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Articles Signifying Renogram Processing Practices-A Systematic Review

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Research Article

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Abstract

The renography represents time activity process detected when one measures the activity in the kidneys after the dose injection of radiolabeled radio tracer(e.g.^{99m}Tc- DTPA,^{99m}Tc-MAG3). Interpretation of this renal scan helps to diagnose whether the drainage function from the kidney is normal or abnormal. This renal tracer's data is processed by mathematical models and data processing techniques like Rutland-Patlak and deconvolution methods to produce renograph. This research study is carried out to review previously published research articles incorporating various methods, their applications and image processing algorithms as well as techniques that were applied to process renal radiotracer's transit time data. This review includes various types, advantages, gaps and possible scopes for existing renogram data processing techniques. After analysis process of 142 articles it is found that, maximum of the articles are associated with renal scan's processing methods that are limited to renal patient's related disease categories and having absence of quantifiable measurement and study of parenchymal radio tracer's transit time counted from renal cortex to renal pelvis path while limited numbers of articles are purely related to applied algorithms for detecting obstruction level qualitatively.

I. Introduction

Renography is a time activity curve graphs representing the variations of radioactive counting rate, its uptake and excretion with respect to time within the organ and respective tissues. It is associated with relative renal transit time functions in which a radiopharmaceutical (e.g.^{99m} Tc- DTPA, ^{99m} Tc-MAG3, ^{99m} Tc-DMSA) remains inside the kidney or inside the part of kidney. Transit time's determination at various stages of radioisotope tracing and defining ROI includes vascular transit time (VTT), entire kidney transit time (KTT), and parenchymal transit time [PTT] [1,10].

The Renogrph and its related images can be used to detect normal or abnormal behaviour of both kidneys including renal artery stenosis, urinary path obstruction, renal hypertension and renal transplant but they can't be used to detect the reasons for any abnormality in kidney functions. The Region of interest (ROI) of kidney includes parallel activities of pelvis or parenchyma activity, vascular activity and nonrenal blood vessels activity. Background in ROI specifies presence of radiotracer in blood and interstitial space of the kidney as well as tissues anterior and posterior to the kidney [24]. Many quantitative estimation mathematical methods like Rutland Patlak [28], Matrix Deconvolution, Integral methods etc. are applied to subtract the background and to analyse renal transit time parameters [7,18,20].

Rutland theory and deconvolution process applied to renogram data to generate time activity curve can be considered as a tool to define renogram. Rutland theory simulates an ideal constant infusion renogram. With an assumption that nothing leaves during initial few minutes and blood activity (BA) is proportional to kidney's intake rate.

Blood Activity (BA) = Vascular ROI count – Tissue ROI Count Kidney Activity (KA)

= Kidney ROI counts – Tissue ROI counts

K = Uptake constant (UC) × ∫ BA dt + a × BA

$$\frac{K}{BA} = UC \times \lceil \frac{\int BAdt}{BA\rceil} + a \text{ (Background Subtraction factor)}$$

While Deconvolution matrix method provided renogram could be achieved by injecting standard bolus injection directly into the renal artery avoiding recirculation. Thus, it is a method of calculating the impulse response function of a system when you identify its response to a real input.

$$R_n = I_0H_n + I_1H_{n-1} + I_2H_{n-2} - \underset{th}{-} - - + I_{n-1}H_1 + I_nH_0$$

Where, R_n, I_n and H_n are the I point present in kidney TAC, blood pool TAC and kidney impulse retention function respectively. It was observed that, capacities of these methods are not fully utilized to detect all types of renal tracer's transit time parameters [7,18,20]. Hence, this review is significant to understand existing requirements and overall status of renogram processing techniques.

Ii. Literature Review Scheme

After scanning online and offline materials related to renogram process,142 articles are selected for systematic literature survey in which 106 papers (75%) are included from which 75 papers i.e.53% papers were related to renal scan signal and image processing ,5 papers (4%) were related to compartmental modelling,26 papers (18%) were partially associated with review, summary and comparative studies,36 papers i.e.25% are excluded from reviewing from which 24 papers (67%) were not closely related and 12 (33%) papers found to be of not of full length.

All included research published articles in this study are taken from electronic databases such as Science Direct, SCOPUS, ELSEVIER, Journal of Nuclear Medicine, Journal of Nuclear Medicine and Technology, IEEE proceedings etc.

Maximum published papers were likewise found to be available on National Library of Medicine (PubMed.gov).

Period considered for surveying these articles is chosen from January 1974 to June 2020 and for reviewing purpose, period from January 1974 to September 2019 is considered.

Criterion of Research Articles

Inclusion Criterion	Exclusion Criterion
• Completely/partially related to renal imaging methods. • Completely/partially related to quantitative and statistical analysis of tracer's transit time • Related to renal image background subtraction methods • Satisfiability of results with evidences using maximum samples • Only standard Scopus medical and engineering journals. • Related to comparison among image processing models and simulation. • Related to interpretation among applied methods and validation with diagnosis. • Articles having maximum number of objects as well as addition of various renal diseases.	• Related to criterion selection of radionuclides • Related to paediatric patient samples • Related to defined protocols of radiotracer injection and cases related to half clearance of it. • Related to CT, MRI, PET etc multimodality imaging. • Related to procedure guideline for Diuretic Renography. • Related to articles that mentioned-scan processing methods only in references or abstracts. • Diseases Survey reports, not having full length articles. • Articles that used those processing techniques as a support and not as a tool for justifying results.

Table1. Inclusion and exclusion criteria for article selection

Iii. Research Article Publication Summary

Important reason for considering these published articles is that, they relate to renal failure reasons, role and applications of radionuclide studies, radiotracers classification by their intake and excretion mechanisms as agents for glomerular filtration, tubular secretion or cortical binding.

Also, they assess parenchymal radiotracer's uptake and excretion process, computer created time activity graphs with dynamic visual presentation of change in activity over the whole process. Similarly, they assess various mathematical image and signal processing techniques including its quantitative or statistical analysis.

3.1 Distribution and Analysis of Article's keywords

a. Keywords related to Image Processing

For the search of articles related to renogram processing 43 keywords were selected that were purely related to image processing technics and methods.

From main 43 keywords 7 words (16%) were linked to Rutland-Patlak method, 7 words (16%) were related to statistical methods, 6 words (14%) were associated to Deconvolution techniques,5 words (12%) related to various image types, 4 words (9%) were related to matrix methods and region of interest. 6 words (14%) were correlated to background subtraction techniques and filtration methods, and 8 words (19%) foX4und to be correlated with images noise and segmentation techniques.

b. Keywords related to Renogram parameters

Total 32 words are selected to search articles of renogram processing out of which 10 words (31%) are related to renal function,8 words are related (25%) are related to transit time, 6 words (19%) wee associated to glomerular filtration rate, 8 words (25%) were related to split function and retention function.

c. Keywords related to Radiotracers

Keywords related to radiotracers are distributed in 6 parameters. Out of 38 keywords, 9 words (24%) were related to MAG3, 8words (21%) were related to DTPA,7+7 words (37%) are associated with Technetium radionuclide and 5 words (13%) of renogram isotope while only 2 words (5%) were related to frusemide diuretic.

d. Keywords related to Renal Diseases

Six renal diseases were considered and related keywords are used to search articles. Out of 29 keywords,9 words (30%) were correlated with renal obstructions, 8 words (28%) were related to renovascular hypertension, 4+4 words (28%) were related to renal transplantations,2+2 words (14%) were associated with renal stenosis.

3.2 Research Type

While reviewing various published articles different categories were considered and articles are classified according to availability of required data base, types of data analysis, various methodologies, their applications and limitations, statistical and quantitative analysis using several principles, case studies related to different renal diseases etc. After classification of articles, only articles that are related to renal scan imaging and signal processing techniques along with quantitative and statistical conceptual analysis are focused for reviewing purpose.

Iv. Research Gaps

While reviewing these researches published articles some research gaps were found in them. Those research gaps are discussed and specified as follows:

- Deconvolution method provides parameters of renal transit, such as Mean Transit Time (MTT) which are independent of input function but depends on assumption of time invariance of the range of transit times through kidney. But this state is not fulfilling though region of interest (ROE) parameter though may be considered as an alternative to MTT.
- For transit time curve, filtering average moving filters are normally used in which the value of each element is replaced by a proportioned weighted average of the element itself. Though this technique seems to be too simple, selection of number of filters elements with exact weighting factors is a critical task to implement.
- Till date the iterative method of deconvolution process depends severely on the precision of the first starting point evaluation of tracer's time, as any minor errors can passed onward into the calculation of all subsequent points. This error needs to be removed from process so that every iteration will be correctly and precisely calculated.
- Most of the articles have mentioned calculated tracer's transit time parameters using filtration, background subtraction methods etc. but actual parenchymal tracer transit time from renal parenchyma to renal pelvis yet remain to count and define appropriately.
- Till date in obstructive renal pathology a total renal scan acquisition time of at least 30 minutes (instead of 20-25 minutes which is required for normal renogram) is recommended. This acquisition period needs to be shortened to define and diagnose renal obstruction in earlier diagnosis time so that patient and technician will be comfortable throughout the process.
- GRF and ERPF measurements yet to define for measuring earlier obstruction detection.

In entirely related articles category, dynamic renal scan was achieved with ^{99m}Tc-DTPA and dynamic renal studies were achieved with ^{99m} Tc -DTPA and obtained impulse kidney response function using deconvolution as well as matrix method [2,8], this method is also useful in deriving intrarenal transit time [3].

Rutland derived and applied iterative deconvolution methods for obstructed kidneys renogram with normal flow [16]. Deconvolution and Rutland-Patlak methods are used to evaluate absolute and relative renal intake and its transit rate through the kidney [1, 23].

Linear regression method uses separate tissue and cardiac time activity curve representing background, while multiple regression method involves multiple backgrounds [24,26]. The most accurate ROI for deducting extra-renal tissue action is neighbouring the kidney, rather one pixel away from the kidney and two pixels wide and such background ROI provided integral and slope values with close similarity to the unfilled kidney part [4].

As shown in fig.5.,9(13%) articles found partially related to mentioned topic by utilizing those image processing tools that were used as a support to solve difficulties occurred while understanding renal diagnosis related functioning parameters.

These articles are in the form of reviewing and summarization of data categories as well as comparative study of number of patient's cases. While categorizing remaining 45 articles from exclusive criterion, 33(73%) articles were found to be not closely or partially related to mentioned topic but those articles are found to be related with effects of different radionuclides, types of renal diseases, effective renal plasma flow (ERPF) and glomerular filtration rate (GFR) measurements.12(27%) articles found incomplete in presenting complete concept i.e. with lack of evidences and absence of mathematically correlated results These parameters can be processed by image processing techniques for image frame like image enhancing, segmenting, histogram application, boundary tracking, masking etc. And processed data validation can be done using various statistical methods of regression or correlation.

Design of renogram analysis can be possibly achieved with following steps:

1. Choosing inputs from sequence of frames of patient's renal scans.
2. Selecting standard or normal frame as a reference required to compare with data input.
3. Cropping unwanted edges of renal frame images so that required part only utilized to process.
4. Applying stretching of image to enhance its brightness so that pixels can be easily accessed.
5. Adaptive equalization process is used to improve contrast in images. It varies from steady histogram equalization in the respect that the adaptive method computes several histograms, each equivalent to a separate section of the image, and uses them to reorganise the precision values of the image.
6. Applying contrast enhancement in renal scan image.
7. Recalculating image specifications with statistical properties which helps to detect difference between previous and updated calculation.
8. Removing pixels that are outside of selected region of interest.
9. Applying boundary tracing algorithm to selected ROI.
10. Applying mask on selected each and every sample frame.
11. Calculating sum of brightness level in every frame.
12. Drawing renal activity graph for both left as well as right kidney.
13. Finally counting renal obstruction quantity to determine precise and accurate quantity of renal obstruction state and stage.

After thorough review of 142 articles published from
year 1974 to 2020, 67 papers were found to be focused on applications/implementations of image processing techniques and algorithms, statistical analysis using renal scan data.

With substantial classification of these 67 articles ,36 articles (54%) are related to theoretical design along with implementation ,22 articles (33%) are associated with estimation and comparative study of mathematical methods and remaining 9 articles (13%) were belonging to article reviews and quantification.

Vi. Conclusion

Objective of this reviewing published articles which are purely related to renal tracer's identification, processing and quantification has been achieved by:

a. Focusing on specific keywords related to Renography technique and classifying them in 4 categories including image processing methods, renogram parameters, types of radiotracers and renal diseases.

b. This classification indicates possibility a well as availability of material and information regarding various experiments, methods, results and their validation towards justification of designed and implemented design/algorithm.

c. This review process helped to find out still present gaps between medical expert's needs and processing methods.

Conclusion of some of research articles are categorized and summarized considering authors contribution with probable future scope in table.2. It shows selected specific articles purely related to renogram image processing techniques and mathematical analysis applied to calculate renal tracer transit time activity parameters and future research scope by studying limitations of it.

In each mentioned article, every one's contribution helps to find a better way to improve correct renal diagnosis the field of renogram analysis.

Research article's summary and presented possible future research

Declarations

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- Research involving human participants and/or animals: NA

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Table 2

Table 2 is available in the Supplementary Files section.

Figures

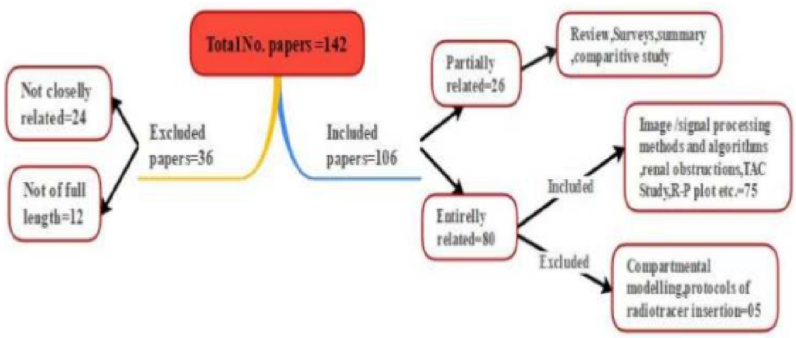

Figure 1

Included and Excluded Research Article Summary

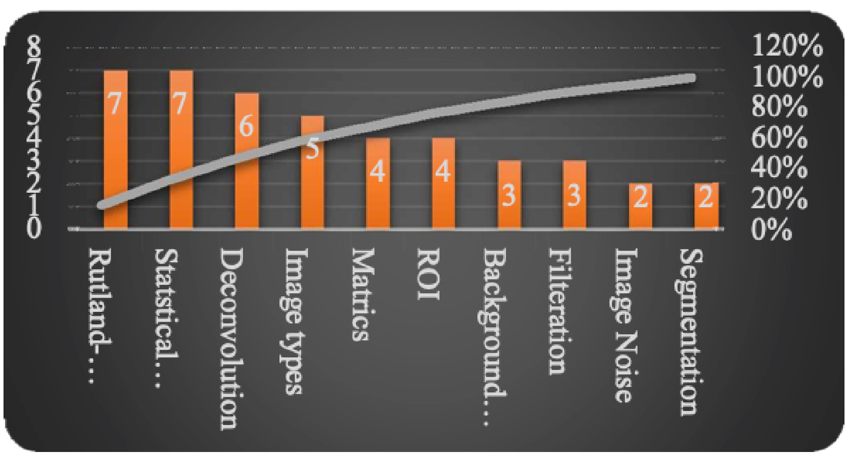

Figure 2

Keywords related to Image Processing

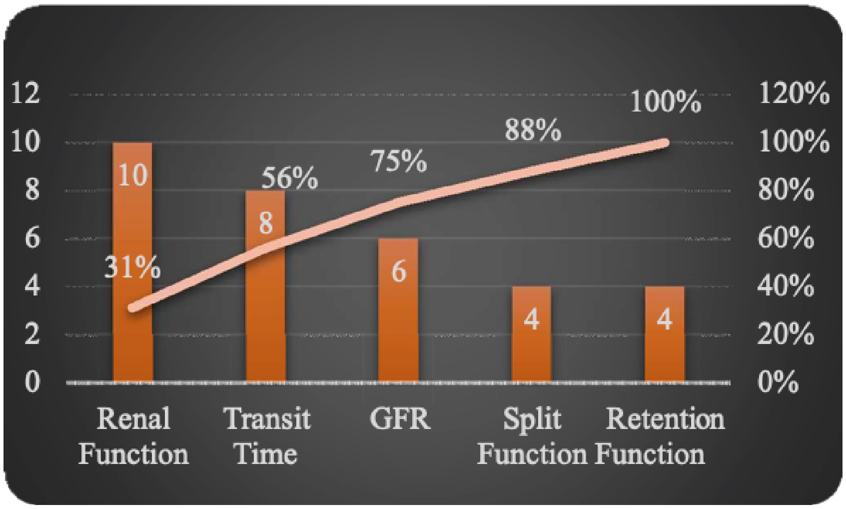

Figure 3

Legend not included with this version

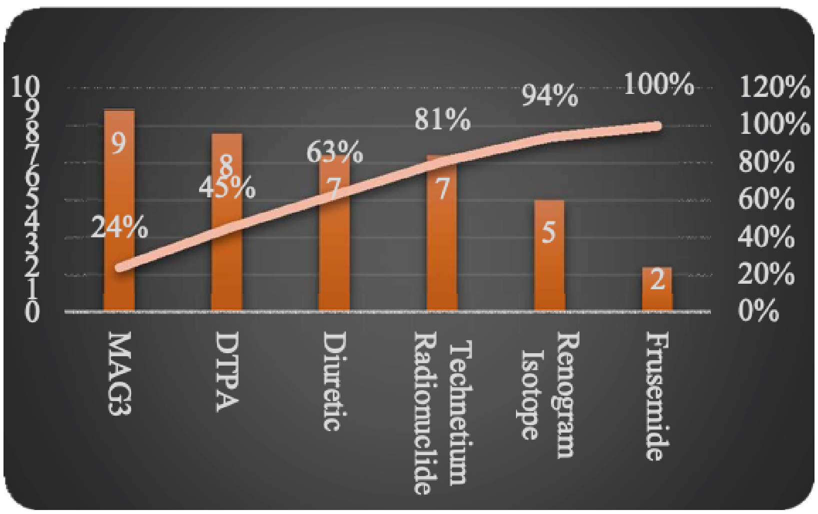

Figure 4

Keywords related to Radiotracers

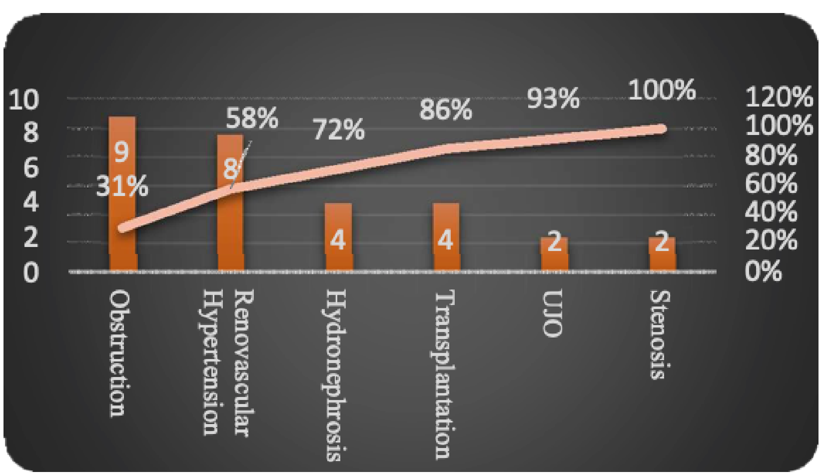

Figure 5

Keywords related to Renal Diseases

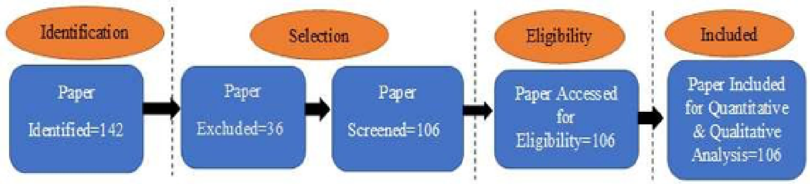

Figure 6

Selection criterion of published articles

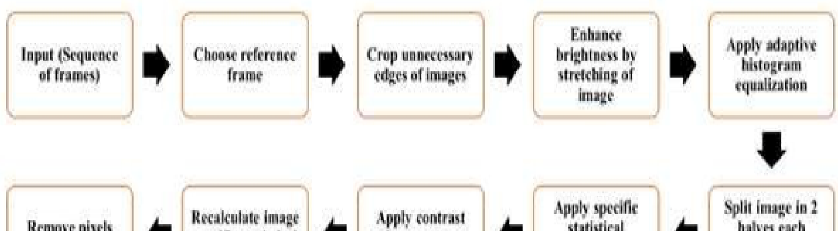

Figure 7

Design of Renogram Processing

Supplementary Files

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- Table2.docx