COMPUTER SIMULATOR OF MAMMOGRAPHY CONTEMPLATING THE CLASSIFICATION OF ACR BI-RADS™

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Abstract: The CADs evaluation performance, developed for mammographic diagnosis, shows inconsistencies, due to the difficulty of obtaining ample and common image databases for all. One solution is the computer simulation of image databases with control mechanisms on the tissue distribution and quantity of tissues. The control mechanisms is based in the characteristics of the classification system of mammary densities of the ACR BI-RADS™. The methodology proposed permits to exercise control over the quantity, localization, distribution and shape of the simulated mammary tissues and over the glandular disc shape and size. To each density pattern was defined a typical set of parameters. When the user chooses one of the sets, he will obtain different mammographies in the desirable pattern. The control over geometric parameters of the tissue structures was obtained with NURBS techniques. The average value of each parameter was obtained empirically. Two hundred mammograms were simulated, being 50 to each pattern. The classification was performed by two specialist physicians who confirmed the distribution of categories among the image databases. It is possible to simulate the mammography patterns, and even using a random distribution is possible to control the shape and the distribution of different simulated mammary tissues with NURBS techniques.

Introduction

According to Instituto Nacional do Câncer (INCA)[1], mammography is nowadays the most effective method of diagnosing breast cancer precociously. CADs (Computer-Aided Diagnosis) systems were developed to help in the diagnosis, where image processing techniques are used to detect lesions in the breast. CADs incorporate medical knowledge that permits the detection and the classification of the mammary lesions, permitting to be used to improve and to give consistency to the diagnosis, becoming a friendly help[2-4]. However, the methodology used in the comparison and evaluation of CADs systems showed certain inconsistencies, such as impossibility of its performance comparison and incapacity to analyze images obtained with different technologies. The reasons for these inconsistencies are the different databases and the lack of an appropriate mammography classification. This problem may be, at first, solved with a database that presents all possible mammography characteristics, from different acquisition technologies to different ethnics. It is believed that an ample and common database to all CADs systems, which has the desirable characteristics, is very difficult to be made. Even if it is possible to make it to solve the performance comparison problem among CADs systems, it still remains the simultaneous variations of the image multiple parameters, such as: the very breast and the different acquisition technologies. These variations prevent the determination of factors that affect the performance of each CAD.

An alternative is the computer simulation of the mammographies with the desirable characteristics, where it is possible to control each one of the involved parameters, in other words, for a same breast it is desirable to have images obtained from different technologies or with different acquisition techniques, permitting with this to evaluate what affects the performance of the CADs.

Our purpose is to developed a software that simulate mammographies contemplating the characteristics of the four categories of the American College of Radiology (ACR) – Breast imaging reporting and data system (BI-RADS™) density pattern[5].

Theory – *Mammary structure simulation*

Healthy breasts are compounded from a set of structures such as ducts, lobules, blood-vessels, glands, parenchyma and fat. These structures vary in shape, quantity, size and distribution. These variations depend on the mammary volume, the age and the woman's hormonal condition[6]. The distribution and the quantity of these structures in the mammary volume may be classified in the mammography by patters[6] and among them is distinguished the ACR BI-RADS™[5].

Mammographic patterns provide analysis and appropriate classification of the images, indicating to physicians the areas which deserve better attention due

ISSN: 1727-1983

to the bigger risk of cancer, thus a systematization of the mammographic report is obtained. Breast and mammography simulation systems are more adequate to the CADs evaluation if they can simulate the images according to their density pattern intended by the user.

ACR BI-RADS™ pattern classifies the breast image in four density patterns, based on a description of the mammary tissue type, being: Pattern 1 – Radiolucente (breasts almost totally fat); Pattern 2 – Low density (breasts with sparse fibrous glands); Pattern 3 – Equal density (breasts heterogeneously dense); Pattern 4 – High density (breasts extremely dense).

The main breast simulation systems developed by Taylor P., et al.[7], Bakic, P., et al.[8], Bliznakova, K., et al.[9] e Oliveira, H. J. Q.[10], do not foresee the possibility of controlling mammographic patterns during the simulation. None of these methodologies shows simulation control mechanisms that permits to determine the mammographic pattern to be simulated.

Materials and Methods

"Non Uniform Rational B-Splines" (NURBS)[11] techniques were used to control the simulated breast shape and structure distribution. These techniques use the math concepts of Bezier curves.

External edge (skin) and internal and external edges of the glandular disc were defined to control the simulated breast shape. The 3 points for each edge that permits to control the shape of each one were used, as figure 1 shows. The points used to define the glandular disc derived from the points used to define the external edge of the breast. The edges are made in a virtual volume of 100x180xHmm^3 , where the H is the breast thickness, chosen by the user.

The edge control points form a triangle, where the vertex with 0 and 2 indexes are part of the curve that forms the edge. The vertex, with index 1, is out of the virtual volume and it is not part of the edge, as it can be seen in the figure 1. Based on these points the edges are designed with Bezier curves by the NURBS techniques.

Figure 2 shows a model used to the confection of the left breast external edge, with compression craniocaudal pattern, constructed through NURBS techniques. It was used control points P0, P1 and P2 represented in the equation 1, where C is the coordinate set of the final curve, obtained with an independent variable u.

$$C(u) = (1-u)^2 P_0 + 2u(1-u)P_1 + u^2 P_2 \qquad (1)$$

Where:
C is the final curve coordinate vector;
u is the C independent variable;
P_o, P_1 e P_2 are the 3 shape control points.

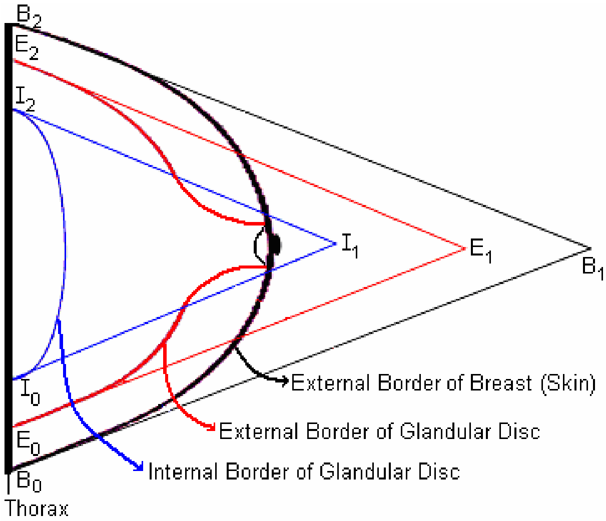


Figure 1: The breast edge (skin) is defined by the smooth black contour and controlled by the B_0, B_1 e B_2 points. The external edge of the glandular disc is defined by the smooth red contour and controlled by the E_0, E_1 e E_2 points. The internal edge of the glandular disc is defined by the smooth light contour and controlled by the I_0, I_1 e I_2 points.

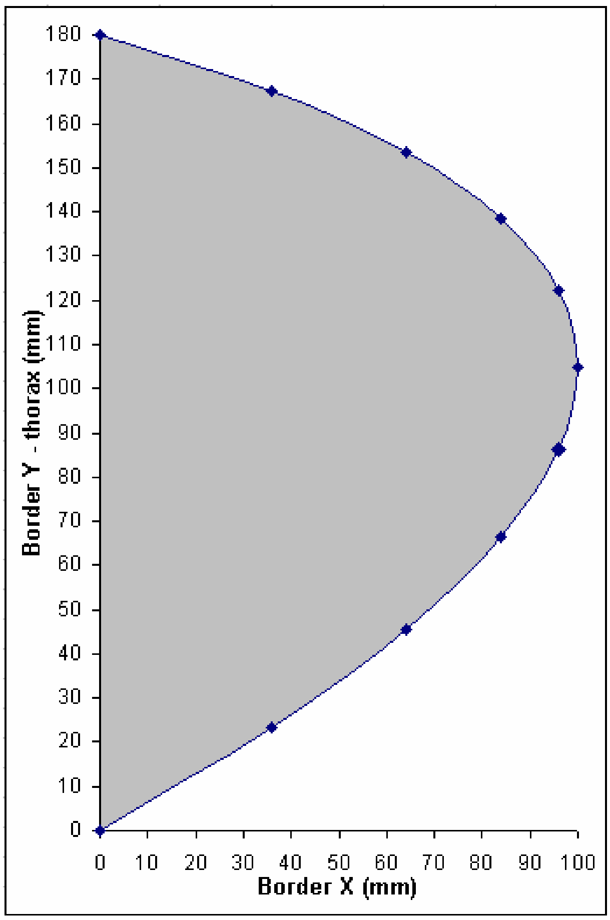


Figure 2: External edge model of a left breast with craniocaudal compression, constructed with 3 control points through Bezier curves.

Considering that subareolar region, of the real breast, contains a higher density level due to the main ducts concentration that arrive at the breast, a specific routine was developed to modify the external edge of the glandular disc in that region as the figure 1 shows.

NURBS techniques were used to make all breast structures, whose three-dimensional setting follows the same methodology developed by Oliveira, H. J. Q.[12].

The following parameters were controlled in order to obtain each one of the density patterns: (a) maximum and minimum dimensions of each structure; (b) quantity of large and small lobules, ducts and vessels, as well as quantity of necessary layers to obtain the chosen thickness (H); (c) proportion of structure quantities to its distribution inside mammary volume. The average value of each parameter is presented in the results.

The definition of the parameters and the necessary values to obtain image in each of the density patterns was helped by two radiologists with at least 10 years experience in diagnostic analyze of the mammogram.

Initially, MIAS[12] real image databases with 320 images were classified, by the radiologists, according to the ACR BI-RAD™ density patterns. This classification worked as a reference to the value definition of each parameter. The final values were obtained in four stages empirically. At the first stage, the values of each parameter were estimated and a database with 200 images was simulated, being 50 to each pattern. At the second stage, the parameter values suffered the first refinement, criteria to obtain the variable edges were defined and the second image database was simulated. At the third stage, new parameter refinement occurred and criteria to proceed the irregular tissue distribution in the mammary volume aiming at obtaining more realism in the image were defined, what originated the third simulated image databases. At the fourth stage, the final parameter adjustment occurred and the fourth image databases were simulated.

A CD-ROM with the simulated image databases obtained in each stage was given to each radiologist to evaluate the performance of the new simulation methodology. The images were named randomly so that there was no relation with the simulation order. The radiologists classified the images according to the ACR BI-RADS™ density patterns. After, the radiologists analyzed the images that were not classified according to the expected and each one gave suggestions for modifications to obtain the correct classification.

In order to evaluate the third and fourth image databases, a third radiologist was invited, who made a classification according to the density patterns, but did not give suggestions for modifications. The purpose of this new specialist in the evaluation was to verify if the involvement of the two first radiologists in the parameter adjustment process was exerting influence in the results.

Additionally, an image sample of the third and fourth databases was classified by experimental software of mammographic density determination according to the ACR BI-RADS™ density pattern. This software was developed by Rodrigues (2004)[13]. It detects the breast edge, divides the breast image region in areas of 10x10 pixels and calculates image values for each area. Using threshold internally established, the software converts the calculated values to each region into representative percentage values of the breast density. Because of this percentage, mammographies are classified according to ACR BI-RADS™ density patterns.

Results

Mammographies on the figure 3 and 4 permit to make a comparison between the simulation methodology previously used (figure 3) with the current methodology (figure 4). On figure 3 the structure distribution is properly regular and the breast edge (contour) is very symmetric, what implicates in an artificial aspect. On figure 4 the structure distribution is irregular and the edge is asymmetrical, what implicates in a more realistic aspect. This is a desirable aspect, therefore it contributes to improve the realism.

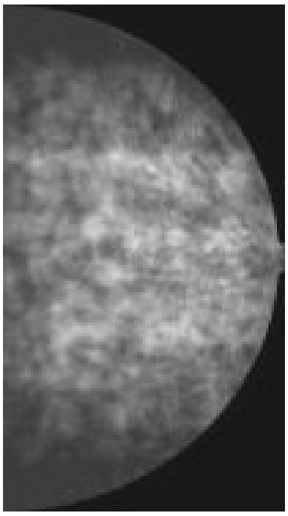


Figura 3: Simulated breast with methodology previous to this paper. User chose density pattern 3 in this simulation.

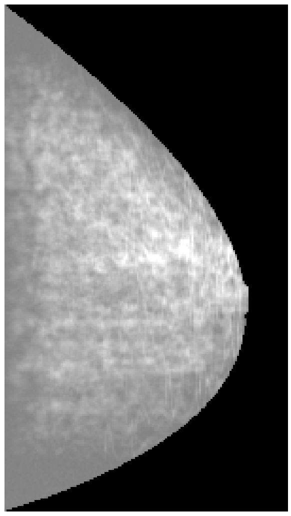
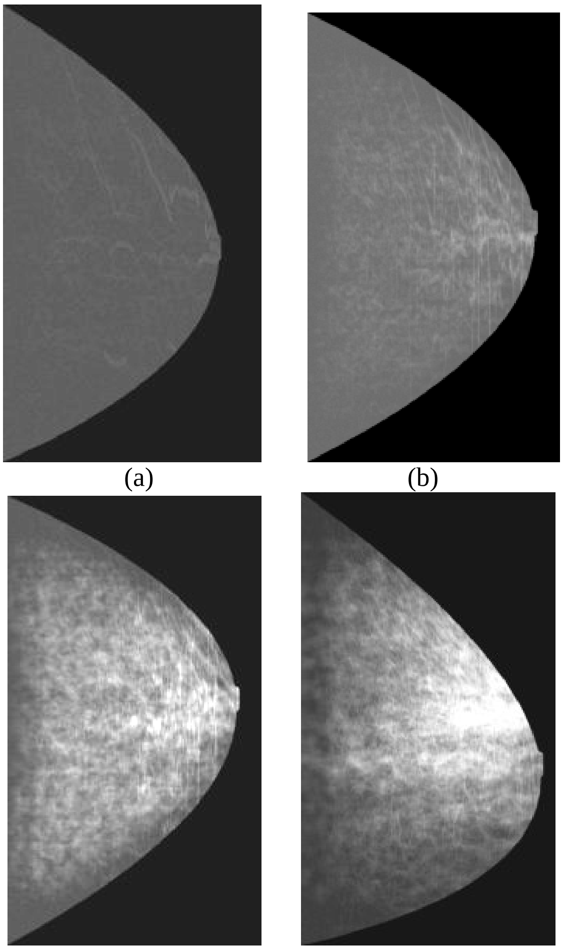


Figura 4: Simulated breast with methodology proposed in this paper. User chose density pattern 3 in this simulation.

Each parameter values necessary to obtain each density pattern, together with a sample image, are presented in this section.

Density pattern 1 (radiolucente – breasts almost totally fat): The quantity of large lobules per layer varies from 1 to 2, being that radii *a* and *b* vary from 1,5 mm to 4,4,mm. The quantity of small lobules per layer varies from 1 to 2 and the radii vary from 0,7 mm to 2,2 mm. Ducts are constructed 1 per layer with 0,3 mm minimum radius and 2 mm maximum and from 11 mm to 34,5 mm length. In the total, from 100 to 160 layers to each breast in this pattern are simulated. A sample of this simulated breast with these characteristics can be seen at the figure 5a.

Density pattern 2 (low density – sparse fibroglandular densities): The quantity of large lobules per layer varies from 6 to 12, being that the radii *a* and *b* vary from 1.5 mm to 7 mm. The quantity of small lobules per layer varies from 12 to 22 and the radii vary from 1.1 mm to 3 mm. The ducts are constructed in quantities per layer that vary from 4 to 8 with 0,3 mm minimum radius and 2 mm maximum and from 11mm to 34.5 mm length. In the total, from 120 to 200 layers to each breast in this pattern are simulated. A sample can be seen in the figure 5b.



(a) (b) (c) (d)

Figure 5: Simulated mammographies with necessary characteristics to obtain ACR BI-RADS™ density patterns. Image (a) belongs to pattern 1; image (b) belongs to pattern 2; image (c) belongs to pattern 3; image (d) belongs to pattern 4.

Density pattern 3 (equal density – heterogeneously dense): The quantity of large lobules per layer varies from 12 to 24, being that the radii *a* and *b* vary from 2,2 mm to 11,3 mm. The quantity of small lobules per layer varies from 18 to 32 and the radii vary from 1.8 mm to 5.5 mm. The ducts are constructed in quantities per layer that vary from 6 to 12, with 0.3 mm minimum radius and 2 mm maximum and from 11 mm to 34,5 mm length. In the total, from 140 to 220 layers to each breast in this pattern are simulated. A sample can be seen at figure 5c.

Density pattern 4 (high density – extremely dense): The quantity of large lobules per layer varies from 60 to 100, being that the radii *a* and *b* vary from 5,5 mm to 27,3 mm. The quantity of small lobules per layer varies from 120 to 180 and the radii vary from 3,6 mm to 12,7 mm. The ducts are constructed in quantities per layer that vary from 60 to 100 with 0,3 mm minimum radius and 2 mm maximum and from 11 mm to 34,5 mm length. In the total, from 170 to 250 layers to each breast in this pattern are simulated. A sample can be seen at figure 5d.

Qualitative Evaluation: In database one, from the 200 simulated images 50 should be pattern 1´s, 50 pattern 2´s, 50 pattern 3´s and 50 pattern 4´s. The specialists classified images in 4 ACR BI-RADS™ density patterns, whose results are presented in table 1. The concordance between the two radiologists classifications was positively interpreted, therefore it indicates that there is uniformity in parameter definition. It can be observed that 50 of the 200 images were not classified according to the user choice that simulated the images, in other words, a pattern to be simulated was chosen, but the result was the attainment of image in another pattern.

After the second 200 image database simulation a new classification by the specialists was carried out, with results available in table 1. There was a better concordance between the simulation and classification of radiologist 1 as presented, in other words, the result obtained with the classification was according to the choice of the pattern during the simulation. The result of this classification carried out by the radiologist 2 did not show a direct concordance with what was simulated. All images simulated for pattern 1 were classified as expected. The images simulated for pattern 2 were classified as being pattern 1, the images simulated for pattern 3 were classified as being pattern 2 and the 50 simulated for pattern 4, only 2 were classified as expected and 48 were classified as being pattern 3. This evaluation indicated that there was no uniformity in the parameter definition and that many of the images were simulated in the proximity of the threshold between 2 patters. The artificiality aspect of the images contributed to this classification divergence. This result served as a base so that a new parameter value set was defined and new structure construction control rules were established.

Table 1: Classification result of the image databases 1 and 2 by the radiologists 1 and 2. Each database was simulated with 200 images, being 50 to each pattern (P1, P2, P3 and P4).

Radiologist	**Database 1**				**Database 2**			
	P1	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**
1	80	40	73	7	50	50	50	50
2	78	42	70	10	100	50	48	2

ISSN: 1727-1983

The images of the third database revealed an improvement of the image visual aspects, as comparison of figure 3 with figure 4 shows. The classification result made by radiologists 1,2, and 3 may be seen on table 2. There is direct concordance between the classification of radiologists 1 and 3 and what was simulated. The evaluation result of radiologist 2 shows that the concordance between what was classified and what is expected improved in relation with the previous database, however the expected control is still distant.

The fourth database, with 200 images, was simulated. Radiologist 3 did not participate in the parameter definition. The classification result made by each radiologist can be seen on table 2.

Table 2: Classification result of the image databases 3 and 4 by the radiologists 1, 2 and 3. Each database was simulated with 200 images, being 50 to each pattern (P1, P2, P3 and P4).

Radiologist	Database 1				Database 2			
	P1	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**
1	50	50	50	50	50	50	50	50
2	91	46	28	35	50	50	52	48
3	50	50	50	50	50	50	50	50

This time there was complete concordance among what was expected and the classification carried out by radiologists 1 and 3 and 99% concordance by radiologist 2.

Classification results of the fourth database simulated images in the ACR BI-RAD™ density patterns revealed that the mammography simulation system has a good qualitative performance, therefore the 3 radiologists, with different radiology school backgrounds, arrived at a good concordance in the simulated image classification.

Qualitative Evaluation: the mammographic density classification software according to ACR BI-RADS™ density pattern was used to qualitatively evaluate the simulated images. Five images from each of the third database pattern, chosen randomly, were used in the classification according to the density patterns. Results are shown on the figure 6. Evaluating the 20 images, it was defined that the density pattern 1 has density variation between 0 and 0.377, pattern 2 has density variation between 1.5768 and 4.79, pattern 3 has density variation between 6.42 and 8.69 and pattern 4 has density variation between 12.72 and 13.56. All images were classified as expected and there was no intersection among the patterns. Intersection may occur when there are images in the decision border line between a pattern and another.

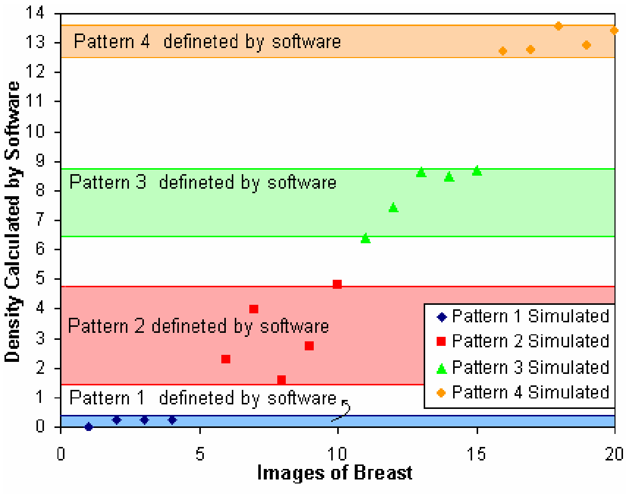


Figure 6: Classification result of the third database simulated images obtained by the mammographic density classification software[13] according to ACR BI-RADS™ density pattern.

The same procedure was adopted for the 40 images of the database 4, where 10 images of each pattern were randomly chosen. Classification result is found on the figure 7. The density variation to pattern 1 occurred between 0 and 0.7287, to pattern 2 occurred between 2.77 and 7.04, to pattern 3 occurred between 8.71 and 11.09 and to pattern 4 occurred between 11.66 and 15.18. Only one of the images does not match with the expected, in other words, it was simulated as being pattern 4 and it was classified as being pattern 3. Moreover, there are images from these databases that are in the threshold between patterns 3 and 4, what reveals that the parameter values used to make the structures were defined in a larger range.

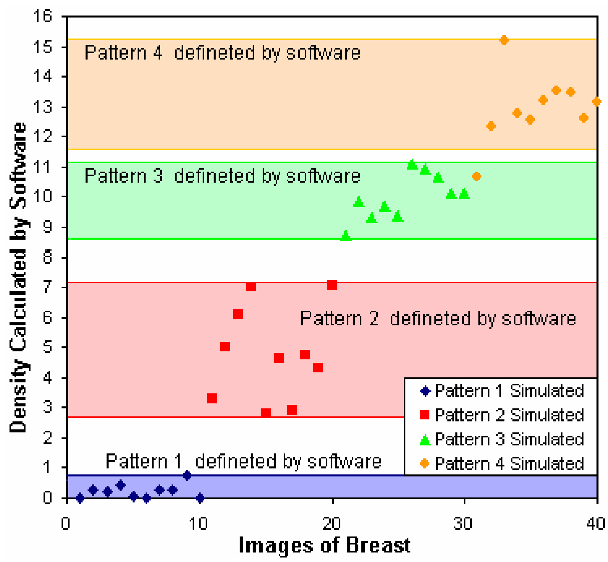


Figure 7: Classification result of the fourth database simulated images obtained by the mammographic density classification program according to ACR BI-RADS™ density pattern.

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Qualitative evaluation revealed that there is a good simulated image density distribution. The control over the pattern choice, to be simulated, occurs as expected, revealing that it is possible to simulate images to a chosen pattern, defining breast structure quantities and sizes, conduct that match with the organ biological structure.

Conclusions

Control over the breast simulation and its internal structures can be obtained with relative easiness, since it is possible to generate four image databases modifying the value range of few parameters. The major difficulty is in the early definition of the value ranges adequate to these parameters, therefore they must conciliate math interpretation of the models with anatomical shapes and quantities. On the other hand, when value ranges that satisfy a certain necessity are defined, they can be registered and used whenever it is needed. It must be highlighted that the value ranges are defined in a way that guarantees variability in structure confection, thus avoiding identical structure simulation.

A major realism in the final images was possible to obtain with the current simulation model, which facilitates interpretation and classification, besides opening way to new applications.

The capacity of simulating images previously according to ACR BI-RADS™ density patterns was successfully obtained, in this way another step was taken in order to have simulated mammographies that can compound ample and complete databases with the purpose of providing an adequate instrument to the CADs performance evaluation.

Acknowledgments

This work was supported by a research Grant No. 01/02190-4 from Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP in www.fapesp.br) and in part by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES in www.capes.gov.br) and Fundação de Amparo ao Ensino e Pesquisa (FAEP in www.faep.org.br).

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