Development of an algorithm for automatic detection of meniscus tears in knee magnetic resonance imaging (MRI) scans.

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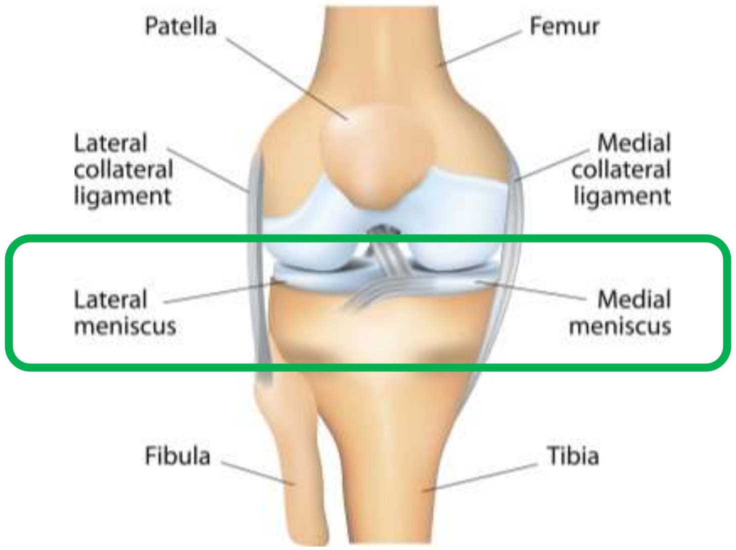
Research Aim

- Determine if a model could succeed in the clinically important task of detecting meniscus tears in knee magnetic resonance imaging (MRI) scans.

- Improve access to quality MRI diagnoses in the absence of specialised radiologists, or to reduce the workload of specialized radiologists.
  - While use of MRI and CT scans have increased, number of radiologists have remained almost the same (McDonald et al., 2015, Kumamaru et al., 2018).

Introduction

- Meniscus is important for:
  - Knee stability
  - Load transfer/distribution (shock absorber)
  - Preserves articular cartilage



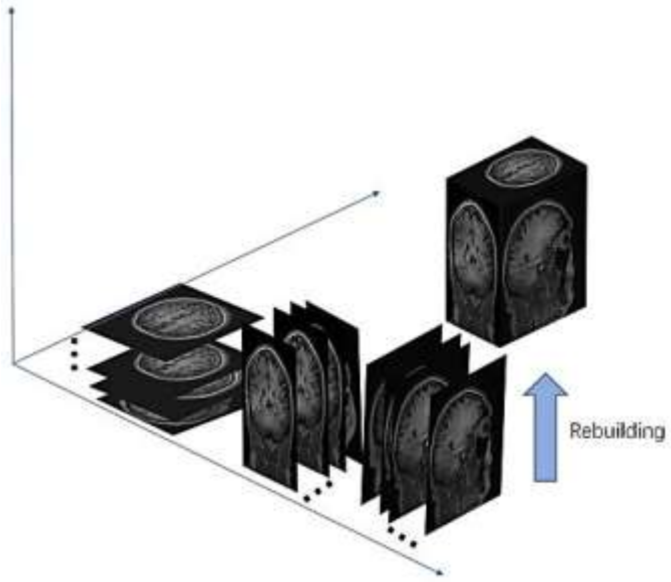
Introduction

- A meniscal tear is a frequent orthopaedic diagnosis and an early indication of osteoarthritis (OA).

- Knee MRIs are not typically ordered for asymptomatic patients.

- 61% of randomly selected participants showed meniscal tears in their knees during magnetic resonance imaging (MRI) scans. They have not had any pain, aches, or stiffness during the previous months (Englund et al., 2008).

MR imaging

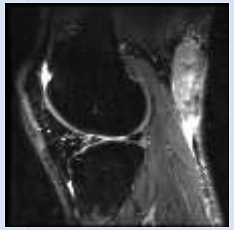
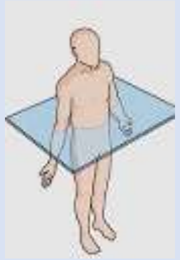


3D planes scanned

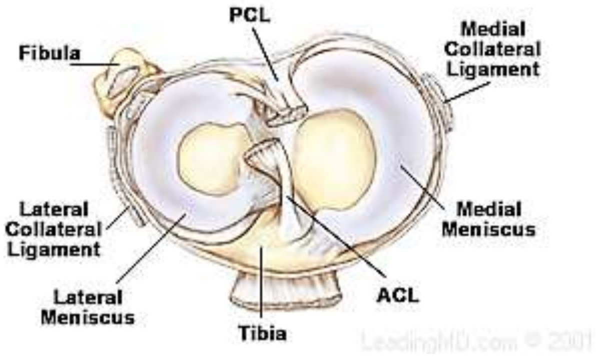
Image	Signal intensity	Clinical use
T1-weighted	- Fat bright - Muscle intermediate - Water, tendon, cartilage dark	- Good anatomical detail - Low sensitivity for soft tissue - Good for meniscal pathology
T2-weighted	- Water bright - Fat intermediate - Muscle and cartilage dark	Good for soft tissue injuries, especially tendon
Proton density (PD) weighted	- Fat bright - Water intermediate - Tendon and cartilage dark	Good for viewing meniscus and ligaments

MRI pulse sequences

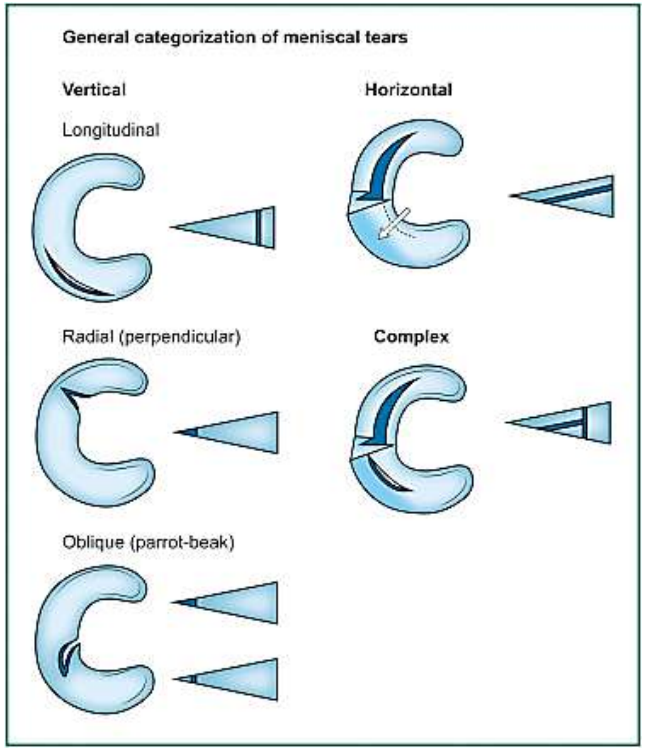
Dataset

Plane	Plane	MRI	Training set	Validation set	Pulse sequence
Sagittal			1130	120	T2-weighted
Frontal/ Coronal			1130	120	T1-weighted
Axial/ Transverse/ Horizontal			1130	120	PD-weighted

Meniscus tears



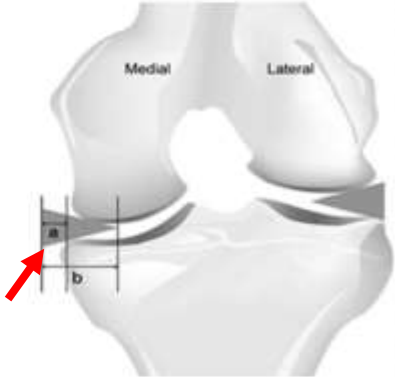
Healthy meniscus



Meniscal tears (Lecouvet et al., 2018)

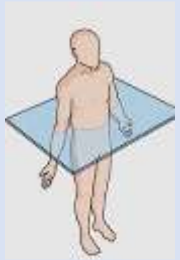
Meniscus tears

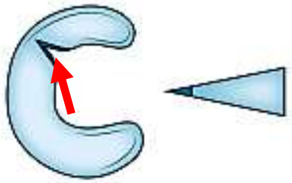
Plane	
Frontal/ Coronal	



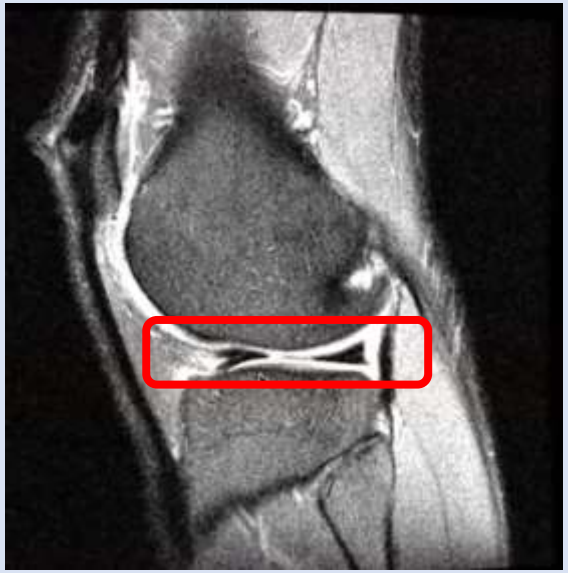
Meniscus extrusion

Meniscus tears

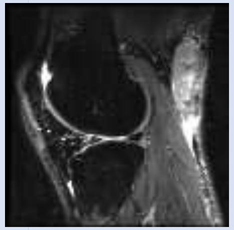
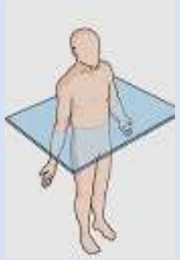
Plane	
Axial/ Transverse/ Horizontal	



Meniscus tears

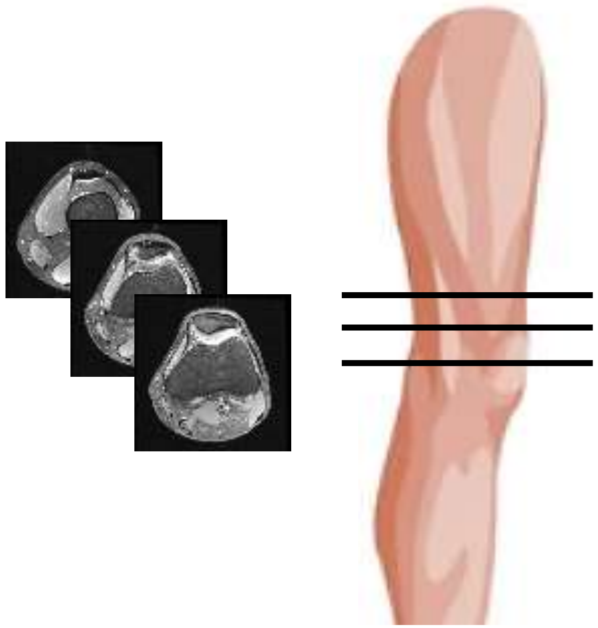
Plane	Normal (bow-tie) appearance	Disruption of medial meniscus
Sagittal 		

Dataset

Plane	Plane	MRI	Training set	Validation set	Pulse sequence
Sagittal			1130	120	T2-weighted
Frontal/ Coronal			1130	120	T1-weighted
Axial/ Transverse/ Horizontal			1130	120	PD-weighted

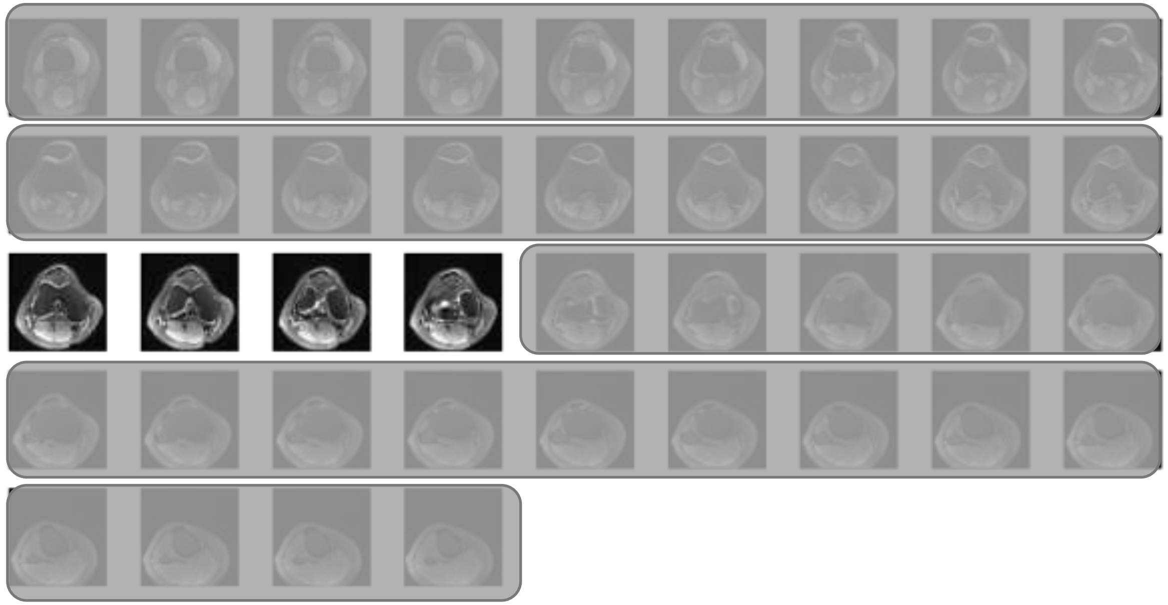
Challenges with dataset

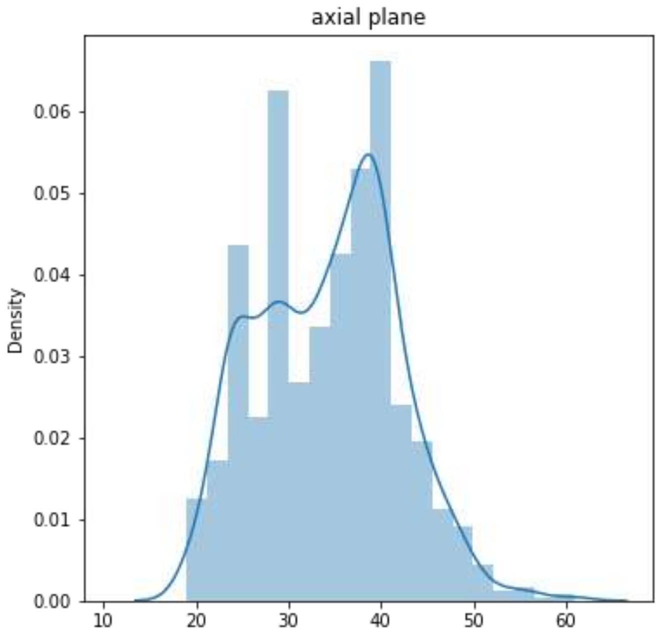
- MRI 2D multislice
  - Small gaps between slices (avoid cross-talk)



Challenges with dataset

- 1130 x s x 256 x 256 x 1
  - where 17 < s < 61

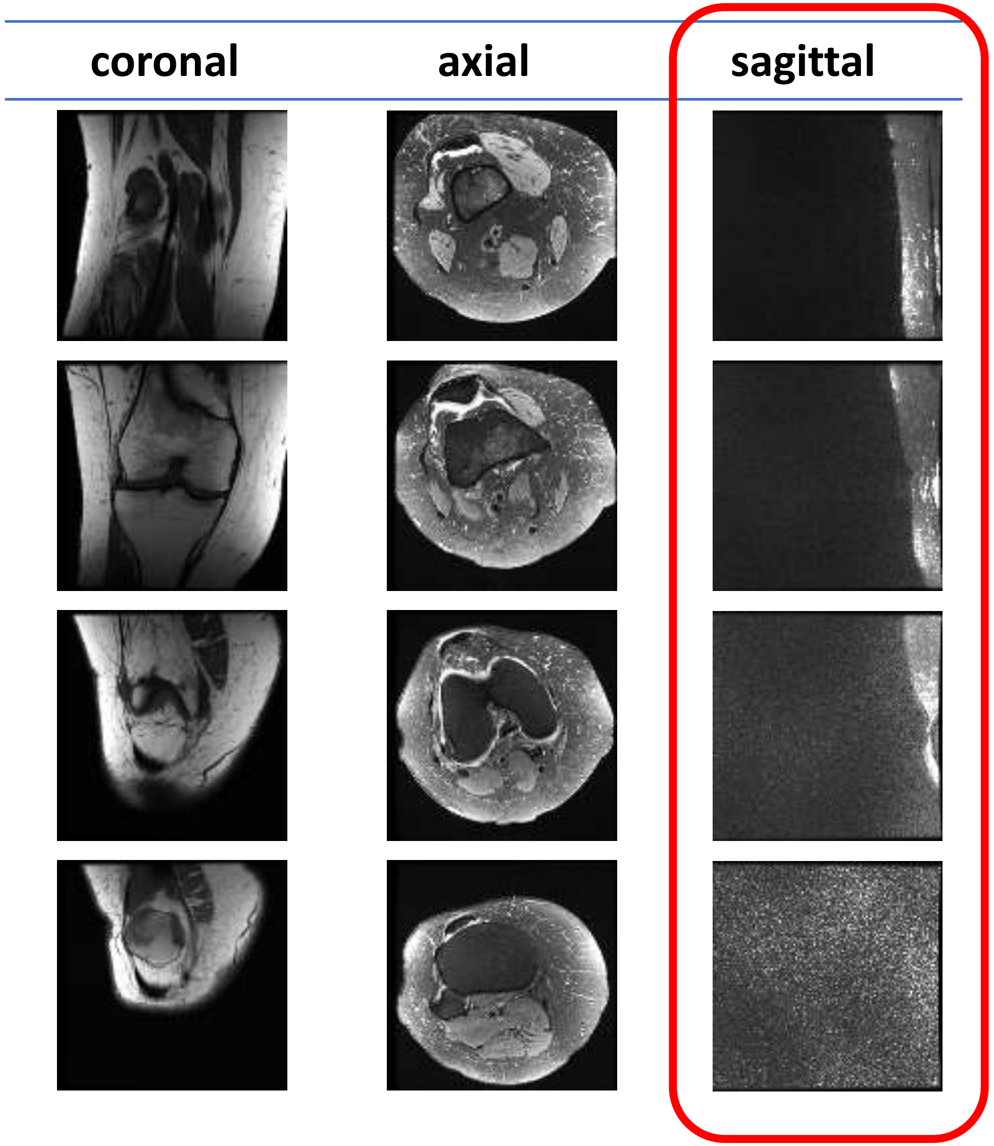




Number of slides per scan

‘Potentially’ bad data points

- MRI 2D multislice
  - Small gaps between slices (avoid cross-talk)
  - Resolution of one plane is prioritized
- Point-of-view (POV) of a plane is not focused.

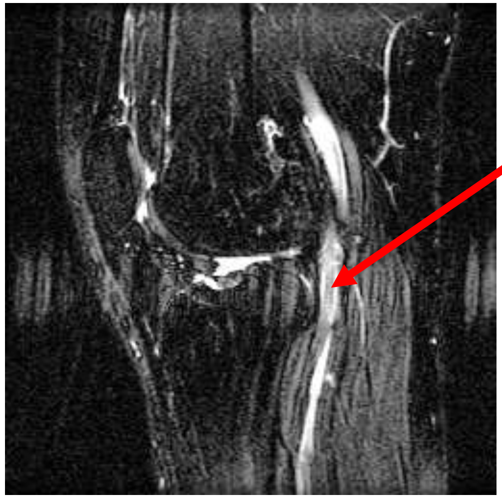


‘Potentially’ bad data points

- MRI 2D multislice
    - Small gaps between slices (avoid cross-talk)
    - Resolution of one plane is prioritized

- ‘Flow’ artefacts in some images

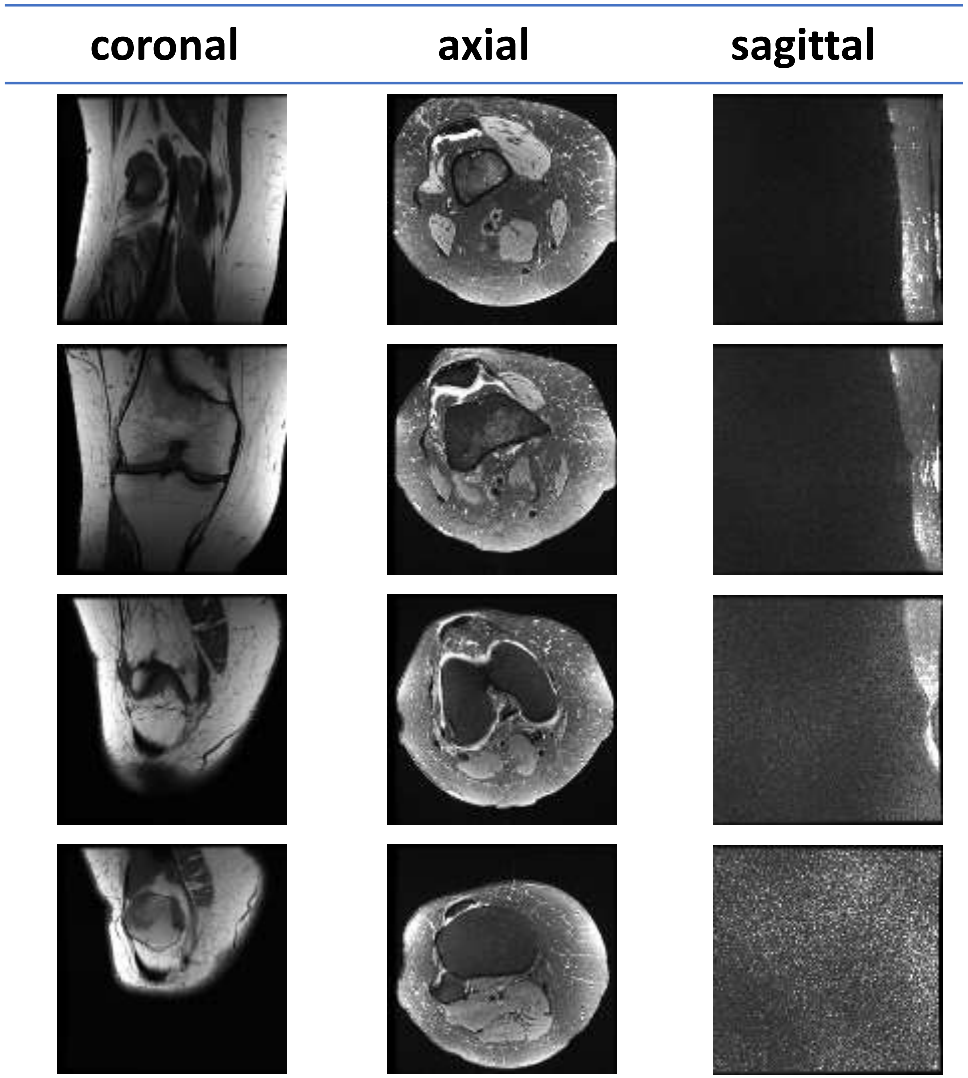
sagittal



Arterial artefact

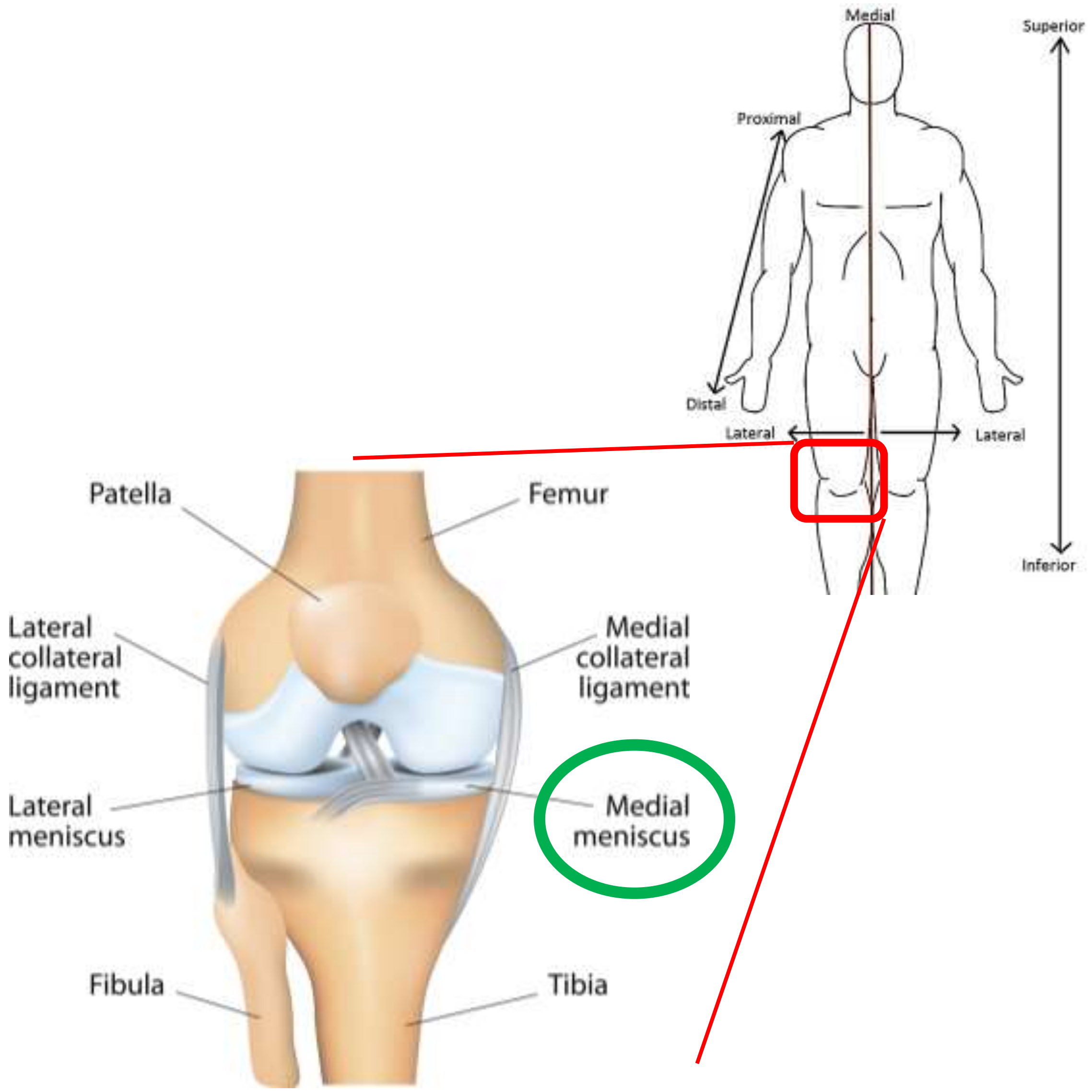
Challenges with dataset

- Hypotheses:
  - Coronal or axial planes were prioritised during scanning
  - Most of the meniscus tears were radial tears (best viewed in axial plane)
  - Ensure root attachment of the meniscus (best viewed in coronal plane)

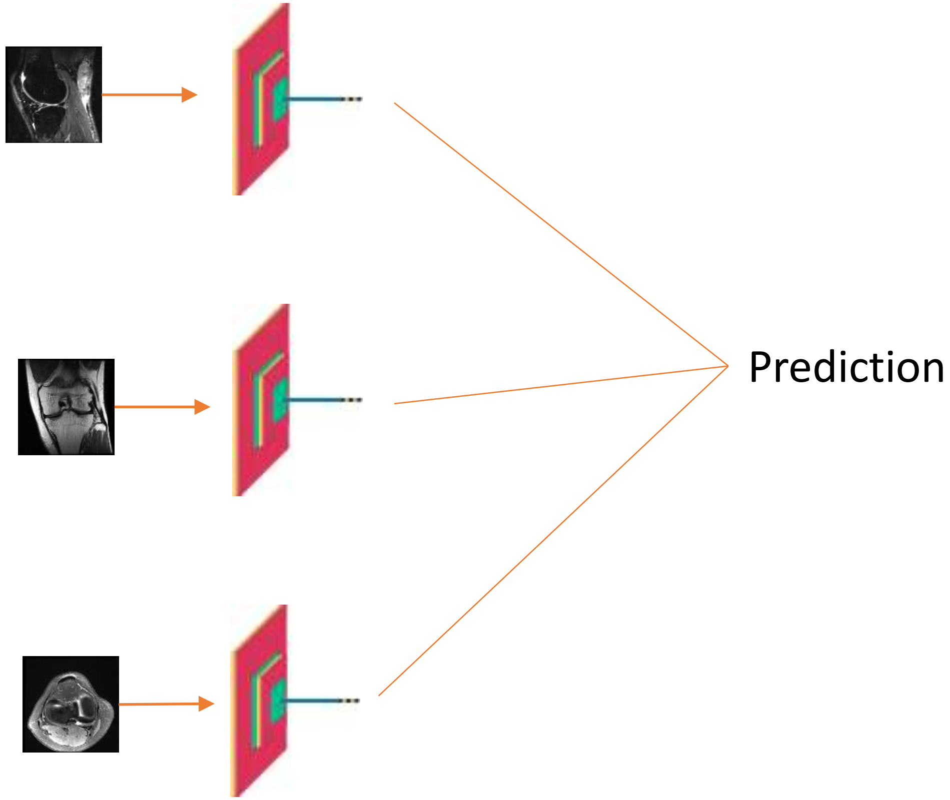


Dataset as inputs

- Extracted 3 middle images or middle image
- Images were intensity normalized. No colour was added.
- No shear, rotation, translation, etc, were performed.



Models



- Separate models for each of the coronal, axial and sagittal planes was built.
- Metric:
  - Accuracy
  - Precision

Models - summary

All models
ResNet50
VGG16
Custom model (based on AlexNet)
Custom model (based on LeCun)
Functional model

- Parameters tuned:
  - kernel regularization
  - batch normalisation
  - dropout
  - early stopping
  - batch size
  - learning rate

Models

Models	Accuracy	Precision
ResNet50	--	--
VGG16	0.558	0.454

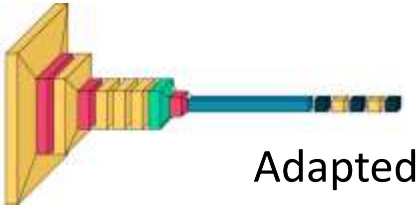
ResNet50

VGG16

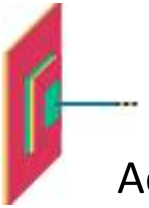
- Pretrained models were overfitting.
- Possible solutions:
  - Apply data augmentation
  - Reduce architecture complexity

Models

Models	Accuracy	Precision
~~ResNet50~~	--	--
~~VGG16~~	0.558	0.454
Custom model (based on AlexNet)	0.575	0.571
Custom model (based on LeCun)	0.575	0.667



Adapted from AlexNet

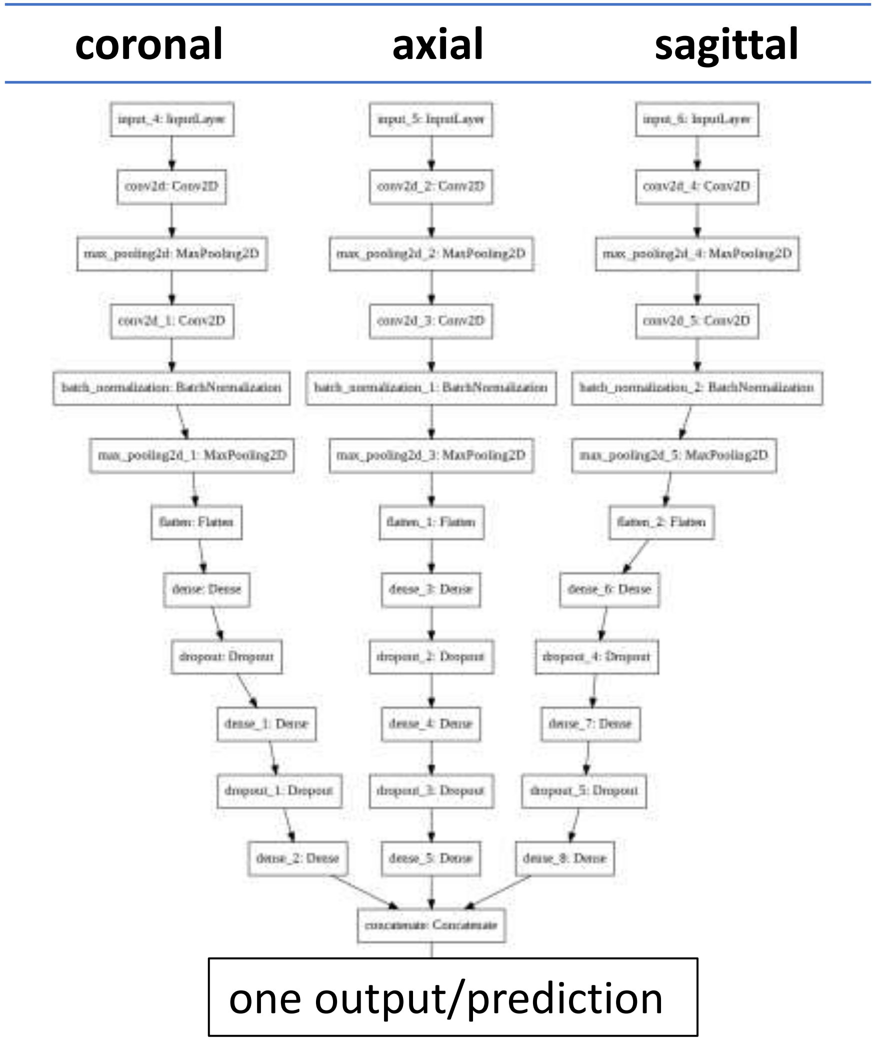


Adapted from LeCun (LeCun et al., 1998)

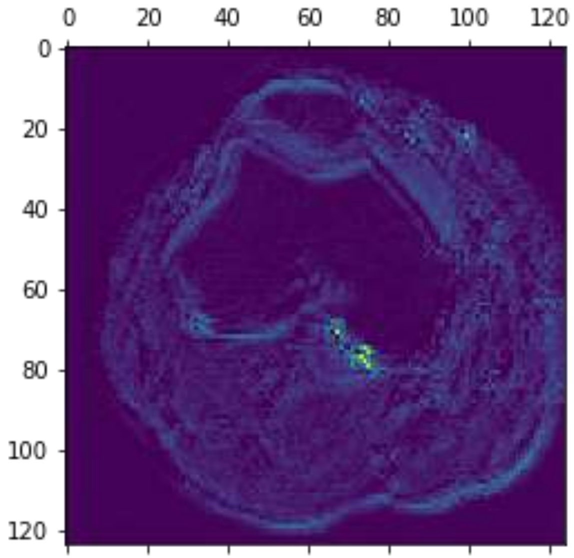
- A smaller model would not lead to better performance.
  - Constrained by images.
  - Small dataset for training.

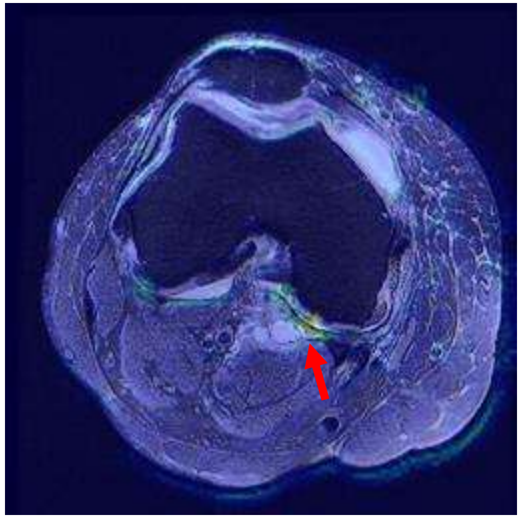
Models

Models	**Accuracy**	**Precision**
~~ResNet50~~	--	--
~~VGG16~~	0.558	0.454
~~Custom model (based on AlexNet)~~	0.575	0.571
Custom model (based on LeCun)	0.575	0.667
Functional model	0.575	1.0



Discussion

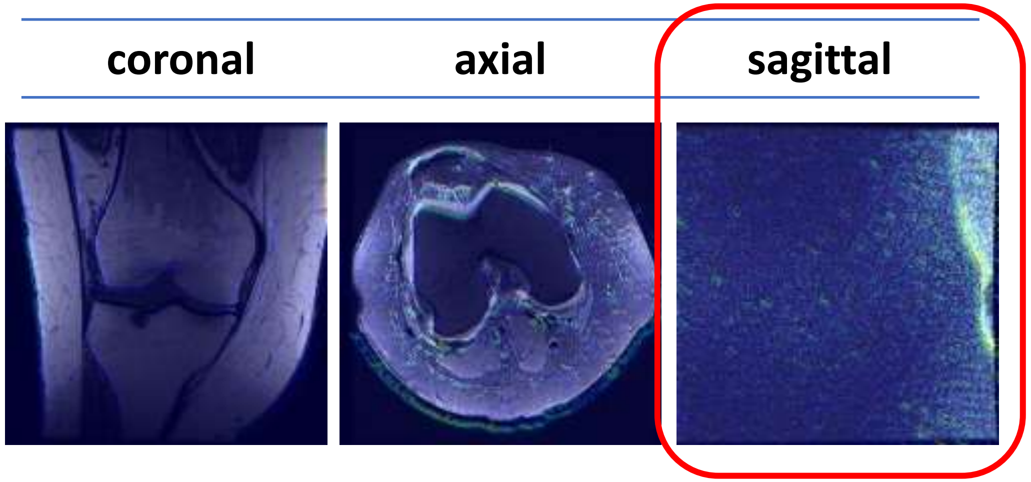




- *Explainability* is a major factor in healthcare.
- Classification activation mapping (CAM) was applied, to understand how the model make decisions.

- Correctly classified as meniscus tear.
- Made ‘sense’.

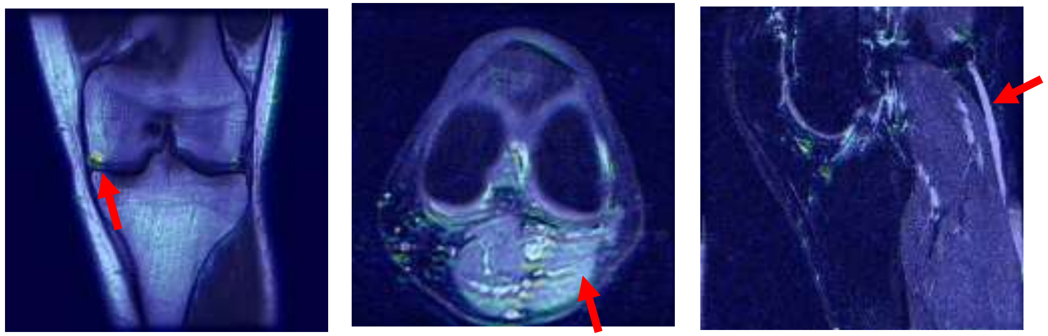
Discussion – ‘potentially’ bad data points



- Training set.
- Correctly trained/ classified as no meniscus tear.
- ‘Learn’ to look past low resolution, misaligned images.

Discussion – ‘potentially’ bad data points

coronal	axial	sagittal



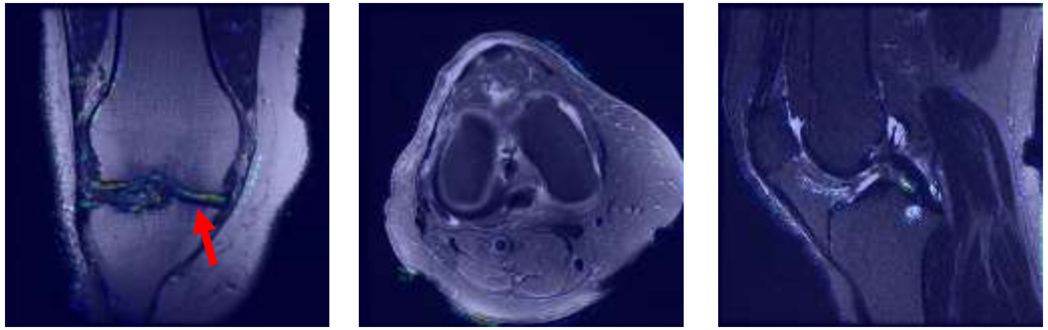
- Training set.
- Correctly trained/ classified as no meniscus tear.
- ‘Learn’ to look past artefacts.

Discussion

- Training set.
- Correctly classified as meniscus tear.
- Looked more like an ACL tear (which is usually associated with meniscus tear).

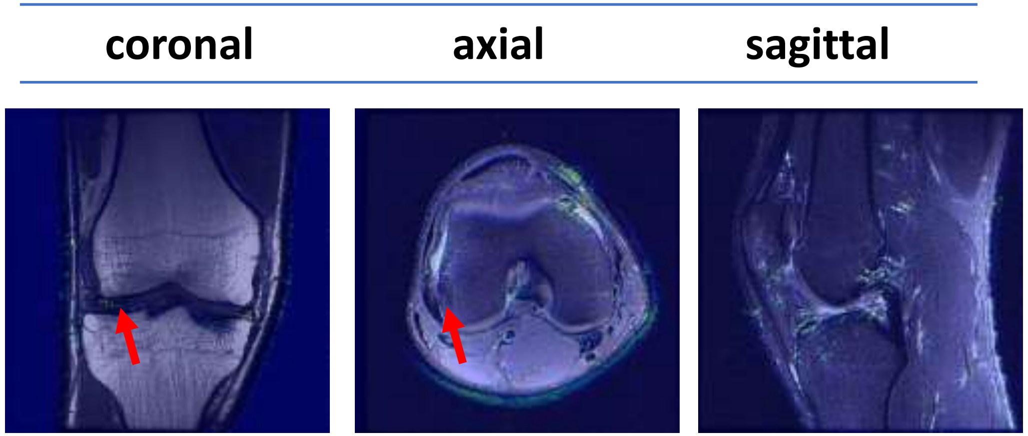
Discussion

coronal	axial	sagittal



- Training set.
- Correctly classified as meniscus tear.
- Also has an ACL tear, but only meniscus region highlighted.

Discussion



- Validation set.
- Based on the axial plane, misclassified as having no meniscus tear.

Conclusion

- Functional model was selected as the ‘best’ model.
  - Most ‘logical’ model
  - Best precision score
  - ‘Learn’ to look past bad data points

- Since explainability is a major factor in healthcare, CAM reveals that predictions made ‘sense’. Areas of interest were at regions of meniscus tears.

Recommendations

- Need for model refinement via consistent selection of clinically meaningful scans, etc.

- Out-of-sample external validation and interpretation of model.