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Improving mammographic lesions' characterization through the combined use of different fractal dimension measures

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Abstract— **it is known that the malignancy of breast lesions is strongly correlated with their shape; the more irregular the lesion is, the more malignant it tends to be. For this reason, CAD systems aimed at assisting the classification of breast lesions often rely on quantitative measures, such as fractal dimension (FD), which can help characterizing the smoothness (or the roughness) of the lesion's shape (1).**

The main purpose of this work is to assess if the concomitant use of the traditional FD measure (which we designate by "contour FD") with a new proposed FD measure (which we designate by "area FD"), both computed through the box-counting method, can improve the classification of lesions according to the BIRADS (Breast Imaging Reporting and Data System) scale. Both FD measures were calculated: *i*) directly from manually segmented lesions, and; *ii*) after applying a region growing/erosion algorithm to the manually segmented lesions, totaling therefore four FD measures. A fifth FD measure, based on the normalized difference between the two area FD measures indicated before, was also computed. We have also investigated if the combined use of contour and area FD can improve the differentiation of breast lesions relative to their type.

Results indicate that the "traditional" contour FD is a useful measure in the differentiation of lesions according to the BIRADS scale and type (mainly breast benign masses, microcalcifications and distortion areas or irregular densifications), although, in some situations, errors occur. The combined use of contour FD with the four proposed FD measures can improve the classification of lesions according to the BIRADS scale. Results also indicate that the differentiation of lesions relative to their type can also be improved by the combined use of contour and area FD measures.

I. Introduction

Computer-Aided Diagnosis (CAD) systems can assist the detection and the differentiation of benign and malignant lesions, increasing the performance of breast cancer diagnosis (2). They help overcoming the main confounding factors that may hinder the detection of these lesions by the clinicians, including eyestrain, environmental issues like illumination, poor image quality, lack of comparative studies and, in some cases, physician experience (3). Some CAD systems used to assist lesion classification rely on quantitative measures that characterize the shape of the lesion, such as fractal dimension (FD) (1). This choice is due to the fact that the malignancy of a breast lesion is strongly correlated with its shape; the more irregular the lesion is, the more malignant it tends to be.

The fractal concept was introduced by Benoit Mandelbrot in the 1970's, with the aim of describing dynamic systems (4). A fractal is defined as a form with self-similarity at all scales and levels of magnification (5); in other words, it is a form composed by transformed copies of itself (4). The interesting properties of some fractals, namely the fact that the limit of their contour size, as one increases the magnification level, is infinite, while the limit of their area value is zero, lead to the definition of FD.

FD can be computed through the box counting method, which consists in partitioning the image into square boxes of equal size and then count the number of boxes that contain at least one pixel of the contour. The process is repeated partitioning the image space into boxes of progressively smaller sizes (this is related to a parameter called the *magnification index*) (1). The FD measure is then obtained from the slope of the best-fitting straight line to the graph plotting the logarithm of the number of boxes *counted* versus the logarithm of the magnification index (1). FD has been used to differentiate breast lesion, such as microcalcifications, benign and malignant nodes (5). Some authors suggested this approach due to the similarity between breast tissue and synthetically generated fractal forms (4).

In this work, we assess whether the combined use of the traditional FD measure (which we designate by "*contour FD*") with four proposed FD measures, can improve the classification of breast lesions according to the BIRADS (Breast Imaging Reporting and Data System) scale. We designated the first of these new FD measures by "*area FD*" due to the fact that, in the box-counting method, it is calculated counting the number of boxes that contain *at least one pixel of the lesion* and not *at least one pixel of its contour*. The next two FD measures are equal to the previous ones (contour and area FD) but they are calculated after applying a region growing/erosion algorithm on the manually segmented images. This approach enables the recalculation of the two initial FD measures after applying an image processing tool that is not fully reversible; if the lesion is regular in shape, the initial and the final FD values shall be similar; otherwise, they may differ significantly. The last FD measure is based on the normalized difference between the two area FD measures indicated before. We have also assessed if the differentiation of breast lesions according to their type could be improved by the combined use of contour and area FD's.

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II. Materials and Methods

A. Images

In this study, we used 230 mammographic images of breast lesions, belonging to female (98,3%) and male (1,7%) patients, aged between 24 and 89 years (mean 55,2 years). The distributions of lesions according to the BIRADS scale and type are presented in Tables I and II.

TABLE I. Distribution of lesions according to the BIRADS scale

BIRADS scale	2	3	4	5
# of images (*n*)	181	26	6	17

TABLE II. Distribution of lesions by type

Lesion type	**# of images**
Benign nodes (BN)	133
Microcalcifications (M)	16
Encapsulation area outlining nodularity (Enc.)	44
Calcifications (C)	13
Higher densification areas (HDA)	5
Irregular densification areas (IDA)	15
Distortion nodes with spiculated contours (DN)	5

The images' exclusion criteria were: *i*) the BIRADS 1 classification; *ii*) lesions visible in only one of the two incidences; *iii*) incomplete lesion on the selected image; *iv*) difficulty in defining lesion localization, and; *v*) other types of lesions such as breast tissue architecture distortion, chirurgical scars or breast inflammation/infection.

B. FD measures

The FD measure, *D*, is calculated through the box-counting method (1), applying the equation presented below

$$D = \lim_{s \to 0} \frac{\log(N(s))}{\log(1/s)}, \quad (1)$$

where $N(s)$ is the number of counting boxes, and $1/s$ is magnification index for each partition (from 64 to 2 pixels). The *D* value corresponds, therefore, to the slope of the best-fitting straight line to the graph plotting the logarithm of $N(s)$ versus the logarithm of $1/s$. The difference between contour and area FD relies on the boxes that are considered for the $N(s)$ term; in the former, only the boxes that contain at least one pixel of the contour of the lesion are considered; in the latter, all boxes that contain at least one pixel of the lesion itself are considered – see Fig. 1.

As mentioned before, we have also computed different FD measures after the application of a conventional growing/erosion algorithm. The growing operation was applied for 20 consecutive iterations, followed by the same number of erosion iterations; both operations were performed considering the 8 nearest neighbors of each pixel – see Fig. 2.

FIGURE 1 Schematic illustration of the difference between boxes that lie in the lesion's contour (A/C) and boxes that belong to the lesion (B/D), for 2 different box sizes (A, B – C,D) .

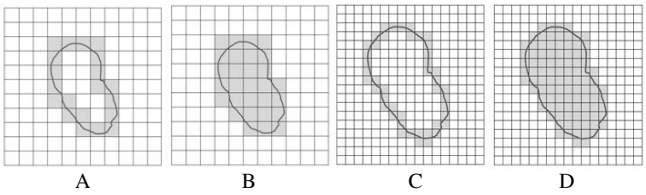

FIGURE 2 Example of A conventional growing/erosion algorithm applied in a benign (A) and in a malignant (B) lesion. *LEFT COLUMN*: initial lesions; *MIDDLE COLUMN*: after growing; *RIGHT COLUMN*: after erosion applied to second column's images.

Therefore, we ended up with five FD measures, namely: contour FD (FD0), area FD (FD1), contour FD after lesion growing/erosion (FD0GE) and area FD after lesion growing/erosion (FD1GE); as mentioned before, the fifth FD measure, FD2, yields the normalized difference between FD1 and FD1GE values, according to the equation

$$FD2 = \frac{FD1GE - FD1}{FD1}. \quad (2)$$

C. Image processing

The 230 images were manually segmented by an expert radiologic technologist. Subsequently, the 5 FD measures were applied to each image.

D. Statistical testing

In this work, we have conducted two types of tests. In the first one, we have assessed if the five proposed FD measures can help classifying the lesions according to the BIRADS scale; in the second, if the FD0 and FD1 measures can help distinguishing lesions according to their type.

For both types of tests, we started by assessing if the FD values for each category (BIRADS value or lesion type) are normally distributed, using the Kolmogorov-Smirnov (K-S, for $n \geq 50$) *or* the Shapiro-Wilk (S-W, for $n < 50$) tests. However, we have always observed that, at least for one of the categories, the FD values did not follow a normal distribution. Therefore, the Kruskall-Wallis (K-W) test, aimed at comparing *k*-independent groups was always

employed, as well as the Mann-Whitney (M-W) test, aimed at performing multiple comparisons on a two-by-two basis.

III. Results and Discussion

A. FD measures vs. BIRADS scale

Table III presents, for the different FD measures, the BIRADS categories that do not follow a normal distribution according to the S-W and the K-S tests, and the *p* values obtained through the K-W test (the corresponding mean and SD values of FD measures are presented in appendix – Table A.1).

TABLE III. Indication of the BIRADS categories that do not present a normal distribution, according to the S-W and K-S tests, and the *P* values obtained through the K-W test.

FD measure	BIRADS		K-W *p* values
	S-W	K-S	
FD0	3	2	0.000
FD1		2	0.081
FD0GE	5	2	0.000
FD1GE		2	0.006
FD2	3,5	2	0.000

From the *p* values obtained with the K-W test we can see that only FD1 values do not differ from each other according to the BIRADS scale. Therefore, the subsequent M-W test was applied only to FD0, FD0GE, FD1GE and FD2 measures. The results are shown in the following tables (IV to VII; the (≠) and (=) signs indicate, respectively, if the corresponding FD measure can distinguish, or not, the BIRADS level indicated in the row from the one indicated in the column).

TABLE IV. M-W test results (*P values*) relative to the BIRADS scale obtained from FD0 values.

FD0	BIRADS 3	BIRADS 4	BIRADS 5
BIRADS 2	0.000 (≠)	0.001 (≠)	0.000 (≠)
BIRADS 3		0.067 (=)	0.008 (≠)
BIRADS 4			0.753 (=)

TABLE V. M-W test results (*P values*) relative to the BIRADS scale obtained from FD0GE values.

FD0GE	BIRADS 3	BIRADS 4	BIRADS 5
BIRADS 2	0.003 (≠)	0.002 (≠)	0.000 (≠)
BIRADS 3		0.020 (≠)	0.087 (=)
BIRADS 4			0.172 (=)

TABLE VI. M-W test results (*P values*) relative to the BIRADS scale obtained from FD1GE values.

FD1GE	BIRADS 3	BIRADS 4	BIRADS 5
BIRADS 2	0.070 (=)	0.597 (=)	0.002 (≠)
BIRADS 3		0.562 (=)	0.021 (≠)
BIRADS 4			0.042 (≠)

TABLE VII. M-W test results (*P values*) relative to the BIRADS scale obtained from FD2 values.

FD2	BIRADS 3	BIRADS 4	BIRADS 5
BIRADS 2	0.000 (≠)	0.000 (≠)	0.000 (≠)
BIRADS 3		0.009 (≠)	0.016 (≠)
BIRADS 4			0.327 (=)

As we can see from Tables IV to VII, the combined use of the different FD measures allows, at least once, the differentiation of all the BIRADS categories from each other. This is best seen if one notices that all the six pairs of compared BIRADS levels (2 from 3,…, 4 from 5) have a (≠) sign in at least one of the four tables.

B. FD0 and FD1 vs. lesion type

Results indicating the lesion types that do not follow a normal distribution according to the S-W and the K-S tests, and the *p* values obtained through the K-W test, are given in Table VIII (the corresponding mean and SD values of FD0 and FD1 measures are presented in appendix – Table A.2).

From the right column of Table VIII, we can see that both FD0 and FD1 measures' values differ from each other according to the lesion type. The M-W test was, therefore, applied for both FD measures. The results are shown in the Tables IX and X (as for Tables IV to VII, the (≠) and (=) signs indicate, respectively, if the corresponding FD measure can distinguish, or not, the lesion type indicated in the row from the lesion type indicate in the column).

TABLE VIII. Indication of the Lesion types that do not present a normal distribution, according to the S-W or K-S tests, and the *P* values obtained through the K-W test.

FD measure	Lesion type	K-W *p* values
	S-W (or K-S)	
FD0	HDA, IDA, C, ENC	0.000
FD1	HDA	0.000

HDA – Higher densification areas; IDA – Irregular densification areas; C – Calcifications; Enc. – Encapsulation area outlining nodularity.

TABLE IX. M-W test results (*P values*) relative to lesion type, obtained from FD0 values. See legend on lesion types on footnote[1].

FD0	M	Enc.	C	HDA	IDA	DN
BN	0.000 (≠)	0.751 (=)	0.037 (≠)	0.125 (=)	0.000 (≠)	0.002 (≠)
M		0.000 (≠)	0.000 (≠)	0.005 (≠)	0.000 (≠)	0.001 (≠)
Enc.			0.108 (=)	0.101 (=)	0.000 (≠)	0.002 (≠)
C				0.571 (=)	0.008 (≠)	0.085 (=)
HDA					0.072 (=)	0.142 (=)
IDA						0.965 (=)

TABLE X. M-W TEST RESULT (*P VALUES*) RELATIVE TO LESION TYPE, OBTAINED FROM FD1 VALUES. SEE LEGEND ON LESION TYPES ON FOOTNOTE[1].

FD1	M	Enc.	C	HDA	IDA	DN
BN	0.000 (≠)	0.000 (≠)	0.140 (=)	0.136 (=)	0.114 (=)	0.058 (=)
M		0.000 (≠)	0.000 (≠)	0.000 (≠)	0.000 (≠)	0.001 (≠)
Enc.			0.000 (≠)	0.794 (=)	0.079 (=)	0.597 (=)
C				0.031 (≠)	0.008 (≠)	0.012 (≠)
HDA					0.230 (=)	0.221 (=)
IDA						0.570 (=)

We can see from Tables IX and X that none of the FD measures was able to, by itself, differentiate all the lesion types from each other, although FD0 is the one that presents the best results. However, Table XI indicates that the combined use of both FD measures reduced the number of lesion type pairs that remained undistinguishable from each other; these are indicated by the darkened table bins containing the "(=)|(=)" sign.

TABLE XI. COMPARISON OF THE M-W TEST RESULTS, RELATIVE TO LESION TYPE, OBTAINED THROUGH THE COMBINED USE OF FD0 AND FD1 MEASURES.. DARKENED RECTANGLES CONTAINING THE "(=)|(=)" SIGN INDICATE PAIRS OF LESION TYPES THAT WERE NOT DISTINGUISHED USING BOTH FD MEASURES. A "(≠)|(=)" SIGN, FOR EXAMPLE, INDICATES A PAIR OF LESION TYPES THAT WAS DISTINGUISHED WITH FD0, BUT NOT WITH FD1. SEE LEGEND ON LESION TYPES ON FOOTNOTE[1].

FD0/1	M	Enc.	C	HDA	IDA	DN
BN	(≠)|(≠)	(=)|(≠)	(≠)|(=)	(=)|(=)	(≠)|(=)	(≠)|(=)
M		(≠)|(≠)	(≠)|(≠)	(≠)|(≠)	(≠)|(≠)	(≠)|(≠)
Enc.			(=)|(≠)	(=)|(=)	(≠)|(=)	(≠)|(=)
C				(=)|(≠)	(≠)|(≠)	(=)|(≠)
HDA					(=)|(=)	(=)|(=)
IDA						(=)|(=)

The obtaining of results that are not statistically different when attempting to differentiate high densification areas from other lesions, such as encapsulation areas outlying nodularity, irregular densification areas or distortion nodes with spiculated contours, or even from benign nodes, can be due to small sample size of some of these lesions (HDA *n*=5; IDA *n*=15 and DN *n*=5) or to the fact that some of these lesions are indeed difficult to distinguish from each other.

IV. CONCLUSION

The combined use of different FD measures can be a valuable approach to the classification of breast lesions according to the BIRADS scale or to their differentiation according to type. Relatively to the first objective of this work, the best results were obtained using the FD2 and FD0 measures, which is demonstrated by the number of bins in Tables IV to VII with the (≠) sign. However, it is when the different FD measures are combined that one gets the best results, as mentioned before. Relatively to the second objective of this work, one observes that the traditional FD0 measure yields better results than the proposed FD1 measure, but their combined use can improve the capacity of distinguishing lesions according to their type. However, we think that the conclusions relatively to this objective are difficult to generalize due to the limited number of samples for some of the lesion types. Therefore, we are increasing the number of examples in our database before conducting new tests on this issue.

These new tests will also include an evaluation on the influence of the growing/erosion algorithms in the final outcome of the proposed FD measures, and a quantitative comparison with other reported morphometrics methods.

[1] BN – Benign nodes; M – Microcalcifications; Enc. – Encapsulation area outlining nodularity; C – Calcifications; HDA – Higher densification areas; IDA – Irregular densification areas; DN – Distortion nodes with spiculated contours.

APPENDIX

TABLE I. MEAN AND SD VALUES OF THE DIFFERENT FD MEASURES RELATIVELY TO THE BIRADS SCALE.

	BIRADS 2	BIRADS 3	BIRADS 4	BIRADS 5
FD0	1.01±0.03	1.04±0.02	1.07±0.05	1.06±0.03
FD1	1.80±0.14	1.85±0.04	1.82±0.04	1.86±0.03
FD0GE	1.00±0.00	1.02±0.00	1.03±0.01	1.03±0.01
FD1GE	1.80±0.14	1.86±0.03	1.85±0.03	1.88±0.03
FD2	0.002± 0.006	0.005± 0.005	0.014± 0.009	0.009± 0.005

TABLE II. MEAN AND SD VALUES FOR FD0 AND FD1 MEASURES RELATIVELY TO LESION TYPE. SEE LEGEND ON LESION TYPES ON FOOTNOTE[1].

	BN	M	Enc.	HDA	IDA	DN
FD0	1.02± 0.03	0.96± 0.04	1.02± 0.02	1.04± 0.04	1.07± 0.04	1.06± 0.03
FD1	1.83± 0.06	1.42± 0.12	1.88± 0.04	1.79± 0.07	1.87± 0.07	1.87± 0.01

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