Identification of space-occupying lesions in medical imaging of the kidney: A review.

Keywords: kidney, renal tumor, medical imaging, magnetic resonance imaging, ultrasound, computed tomography.

INTRODUCTION

Usually, the kidneys can be affected by renal masses or space-occupying lesions (LOE). When reference is made to the term renal mass, all benign and malignant processes that occupy, distort and affect the renal parenchyma and its environment are included, regardless of etiology, shape and volume. Therefore, renal masses include all cystic formations (abscesses), calculi, pseudotumors, neoplasms, inflammatory diseases and traumatic lesions. Thus, for the evaluation of cystic renal masses in medical imaging, according to their characteristics such as their wall (thin, irregular, thickened), septa (thin, irregular, thickened), borders (defined or not) and size, classifications such as Bosniak's classification shown in Table 1 are used, which classifies renal cysts into five categories based on the appearance of the image, to help predict whether it is a benign or malignant tumor[1] .

Table 1

Classification of Bosniak Fuente Quiroga et al. [1]

Bosniak Category	Features	Attitude
I	Simple benign cyst with a very thin or thin wall containing no septa, calcification or solid components. It has water density and is not enhanced by contrasting material.	Benigno
II	Benign cyst that may contain some very thin or thin septa. There may be fine calcification in the wall or septa. Lesions <3cm with uniformly high attenuation, well-defined borders and no contrast enhancement.	
III	These cysts may contain more very thin or thin septum. Minimal enhancement of a very thin or thin septum or wall may be seen on contrast. There may be minimal thickening of the septum or wall. The cyst may contain calcification, which may be nodular and thick, but there is no contrast enhancement. There are no soft tissue elements that enhance with contrast. This category also includes renal lesions ≥3cm. Totally intrarenal, no contrast enhancement and high attenuation. These lesions have, in general, well-defined borders.	A small proportion are malignant.
IV	These lesions are indeterminate cystic masses with thickened frregular otabic walls in which contrast enhancement can be observed.	Malignant in >50% of the lesions.
V	These lesions are clearly malignant cystic lesions that contain soft tissue components that are enhanced by scintigraphy.	

Any LOE, regardless of its etiology, behaves with changes in shape and volume, with vascular alterations and with the creation of a compartment syndrome on a larger or smaller scale. [2] . The diagnostic verification of these effects is performed by Ultrasonography and Doppler ultrasound, Computed Tomography (CT) studies without and with contrast medium, Intravenous Urography (IVU) and Magnetic Resonance Imaging (MRI)[3] . By way of illustration, Figure 1 shows various cystic formations in an image acquired by MRI modality. [4] .

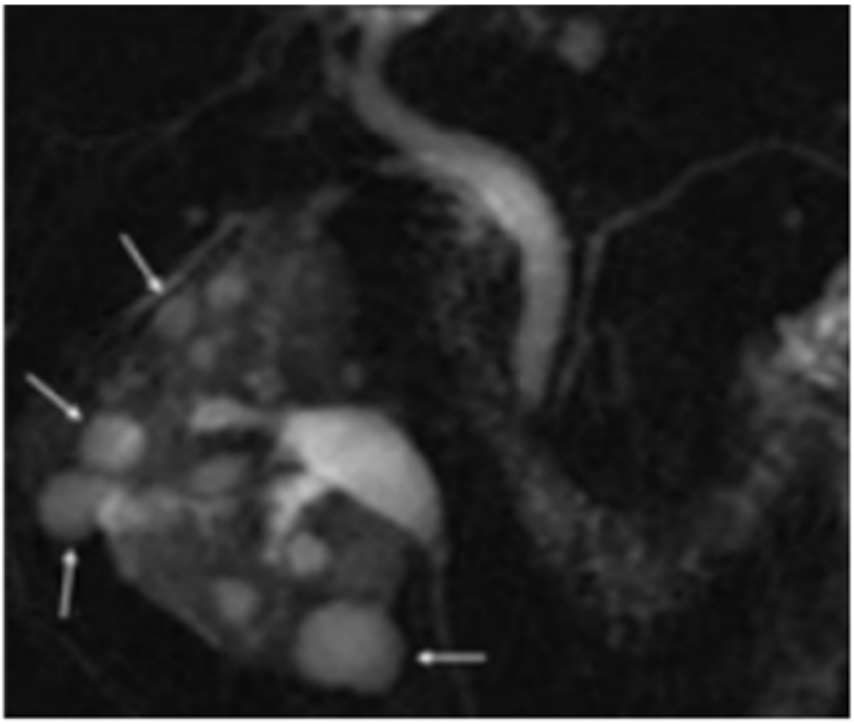

Figure 1

Axial view of renal space-occupying lesions identified as cysts, indicated by the arrows in the image. Source: Tonolini et al. [4] .

Additionally, it is necessary to point out that one of the most important LOE, due to its great impact on a patient's health and finances, is renal tumors (RT), a retrospective view of which can be reviewed in the article developed by Ameri et al.[5] .

On the other hand, the World Health Organization (WHO), through the Global Cancer Observatory (GCO). [6] , reported that in 2018 there were 403,262 cases of kidney cancer in the world (Figure 2); while more than 21 thousand new cases are diagnosed each year in Latin America.

CAncer	Number	Uncertainty interval	Gross rate *	ASR (World)
All cancers	18078 957	[17493000.0-18684500.0]	236,9	197,9
bladder	549393	[529899.0-569604.0]	7.2	5.7
Brain, central nervous system	296851	[282359.0-312086.0]	3.9	3.5
Chest	2088849	[2003730.0-2177580.0]	55.2	46.3
Cervix	569847	[545771.0-594985.0]	15.1	13.1
Colorrecto	1849 518	Not available	24.2	19.7
Uterine body	382069	[375428.0-388827.0]	10.1	8.4
Gallbladder	219420	[207100.0-232473.0]	2.9	
li∩Hodgkin's disease	79990	[72456.8-88306.4]	1.0	0.97
Hypopharynx	80608	[72503.2-89618.9]	1.1	0,91
Kaposi's sarcoma	41799	[30936.3-56475.9]	0.55	0.50
Kidney	403262	[387315.0-419865.0]	5.3	4.5 4.5
Larynx	177422	[165998.0-189632.0]	2.3	2.0

Figure 2 .
Estimated new cases of renal cancer in 2018, worldwide, both sexes, all ages. Source: Global Cancer Observatory (GCO)[3] .

Additionally, in Spain, according to the Spanish Society of Medical Oncology, renal cell carcinoma (RCC) is the most frequent solid lesion in the kidney, representing approximately 90% of all malignant renal tumors, with a rate of 2-3% of these malignant tumors in adults. [7] . Thus, each year there are 7,300 new cases of renal cancer, causing more than 2,100 deaths, and according to the scientific society it is estimated that in 2020, 1,300 more cases will be diagnosed than in 2019. [6] . On the other hand, in Colombia, in 2018, 101,893 cases of cancer were presented of which 47,876 cases correspond to the male gender; while 54,017 cases are linked to women[6] . However, very few statistics are currently reported on renal cell cancer in the Colombian population. One of them, is the one published by the National Institute of Health of Colombia, which reports the incidences of the different types of cancer, in the population of subjects under 18 years of age, per 100000 inhabitants between the years 2015 to 2018, showing Acute Lymphoid Leukemia cancer as the one with the highest incidence[8] .

Although kidney cancer is not one of the most recurrent cancers in the population, it is a type of cancer that is generally asymptomatic in its initial stages and, therefore, its early diagnosis is more difficult. In this sense, according to the Colombian Society of Urology, many renal masses are not palpable until the later stages of the disease, that is, more than 50% of CRC are detected by chance in imaging tests to investigate different symptomatic pictures[9] . Another feature that can make detection complex is that kidney cancer is not a single disease, but is composed of several different types of cancer classified by histology that are disparate in presentation, clinical course and genetic basis[9] .

Today, thanks to advances in technology, organs can be imaged for LOE, but even so, in the case of renal tumors, it is difficult to differentiate between benign and malignant tumors[10] . Additionally, radiological studies based on CT, US and MRI can be used to classify both renal and non-renal tumors[11] .

For this reason, in this article a systematic review was carried out to describe the various advances that have been reported in the scientific literature regarding the segmentation of the kidney and its LOE in medical images from different sources such as computed tomography, magnetic resonance imaging and ultrasound. Finally, based on the documentary review of the work that the academic and scientific community has been developing regarding the automatic recognition of renal tumors, it was possible to establish a comparative analysis of the types of images, automatic techniques and metrics used in the various studies documented in this work, managing to determine which are the most used in the processing of medical images for the segmentation of the kidney and its LOE.

MATERIALS AND METHODS

The comprehensive interpretative paradigm was used, employing the review method through the content analysis technique. In the study, data were collected and selected in the form of articles or units of analysis, related to the object of study and by means of a comparative technique the relevant information was synthesized, allowing the identification and analysis of both the fundamentals of manual and automatic techniques involved in the approach to the human organ called kidney and its space-occupying lesions, as well as the antecedents, related to this subject, reported in the literature. For this purpose, the following phases were developed:

Identification of the theoretical foundations related to the methods of characterization and/or segmentation of the aforementioned organ and its LOE in their manual (clinical context) and automatic (bioengineering context) versions.

Approach of the background by means of a critical review of units of analysis based on articles consulted in different specialized databases such as PubMed, academic Google, academic databases and high impact journals with quartile 3 or higher. Specialized document management software was used in the search.

Classification of 28 documents according to the scope, year and context of the research, from 2005 to 2020. In the search, the types of documents were classified into document review articles and articles presenting proposals for automatic techniques for the segmentation of both the kidney and its LOE.

RESULTS

Main contributions in the clinical-surgical and bioengineering contexts related to the approach to the kidney and its space-occupying lesions.

Contributions in the clinical-surgical context

Table 2 presents a synthesis of various scientific investigations whose findings have contributed to the generation of relevant information that has leveraged the professional performance of medical specialists in the nephrological area, i.e., in the clinical-surgical context. In it, various resources can be identified that have allowed nephrologists to characterize, in an approximate manner, both the kidney and the pathologies involving renal space-occupying lesions.

Table 2

Main contributions in the clinical-surgical context of the articles analyzed.

Reference	Contributions
Agnello et al 12(2020)	It provides information to differentiate malignant and benign renal cysts considering an important number of clinical cases.
Ginmpdy col13(2019)	It provides a clinical guideline for the standardization of imaging tests useful for the evaluation of cysts that occur frequently in children. This research was endorsed by several pediatric societies in Europe and establishes US as the standard imaging modality for the detection of this type of cyst.
|Helenon et al.(2018)14	It proposes the combined use of Bosnicak (CB), US and CT (with and without contrast) to characterize, especially, small cysts.
Bartlet et al 15(2015)	They point out as the main finding the causal association between thiatamide with the drug crizotuiib and the development of renal cysts in patients with non-small cell lung tumors.
Elnoyan16(2009)	Refuteι∑an the idea of "suitability" of both US and CT for the detection of a good variety of renal cysts (simple, complex, inherited, asymptomatic or not).
Israd and Bosniak17(2005)	Presents a detailed description of BC for renal tumors and exemplifies its use.
Graumann et al 18(2013)	Evaluates 8402 renal CT cases highlighting the usefulness of CB in the characterization of moderate-complicated renal cysts and their surgical approach.
Ahmady col 19(2019)	It indicates that the apparent diffusion coefficient is an adequate predictor for the prognosis and evolution of renal carcinoma, considering MR images.
Ishigamiy col 20(2015).	Identify cellular differentiation in renal tumors to establish the growth intervals of these tumors and their overlap in multifocal tumors.
Walsh et al.21(2010)	Reports the clinical case of a patient with renal cyst niptuia secondary to trauma.
Tonolini et al4(2015)	In patients with chronic renal insufficiency, spontaneous bleeding may influence renal LOE apaiition due to renal tissue involvement.
Peters et al.22(2013)	Ara1iτa 548 adrenal tumors to establish the invaluable ability of the various radiological modalities to detect the growth of this type of tumor.
Rheey col 23(2016)	It establishes the usefulness of positron emission tomography (PET) during the preoperative stage of renal cell carcinoma when CT fella in its detection.

Miltiadis et al21 201)	Characterization of radiofrequency, microwave and choroablation-based ablation for the approach to small renal carcinomas.
Mauriy col24(2017)	They identify advantages and disadvantages of ablation and the importance of accompanying these techniques with various medical imaging modalities as well as enhancement processes such as fna-perfusion-aspiration.

Source: Own elaboration.

In summary, the information presented in Table 2 shows the interesting connection that has been established over time between medical imaging modalities and clinical practice, oriented to the approach to the kidney and pathologies derived from the presence of renal LOE, which has always been in line with the guidelines established by the pioneers of this important area of medicine.

Contributions in the context of bioengineering.

Table 3 shows the main findings that have been identified, in the context of bioengineering, after analyzing the references that interconnect the automatic segmentation of the kidneys and their LOE considering strictly proposals, fully automatic, developed using as resources the binomial "computer science-mathematical models".

Table 3

Main contributions in the context of bioengineering of the articles analyzed.

Reference	Contributions
Jin et al 25 (2016).	Develops a technique for three-dimensional (3D) segmentation of the kidney using Hough's formed trails, active appearance models and a random algorithm on 37 renal CT images with a Dice coefficient (De) greater than O S.
Shehata et al 26(2018)	Implements an automatic method for 3D segmentation of the kidney using a Markov-Gibbs random field based technique on 64 renal MRI images with an average De of 0.95 ± 0.01, a Haussdorf distance of 3.9 ± 0.76 mm.
Myionenko and Hatainizadeh 27 (2019)	Presents a technique for kidney and renal tumor (RT) segmentation, in CT, using deep learning based on convolutional neural networks in the context of the kidney tumor segmentation challenge (KiTS-2019). They report a De of 0.97 and 0.81 for kidney and renal tumor segmentation, respectively.
Kimy col 28 (2016)	Characterizes, via volume, polycystic rail phonons by means of a level set based computational technique using 2000 NMR images.
Yaiig et al 29(2018)	Segment the kidney and TR, in CT, using U-Net networks. They report a De of 0.92 and 0.82 for the segmentation of the kidney and TR, respectively.
Klíne et al 30 (2019).	They employ a technique for the segmentation of kidney and renal polycystic LOE, in CT, using proftuitive learning based on fully convolutional neiuoiial networks in the context of KiTS-2019. They report a De of 0.9638 and 0.6738 for kidney and renal tumor segmentation, respectively.
Vu et al 31 (2019).	Segments the kidney and TR, in CT, using TU-Net networks. They report a De of 0.9020 and 0.4080 for kidney and renal tumor segmentation, respectively.
Yin et al 32 (2019).	Segments the kidneys, in US images, using a technique based on a pre-trained neural network of deep learning and contour maps.
Santini and co1 33(2019)	Characterize kidney and TR using U-Net They report a De of 0.96 and 0.74 for kidney and renal tumor segmentation, respectively, in 300 CT images.

Nithya et al 34(2020)	Obtains the morphology of renal calculi, in US, with an agπιραιιiento technique based on the k-means algorithm generating an accuracy of 99.61%.
Litiuev et al 35 (2019).	Effective segmentation of lyphoid aggregates considering biopsy images for kidney transplantation. U-Net is used for this purpose.
Rana et al.36 (2019)	Extract regions of interest, in US images, for the characterization of renal carcinomas and aiigioniiolipornas using a vectoiial support machine.
Heller et al 37(2019)	It uses deep learning to characterize the rifnon and its tumors in 90 CT images reporting a maximum Dc of 0.974 for the organ and 0.923 for the tumor.
Heller et al 38(2019)	This reference describes in detail the KiTS19 challenge and the data used.

Source: Own elaboration.

According to the information shown in Table 3, it can be affirmed that intelligent operators have positioned themselves at the forefront of mathematical-computational algorithms when attempting to generate automatic techniques for the characterization of both the kidney and the space-occupying lesions associated with this organ.

DISCUSSION

The articles analyzed in this article were published between 2005 and 2020 in high impact journals with a high h-index and with 80% of them positioned in quartile 3 or higher, according to the ranking established in Scimago. This indicates the current relevance of formal research related to the kidney and its LOE.

The documentary review allows establishing as a basic finding that the main imaging modality used in the automatic segmentation of the kidney corresponds to **CT** images, followed by MRI images and images obtained by Ultrasound. The greater use of Computed Tomography can be explained from the same characteristics that this technique presents, such as the possibility of providing images of excellent resolution, not requiring invasive processes and not causing pain, allowing to obtain detailed images of different tissues of the body. In addition, the practical process developed for obtaining this type of images is more efficient than MRI which, in turn, is more expensive in monetary terms. However, in Computed Tomography, as shown in Table 4, the effective radiation dose that a patient can receive is around 10 mSv which is equivalent to the dose that a person (on average) receives from background radiation in three years, hence it is contraindicated for patients who cannot undergo high doses of radiation, such as pregnant women, patients with hypersensitivity to iodinated contrasts and/or patients with cardiac, renal or hepatic insufficiency[39] .

Table 4

Background radiation and effective radiation dose in adults for Computed Tomography in Abdominal Region. Source: Radiological Society of North America (RSNA). https://www.radiologyinfo.org/sp/info.cfm?pg=safety-xray

ABDOMINAL REGION	Procedure	Approximate effective radiation doses	Comparable natural background radiation for:
	Computed tomography (CT) -abdomeny pelvis	10 mSv	3 years
	Computed tomography (CT) - abdomen and pelvis, repeated with or without contrast material.	20 mSv	7 artos

	Computed tomography (CT)-colonography	6 mSv	2 years
	Intravenous pyelogram (IVP)	3 mSv	1 year
	Barium enema (lower Gl tract X-ray)	8 mSv	3 years
	Barium study of the upper GI tract	6 mSv	2 years

During the present review, Magnetic Resonance Imaging (MRI) took second place among the imaging techniques used. Unlike CT, MRI is a technique that obtains images of internal organs and tissues through the use of magnetic fields by means of large magnets and radiofrequency waves. The main advantage of MRI compared to CT is that it does not use ionizing radiation, reducing the risks of cancer, but also this technique allows very thin slices, with sub-millimeter precision and, therefore, it can generate high-resolution multiplanar images without the need to change the patient's posture. It should be mentioned that MRI has certain disadvantages such as the long duration of the examination for taking the images, the economic factor since the cost is higher than in the other techniques for obtaining images, and of course there is also the fear and the feeling of claustrophobia that a patient experiences inside the tunnel used in this technique. In the case of ultrasound, like MRI, it has the advantage of the absence of radiation, besides offering a very good visualization of soft tissues and the differentiation between solids and liquids, it is also a cheaper technique but it overlaps anatomical structures, this being its main disadvantage.

Regarding the metrics or performance functions considered in the different studies consulted, it was found that the **Dice Coefficient (Dc)** is the most widely used for the validation of computational models, although other methods are also used, such as Linear Correlation, Bland-Altman analysis, Inter-class Correlation Coefficient, Modified Hausdorff Distance, among others. It is important to note here that the Dice coefficient is a dimensionless quantity, without units of measurement and generates values bounded between zero and unity. The preference for the **Dc** can be explained by the fact that it is a way of establishing degrees of similarity between segmented structures in a more robust, simple and accurate way than the other metrics mentioned. In addition, its interpretation is very intuitive, yielding perfect similarity between manual and automatic segmentations when its value is unity and null similarity if the **Dc** is zero. If, in addition, we add the fact that its computational programming is super simple, then we can affirm that all these characteristics make Dc a very attractive metric and, therefore, of very frequent use.

In addition, there is no doubt that the various automatic techniques considered in the context of bioengineering, especially those linked to artificial intelligence, are increasingly gaining ground in the design of clinical support protocols in synchronous and asynchronous situations that allow clinical specialists to perform their work more efficiently. This is directly in line with the efforts of the international scientific community to promote the appropriate positioning of intelligent techniques in the medical and surgical contexts, thus providing an important resource for specialists to perform their work more effectively and efficiently, which naturally benefits patient health. In a complementary manner, it is also important to visualize the potential of these automatic techniques in various cross-cutting scenarios such as academic, technical, medical, clinical and surgical spaces related to the kidney and its associated diseases.

Finally, it is highlighted the fact that several of the studies or articles, considered in this review, were generated in the framework of the event called Kidney Tumor Segmentation Challenge (KiTS19) which was held together with the International Conference on Medical Informatics and Computer Assisted Intervention (MICCAI) in 2019. These events were created to technologically underpin the processes that clinical experts develop on a daily basis and, therefore, seek to perfect the computational techniques proposed by a significant number of researchers, worldwide, so that in the years to come there will be a diversity of efficient, effective, very well positioned and above all invaluable computational techniques that will contribute decisively to the welfare of the population afflicted by the pathologies arising from space-occupying lesions in the kidney.

CONCLUSIONS

Throughout the development of medicine, various researchers have established the fundamental guidelines that allow clinical specialists to perform their professional work adequately. However, the development of articles of this nature allows us to realize situations that are already beginning to strongly influence this work. In this sense, it can be affirmed that, according to the global panorama described, medical professionals increasingly require the permanent accompaniment of techniques linked to bioengineering, especially in order to perform their work efficiently and respond to the challenges of a highly technological society.

It is also important to point out that technology will never completely displace the wisdom and expertise of qualified personnel in the health sector; on the contrary, this type of resource is gradually becoming the ally required by specialists in this sector to make their work much more efficient.

According to the literature analyzed, it can be seen how the conjunction between the highly developed skills of clinicians and the implementation of computational algorithms based on mathematical models has gained special relevance as a clinical support to the staff of the medical community linked to the nephrological area. This situation is particularly attractive, especially in the process of accurately locating and obtaining both the morphology of the kidney and the LOEs that affect its functioning, as well as in the generation of useful descriptors when attempting to characterize healthy or pathological anatomical structures related to the kidneys of human beings.

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