstico manual ou automático. Visualmente, as imagens CBCT normalizadas (ALL) estão mais uniformes, visualmente mais comparáveis entre elas e também às imagens MSCT RAW e ALL, padrão de referência no que se refere à avaliação da densidade óssea através das HU (Figura 3). Os níveis de cinza sugerem o mesmo, como demonstrado nas Tabelas 1 e 2. Apesar do processamento de normalização da região de interesse apenas (ROI) apresentar números interessantes e um resultado visual da *ROI* com melhor qualidade de processamento a primeira vista, o resultado observado não é lógico, mostrando uma distribuição exagerada na extensão do *grey level* na região de interesse, sendo assim não recomendada. Isto se baseia no fato de desejarmos tornar as imagens o mais semelhante possível dentro do conjunto através do processo de normalização, mas não os tipos ósseos mais semelhantes entre eles, pois isso acabaria diminuindo o poder de classificação entre as diferentes qualidades ósseas.

Uma das limitações do nosso estudo foi o tamanho da amostra. Os exames foram obtidos de pacientes incluidos em uma pesquisa clínica prospectiva, com critérios de inclusão rigorosos. Além do mais, parte dos pacientes já havia sido avaliada por outros profissionais, chegando para triagem com exames realizados nos últimos meses. Por motivos éticos, repetir os exames foi impossível a fim de padronizar a mesma modalidade (CBCT/MSCT), o mesmo aparelho e as mesmas regulagens de parâmetros, já que eram provenientes de serviços radiológicos diferentes.

Uma das contribuições mais importantes deste estudo é incrementar a qualidade dos exames através de técnicas de pós-processamento de imagem, evitando os pontos negativos em se obter imagens de ótimo contraste durante a aquisição: altas doses de radiação, maior tempo e maior custo de exame. [29] A possibilidade de se diminuir a variabilidade entre exames e melhorar a mensuração da qualidade óssea pré-operatória, otimizando o planejamento e a previsibilidade de um tratamento também merece ser destacada.

Mesmo que este seja um método relativamente simples e conhecido no campo do processamento digital de imagens, não se tem notícia desta abordagem aplicada na Odontologia, em MSCT e especialmente em CBCT, para medição da densidade óssea afim de se avaliar a qualidade óssea para implantes de uma maneira mais confiável.

Devido as características clínicas deste trabalho, estudos adicionais *in vitro* devem ser conduzidos, com variáveis controladas e amostra maior, para um melhor refinamento desta metodologia. A utilização de *phantom* e/ou um método de referência padrão-ouro pode ser importante. Adicionalmente, pode-se avaliar no futuro a correlação de exames padronizados com parâmetros clínicos e a avaliação da qualidade óssea não apenas baseada na intensidade da imagem, mas em conjunto com uma abordagem macro e microestrutural do tecido ósseo em CBCT de alta resolução.

Neste estudo, como conclusão, a utilização da normalização de intensidade em tomografias computadorizadas *cone beam* e *multislice* demonstrou reduzir as discrepâncias entre diferentes aparelhos e a variabilidade entre exames na avaliação da qualidade óssea em sítios receptores de implantes na maxila e mandíbula.

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ANEXO 1 - CARTA CCEFO - PUCRS

Comissão Científica e de Ética
Faculdade da Odontologia da PUCRS

***Porto Alegre* 09 de abril de 2014**

O Projeto de: ***Dissertação***

Protocolado sob nº: 0024/14

Intitulado: Relação entre densidade óptica, análise de textura óssea e espessura da cortical em tomografias computadorizadas com estabilidade primária de implantes curtos.

Pesquisador Responsável: Profa. Dra. Rosemary Sadami Arai Shinkai

Pesquisadores Associados: Danilo Renato Schneder

Nível: Dissertação / Mestrado

Foi ***aprovado*** pela Comissão Científica e de Ética da Faculdade de Odontologia da PUCRS em *Nove de Abril de Dois Mil e Quatorze*

Este projeto deverá ser imediatamente encaminhado ao CEP/PUCRS.

Profa. Dra. Luciane Macedo de Menezes
Coordenadora da Comissão Científica e de Ética da Faculdade de Odontologia da PUCRS

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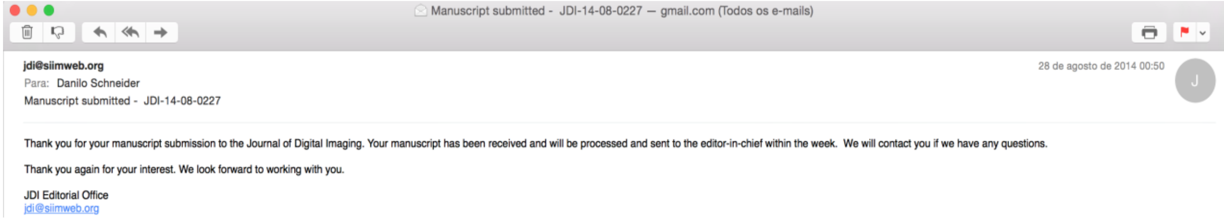
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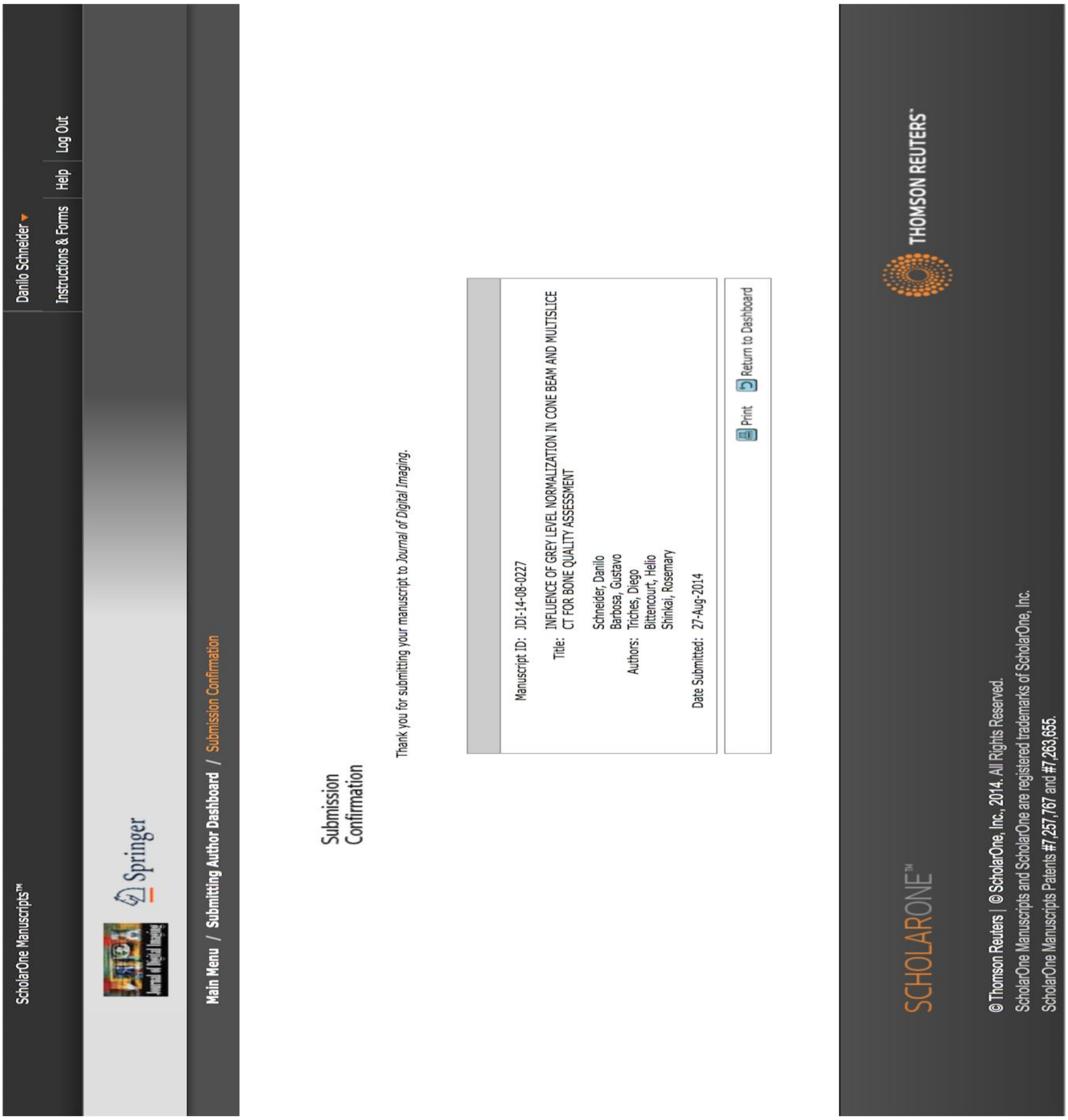
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