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RESEARCH ARTICLE

APPLICATION OF MRI- MRI-DIFFUSION-WEIGHTED IMAGING ANDADC VALUES IN ONCOLOGY

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Abstract

DWI, or diffusion-weighted imaging, uses water protons to deliver microscopic information that conventional MRI cannot. DWI quantifies the extracellular, intracellular, and transcellular Brownian motions of water molecules.(1). Quantitative and qualitative measure of DWI that represents the diffusion movements of water molecules in different tissues is the apparent diffusion coefficient, or ADC. ADC is a quantitative measure derived from DWI that integrates the effects of water diffusion and capillary perfusion(2). Compared to benign lesions, malignant tumours typically exhibited diffusion restriction, which is reflected in bright images with high signal intensity and lower ADC values, which are reflected in images with low signal intensity. Therefore, the ADC value aids in distinguishing between benign and malignant tumours. Typically, benign lesions have high ADC values and malignant lesions have low ADC values.These days, diffusion-weighted imaging is used much more often in oncology. DWI has several benefits, including being non-invasive and not requiring a contrast agent. It is a rapid method that yields both qualitative and quantitative data regarding the type of tumour in a matter of minutes. Both the prognosis and the response to treatment can be evaluated. It is possible to distinguish between lesions that recur or persistent fibrosis following chemotherapy or radiation therapy. Additionally, it aids in distinguishing between neoplastic and hyperplastic lymph nodes. Therefore, distinguishing between benign and malignant tumours is the primary function of the DWI/ADC value.

Introduction:-

The movement of water molecules in the extracellular, intracellular, and intravascular spaces in biological tissues is the source of the DWI signal. Significant amounts of the signal on DWI emanate from the intravascular space because tumours have enhanced vascularity. Tissue cellularity and cell membrane integrity are related to the extent of restriction to water diffusion [2]. Malignant tumours typically exhibit hypercellularity and enlarged nuclei. These histopathologic features cause diffusion restriction, which lowers the ADC value by decreasing the extracellular matrix and the diffusion space of water protons in the extracellular areas (6,7). DWI has several benefits, including the

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ability to diagnose and characterisetumours, monitor treatment response, distinguish residual/fibrosis from recurrence, differentiation of hyperplastic nodes from metastatic nodes and require no contrast. Thus, the application of DWI with corresponding ADC values helps in the diagnosis of malignancy of various tissues and organs of the body, like the liver, pancreas, intestine, prostate, ovaries, uterus, breast, bone, lung etc.

Discussion:-

Magnetic field and computer-generated radio waves are used in magnetic resonance imaging (MRI), a medical imaging method that produces fine-grained images of our body's organs and tissues. It is a non-invasive method of examining the body's tissues, organs, and skeleton. It creates detailed pictures of the interior of the body that aid in the diagnosis of numerous illnesses.

The magnetic characteristics of several atomic nuclei are used in the MRI principles. All bodily tissues, including water molecules, contain hydrogen nuclei with single photons. Cells often have a randomly distributed distribution of hydrogen nuclei. The hydrogen nuclei in the patient's cells line up with the powerful magnetic field of the MRI scanner when the patient is in it. Radio waves can be used to rotate the nuclei, which then oscillate in the magnetic field as they balance out. They simultaneously release a radio signal, which the antenna coils pick up. Computers can create detailed images of the body's organs from the signal.

Nikola Tesla made the discovery of a rotating magnetic field in 1882. Raymond Damadian was the one who first used MRI in the medical area in 1972.

This method was proven to be highly effective in diagnosing a variety of pathological bodily abnormalities. The use of several pulse sequences aids in both diagnosing and characterizing the lesions. Different MRI pulse sequences are also used to evaluate cancer stage and therapy response. The recently developed methods of diffusion-weighted imaging (DWI) and associated ADC values greatly aid in the diagnosis and treatment of cancer in a number of organs.

DWI, or diffusion-weighted imaging, uses water protons to deliver microscopic information that traditional MRI cannot. Water molecules' extracellular, intracellular, and transcellular random Brownian motions are measured by DWI.[(2,7,8)]

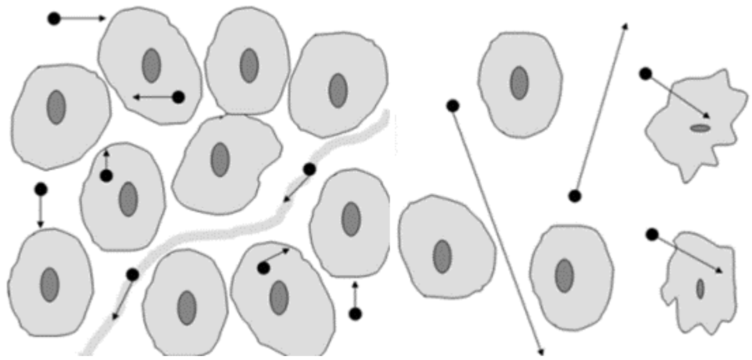
One quantitative measure of DWI that captures the diffusion movements of water molecules in different tissues is the apparent diffusion coefficient, or ADC. ADC is a quantitative metric that integrates the effects of water diffusion and capillary perfusion and is computed using DWI. Malignant tumors typically have lower ADC values and diffusion restriction than benign ones.[(2, 7, 8)]

Diffusion-weighted imaging - The key concepts of DWI are
Diffusion of Water Molecules in Tissue
Measuring Water Motion (Apparent Diffusion) Using DWI
Interpretation of DWI (Qualitative and quantitative analysis)

Diffusion of Water Molecules in Tissue

DWI investigates the body's water molecules' random mobility. Outside the body, water molecules are constantly moving randomly in a Brownian motion. Free diffusion, the unrestricted movement of water molecules, occurs physiologically. On the other hand, because water molecules' motion is altered and constrained by their interactions with cell membranes and macromolecules, it is limited in pathological situations within biological tissues. Tissue cellularity and cell membrane integrity have an inverse relationship with the extent of restriction to water diffusion in biological tissues. In tissues with a high cellular density and many intact cell membranes, such as high-grade tumor tissue, the movement of water molecules is more constrained.

Water molecules cannot move freely in the extracellular or intracellular areas due to the lipophilic cell membranes. On the other hand, water molecules can move more freely in regions with limited cellularity or where the cellular membrane has been broken (such as low-grade tumors). Water molecules can diffuse more easily in a less cellular environment since there is more extracellular space available. They can also freely pass through damaged cell membranes to enter the intracellular compartment from the extracellular space.



A B

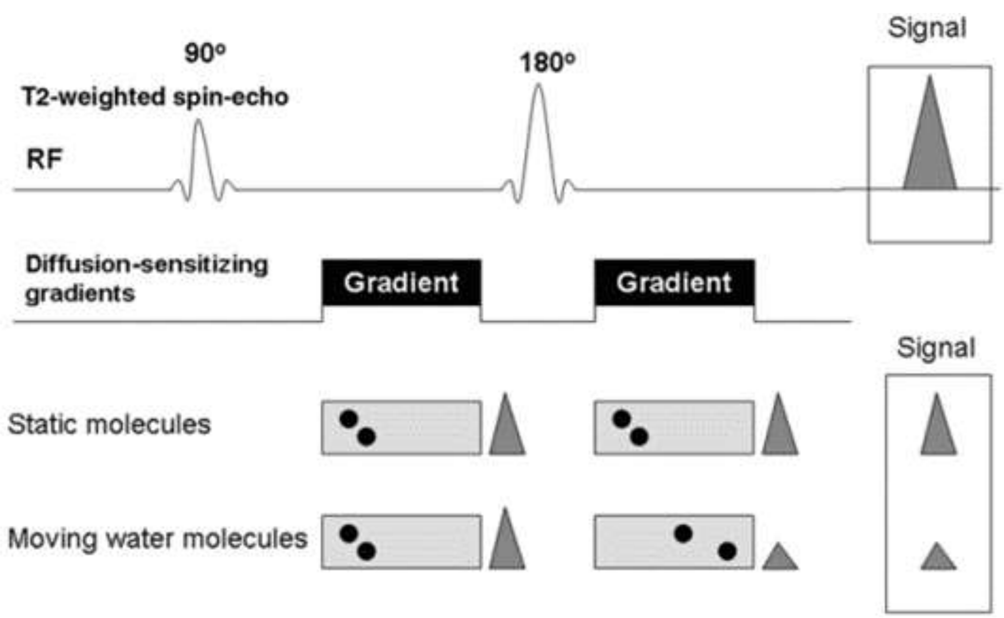
Diffusion of water molecules.

A- Cellularity and intact cell membranes: restricted diffusion. The illustration depicts one voxel of tissue with blood arteries and cells that was assessed using diffusion-weighted imaging (DWI). In the extracellular, intracellular, and intravascular spaces, see water molecules (black circles with arrows), which all contribute to the recorded MR signals. Cell membranes, which function as a barrier to water transport, and the decreased extracellular space in this highly cellular environment limit the diffusion of water.

B. Defective cell membranes and low cellularity result in less free diffusion. A proportionate increase in extracellular space permits more unrestricted water transport in a less cellular environment than in a more cellular one. Water molecules can also flow between the extracellular and intracellular compartments when cell membranes are defective.

Measuring Water Motion (Apparent Diffusion) Using DWI

MRI apparatus that could be used to measure and identify water diffusion in vivo. use of a symmetric pair of diffusion-sensitizing (bipolar) gradients surrounding the 180° refocusing pulse to modify a conventional T2-weighted spin-echo sequence. Many DWI sequences being used in clinical settings are based on that methodology. The first diffusion gradient provides phase information to static molecules, however the second diffusion gradient will rephase information without appreciably altering the measured signal intensity. In contrast, water molecules in motion pick up distinct phase information from the first gradient; however, because of their mobility, the second gradient will not fully rephase their signal, resulting in a signal loss.



Measuring the diffusion of water. Using a T2-weighted spin-echo sequence, water diffusion is measured. They used a 180° refocusing pulse with a symmetric diffusion-sensitizing gradient. The observed signal strength is maintained in this schematic illustration because stationary molecules are not impacted by gradients. On the other hand, the initial gradient provides the flowing water molecules with phase information, which the second gradient does not completely rephase, resulting in signal loss. Water diffusion is thus identified as a reduction in the intensity of the recorded MR signal.

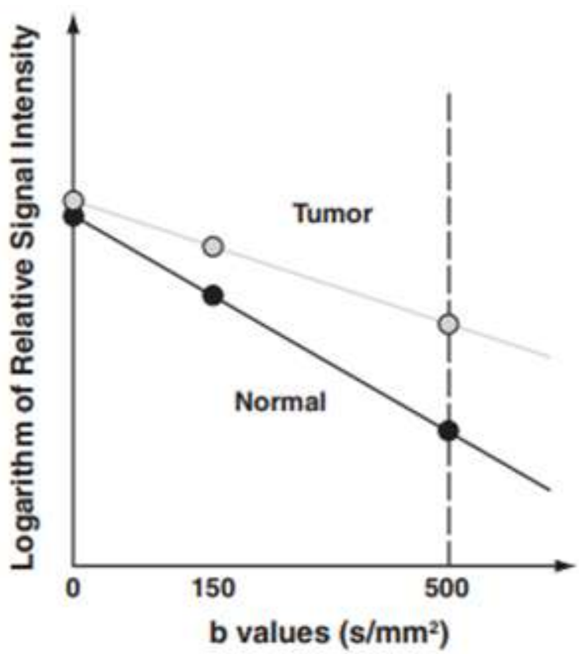
Water molecule mobility is therefore identified at DWI as attenuation of the observed signal intensity. The amount of signal attenuation is proportional to the amount of water velocity. By altering the gradient amplitude, applied gradient duration, and time interval between the paired gradients, the DWI sequence's sensitivity to water motion can be changed. The diffusion sensitivity on clinical MR scanners can be readily adjusted by adjusting the "b value," a parameter that is proportional to these three variables. The gradient amplitude, not the duration or time intervals between gradients, is often adjusted when the b value is changed.

With lower b values (e.g., b = 50–100 s/mm2), water molecules with a high degree of motion or a wide diffusion distance (e.g., within the intravascular space) would exhibit signal attenuation. On the other hand, slow-moving water molecules or small diffusion distances typically require large b values (e.g., b = 1,000 s/mm2) to be perceived because they exhibit more progressive signal attenuation with increasing b values.

Interpretation of DWI -

Qualitative and quantitative Assessment of DWI

To allow for meaningful interpretation, DWI usually uses at least two b values (e.g., b = 0 s/mm2 and other b values from 0 to 1,000 s/mm2). In general, the degree of signal attenuation from water molecules increases with the size of the b value. Tissue characterization based on variations in water diffusion is made possible by observing the relative attenuation of signal intensity on images taken at various b values. For example, because water transport is less constrained in a heterogeneous tumor, the more cystic or necrotic portion of the tumor would exhibit more signal attenuation on high b-value pictures. The more cellular solid tumor regions, on the other hand, will nevertheless have comparatively high signal intensity. Visual evaluation of the relative tissue signal attenuation at DWI is used for cancer patient treatment response assessment, tumor characterisation, and tumor detection.



As a result, according to the equation SD = Soe-bxADC, the signal intensity on DWI is inversely proportional to the mobility of water molecules. SD is the signal intensity without diffusion weighting, and b is the diffusion sensitization factor.

These days, diffusion-weighted imaging is used much more often in oncology. DWI's benefits include not requiring a contrast agent, being a rapid, non-invasive procedure that takes only a few minutes, and offering both qualitative and quantitative data regarding the type of tumor. DWI can be used to evaluate the prognosis and response to treatment. It is possible to distinguish between lesions that recur or persistent fibrosis following chemotherapy or radiation therapy. Neoplastic infiltration or hyperplasia may be the cause of the enlarged lymph nodes linked to cancer. Differentiating between lymph node involvement from hyperplastic or neoplastic infiltration might be aided by the DWI. DWI has been used extensively in oncology for tumor detection and characterisation as well as therapy response monitoring. Therefore, distinguishing between benign and malignant tumoral processes is the primary function of the DWI/ADC value.

Each image pixel's ADC value is determined and shown as a parametric map. The ADCs of various tissues can be obtained by highlighting areas of interest on these maps (3).

Application of DWI/ADC Value in Various Cancer Conditions

Neurology[12]

Nowadays DWI and ADC are used routinely with other MR pulse sequences for the evaluation of brain tumours. This provides important information about the tumour characterization, grading, and treatment response.

Low ADC values are suggestive of hypercellular malignancies such as lymphoma, high-grade gliomas and metastases. The dysembryoplastic neuroepithelial tumourswhich are benign in nature-typically have higher ADC values compared to astrocytic tumours, while medulloblastomas usually present lower ADC values than ependymomas and posterior fossa astrocytomas.

Furthermore, monitoring changes in ADC during therapy provides a non-invasive method to assess treatment response. An increase in ADC typically indicates a positive response to treatment, whereas unchanged ADC values may suggest non-response.

Overall, DWI and ADC measurements are critical for accurate brain tumour diagnosis, grading, and monitoring which help in treatment planning and follow-up.

Head and neck[3]

Various cancers of the thyroid gland , parathyroid, salivary glands, oral cavity, larynx, pharynx, paranasal sinuses and associated lymph nodes of the neck involvement can be diagnosed and characterised by DWI and ADC values.

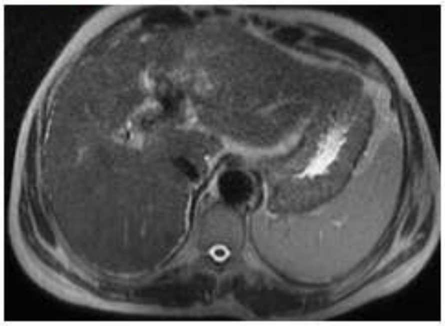
Cervical lymphadenopathy may be due to infectious, inflammatory and neoplastic conditions. DWI and ADCvalues help to differentiate infections or neoplasms. Usually, malignant neoplastic lesions show diffusion restriction and low ADC values compared with non-malignant lesions. Diffusion restriction and Lower ADC values are seen in malignant nodes, compared to benign nodes.

Hepatobiliary system [2]

LIVER- The common malignant mass lesions in the liver are hepatocellular carcinoma, metastases, cholangiocarcinoma. The common benign lesions are hemangioma and focal nodular hyperplasia. The malignant lesions show diffusion restriction and thus low ADCvalues. The benign lesions show no diffusion restriction and have high ADC values.The advantage of DWI is,that even lesions less than 20 mm can be diagnosed. Grading of lesions whether high grade or low grade can be assessed.

GBmalignancy – Application of DWI and ADC value with other pulse sequences have a highsensitivityand specificity in diagnosinggall bladder malignancy

A



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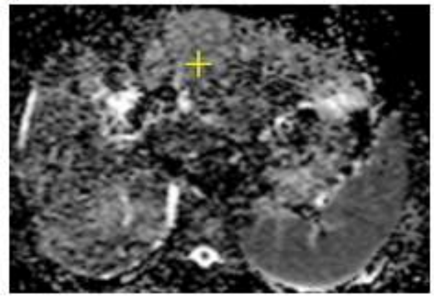
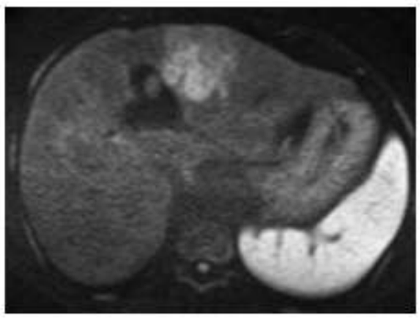




B

Fig A - Axial T2 image shows a suspicious hyper intense lesion LT lobe segment 4 A. Fig B - DWI shows restricted diffusion-increased signal intensity and C corresponding ADC shows low signal intensity –A Case of Hepatoma

Gastrointestinal and oesophagus[4]

DWI and ADC values have demonstrated good specificity and nodal staging accuracy in oesophagalcancer.Gastric carcinoma is highly cellular and shows a significantly lower ADC value than normal gastric walls or benign lesions.

In colorectal cancer, DWI-MRI is widely used because of its ability to provide quantitative insights into tumour characteristics and treatment response. DWI is used in staging colon cancer, particularly for local and vascular invasionFor rectal cancer, DWI adds value to MRI protocols by improving specificity in detecting perirectal infiltration and aiding in treatment response assessment. The metastatic involvement of lymph nodes in the pelvis and abdomen diagnosed and differentiated by DWI and ADC values from hyperplasia.

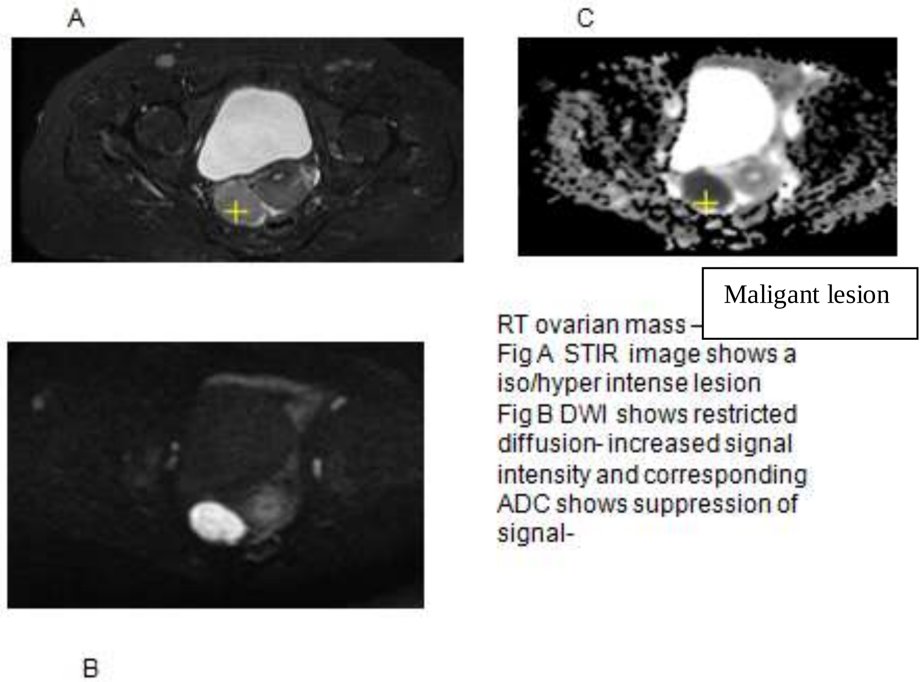
Pancreas [2]

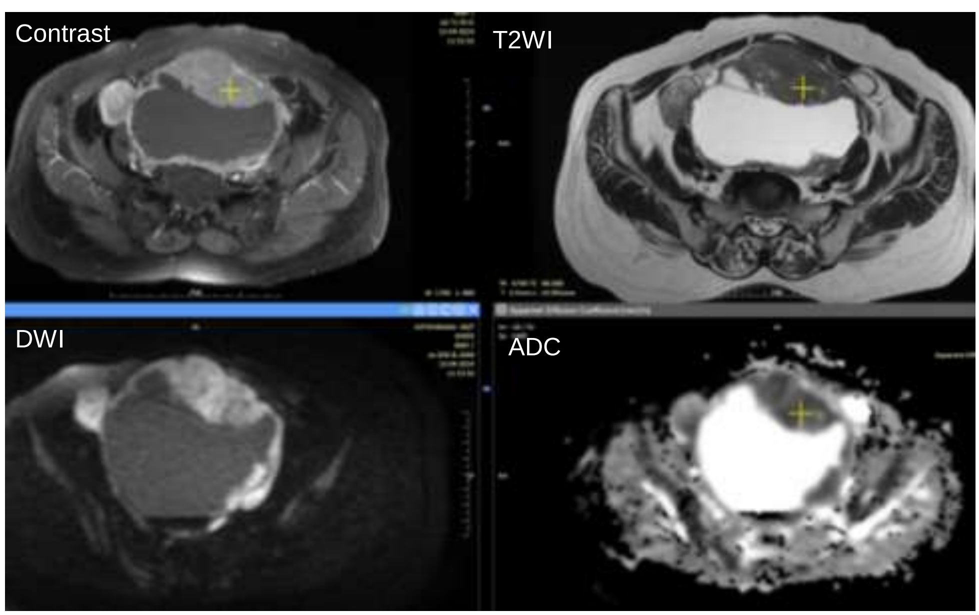
DWI is highly accurate in identifying pancreatic ductal adenocarcinoma. PDAC typically presents with diffusion restriction, with focal hyperintense areas and corresponding low ADC values. The malignant pancreatic lesions generally have lower ADC values compared to benign lesions.

Gynaecology[10]

Early diagnosisof endometrial carcinoma, myometrial extension, lymph node involvement, MRIwith DWI and ADC value may be a good modality

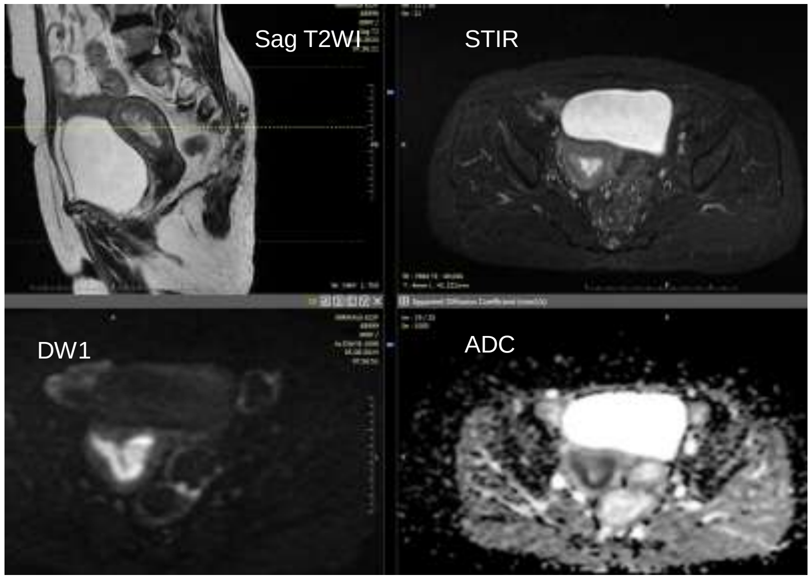
Uterine cervical cancer ,the diagnosis of the lesion, parametrial involvement, and nodal involvement can be assessed by DWI and ADC.DWI also seems to increase the diagnostic accuracy of ovarian cancer, the nodal involvement, peritoneal deposits and staging. Treatment monitoring, prognosis, assessment of residual/fibrosis after chemo or radiotherapy and recurrence is possible.





Ovarian malignancy- solid cystic mass

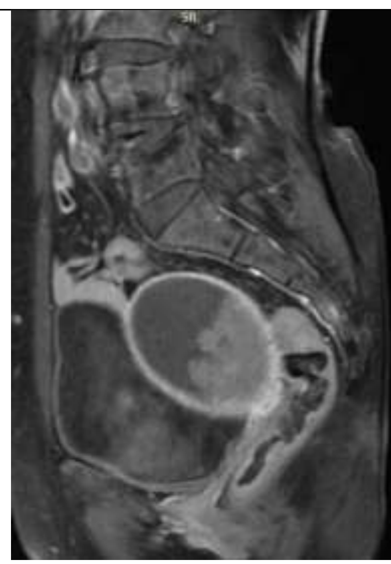
Contrast study shows enhancing solid components. T2WI shows iso-intense solid component and hyperintense cystic component. DWI shows restricted diffusion-increased signal intensity ADC shows suppression of signal

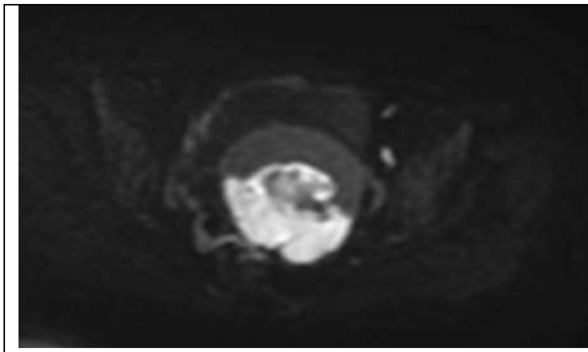


CA ENDOMETRIUM

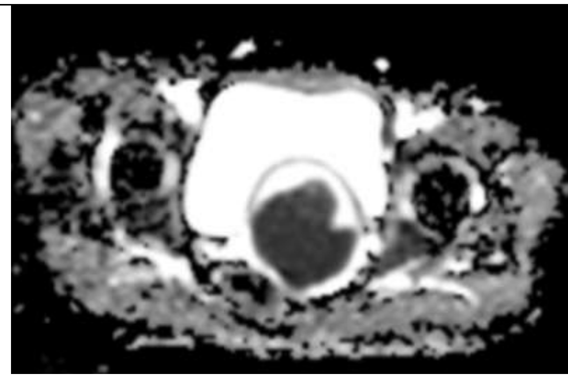
Sag T2WI and STIR images show thickened hyperintence endometrium. DWI shows diffusion restriction and ADC suppression of signal

CA Endometrium

	1
Sag T2WI image shows a lobulated isointense lesion that appears to arise from the posterior endometrium and projects into the distended uterine cavity.	**Contrast study shows the well-enhancing lesion**



DWI shows diffusion restriction- bright signal



ADC shows suppression of signal as black

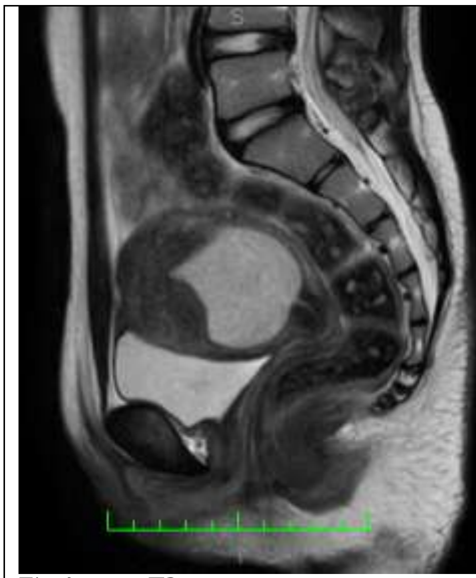


Fig A - sag T2

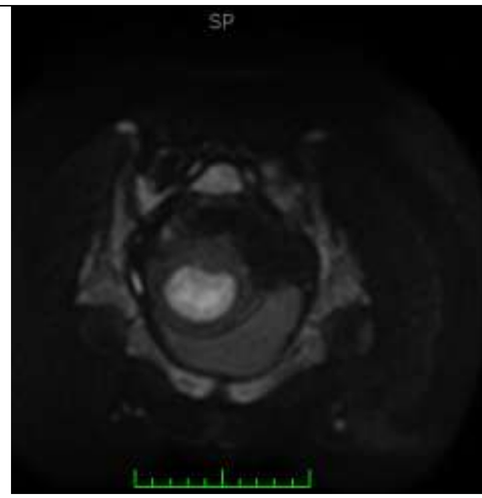


Fig B - DWI

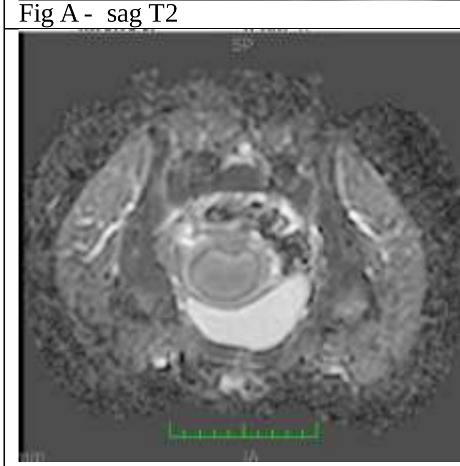


Fig C- ADC

ENDOMETRIAL POLYP

Fig A -Sag T2 image showing hyperintense lesion filling and distending the endometrial cavity

Fig B & C showing hyperintense signal in diffusion weighted image without corresponding suppression in ADC indicative of a benign lesion

E

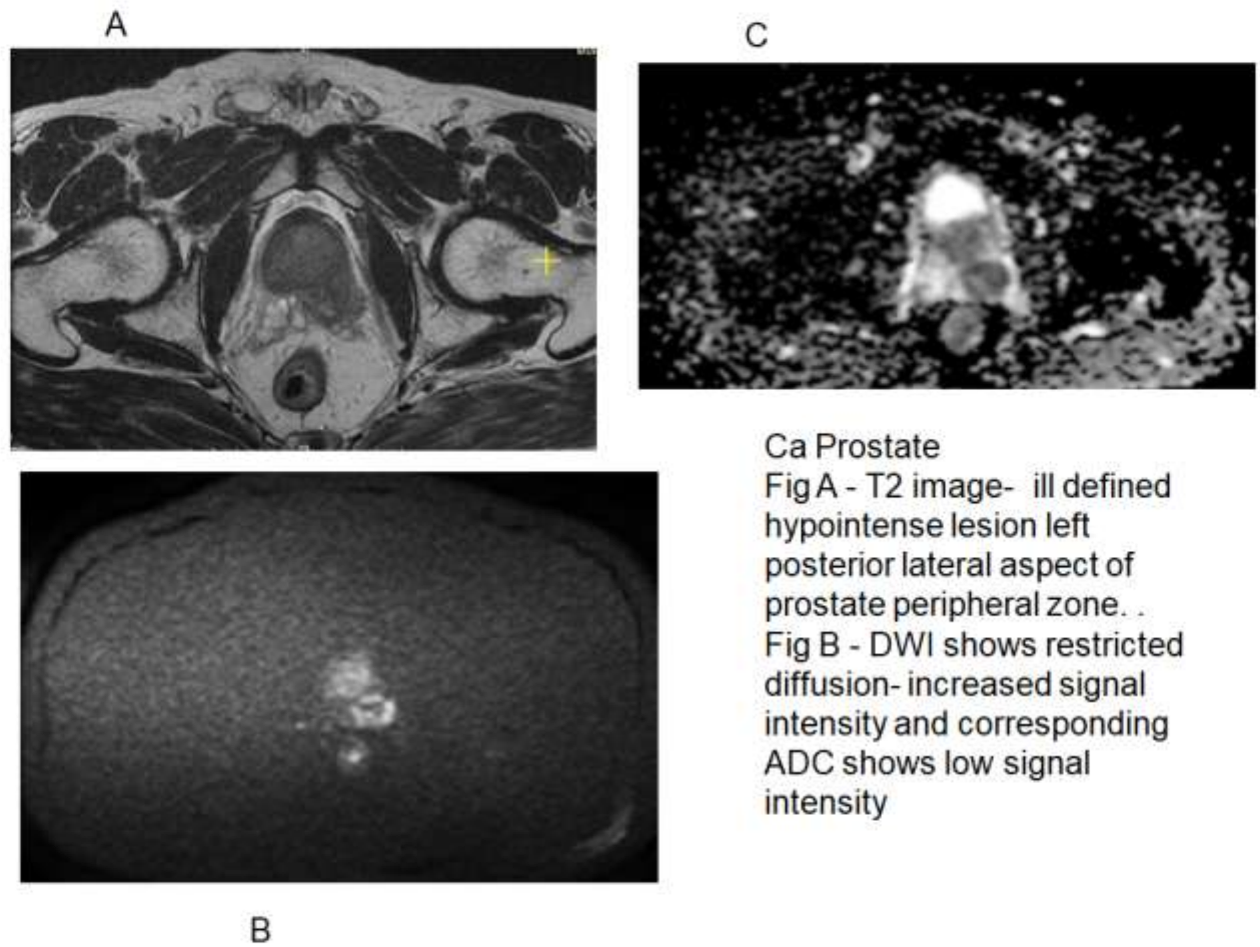
Urinary system and adrenals[11]

Malignant tumours of the renal system like renal cell carcinoma have lower ADC values than benign ones.A benign condition, renal oncocytoma mimicking renal cell carcinoma can be differentiated by DWI and ADC. The oncocytoma had significantly higher ADCs compared with solid RCC.

Adrenal masses - Malignanttumours show bright signals on DWIs, and ADC values are lower than benign tumours

Prostate cancer – Normally the peripheral zone of the prostate has high signal intensity on T2-weighted images. Prostatic cancer is seen as low signal-intensity

lesions on T2-weighted imagesat the peripheral zone. DWI shows diffusion restriction seen as a high signal intensity lesion with a decrease in ADC values.

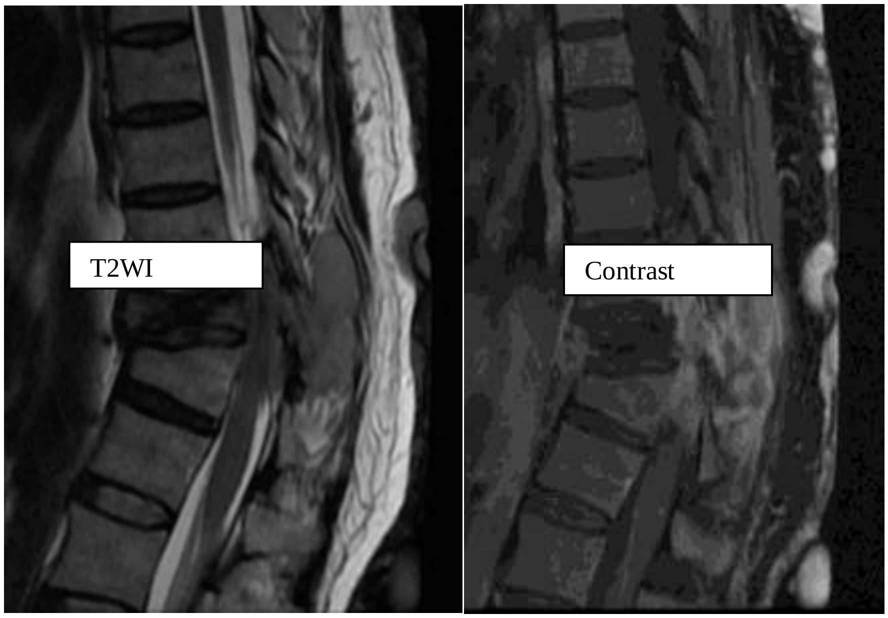


Ca Prostate
Fig A - T2 image- ill defined hypointense lesion left posterior lateral aspect of prostate peripheral zone. .
Fig B - DWI shows restricted diffusion- increased signal intensity and corresponding ADC shows low signal intensity

Musculoskeletal system9

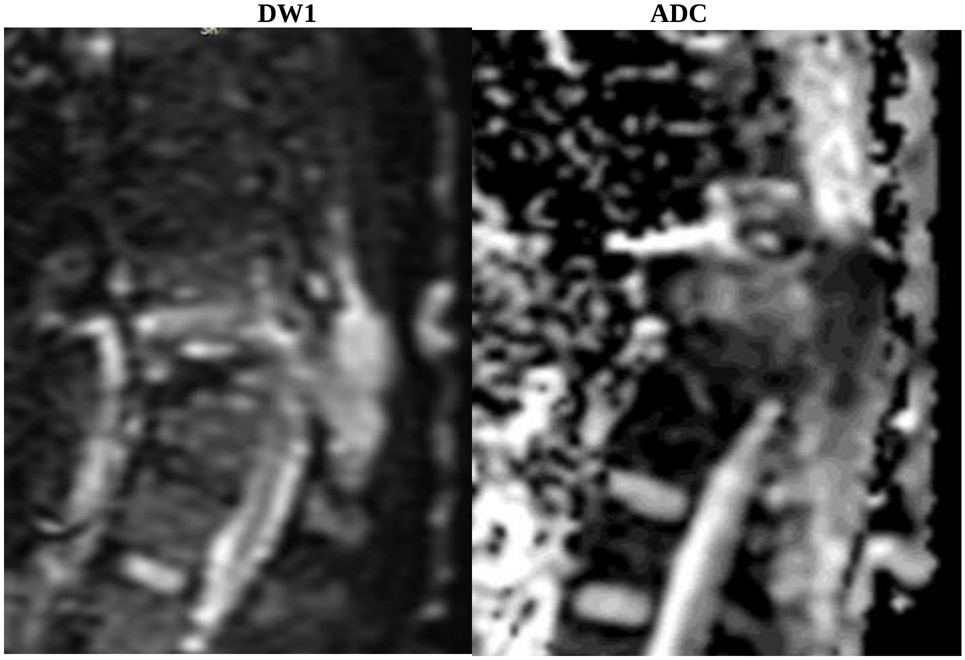
The malignant lesions like sarcomas, lymphomas, multiple myeloma, and metastasis show lowerADC and diffusion restriction than benign tumourssuch as exostosis, bone islands CMF etc. DWI have a high role in the differentiation of benign osteoporotic and malignant vertebral compression fractures

METASTASIS

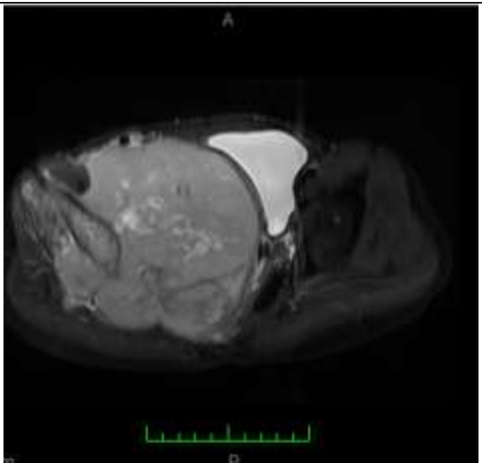
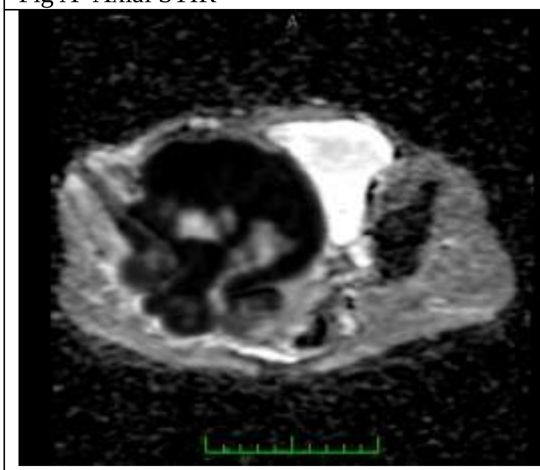


T2WI and contrast study shows destruction of
T12 vertebra with enhancing soft tissue components

DW1 **ADC**



DWI and ADC- shows diffusion restriction - bright signal, corresponding ADC shows suppression of signal—black.

 Fig A -Axial STIR	 Fig B-DWI
 Fig C-ADC	EWING'S SARCOMA Fig A- showing a marrow infiltrating lesion involving ilium and acetabulum with exophytic iso to hyperintense soft tissue component Fig B &C – Showing diffusion restriction seen as hyperintense signal in DWI and corresponding ADC shows suppression of signal - black

Lung (5)

By DWI and ADC values,differentiation of malignancyand benign lung tumours is possible.

Breast(6)

DWI MRI identifies the occult malignancy which is difficult to get with a routine mammogram. Thus, this modality can be used as a breast cancer screening tool.

The malignant breast lesions show diffusion restriction and appear as hyperintense lesions. Thus, without using contrast material breast malignancies can be detected more accurately.


Fig A

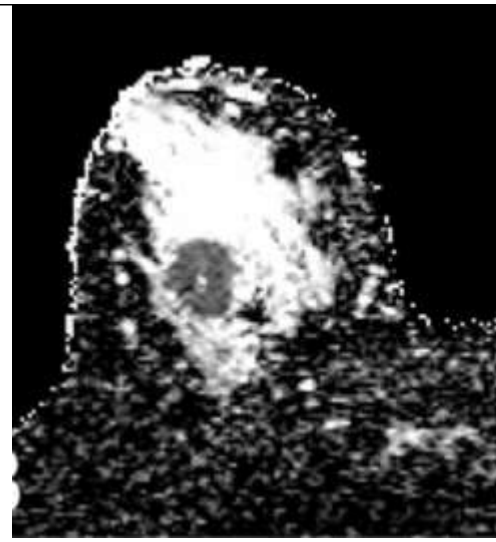


Fig B

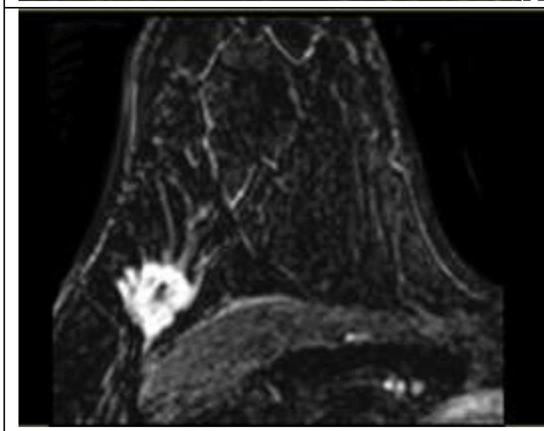


Fig- C

MR mammogram - Fig- A- DWI shows restricted diffusion- increased signal Fig- B- Corresponding ADC shows low signal intensity Fig -C contrast study shows enhancement

Conclusion:-

DWI and ADC have a definite role in evaluatingcancer conditions of various systems. These techniques are non-contrast, non-invasive, and take only minutes for scanning. They increase the diagnostic accuracy, and tumourcharacterisation,planning treatment and help to monitor the treatment response and differentiate recurrence from residual/fibrosis by providing crucial insights into tissue diffusivity and cellularity.

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Conflict of interest:
None.

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