DIFFUSION BASED SHAPE-AWARE LEARNING WITH MULTI-SCALE CONTEXT FOR SEGMENTATION OF TIBIOFEMORAL KNEE JOINT TISSUES: AN END-TO-END APPROACH

Authors: AKSHAY DAYDAR, ALIK PRAMANICK, ARIJIT SUR and SUBRAMANI KANAGARAJ from IIT GUWAHATI, ASSAM, INDIA

INTRODUCTION

- **According to WHO →** Knee Osteoarthritis (KOA) is degradation of joints in knee with **loss of cartilage, joint space narrowing, osteophytes,** and sometimes **joint inflammation,** resulting in **pain** and **decreased function** with worldwide **Prevalence** in **2024: 364.58 million. *RKOA- Radiological KOA**
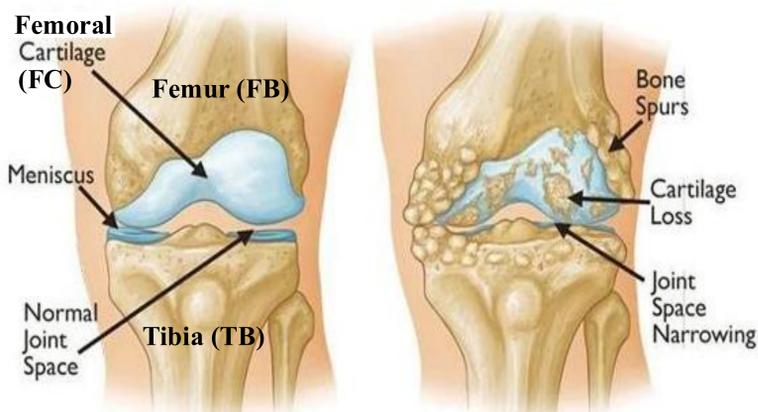

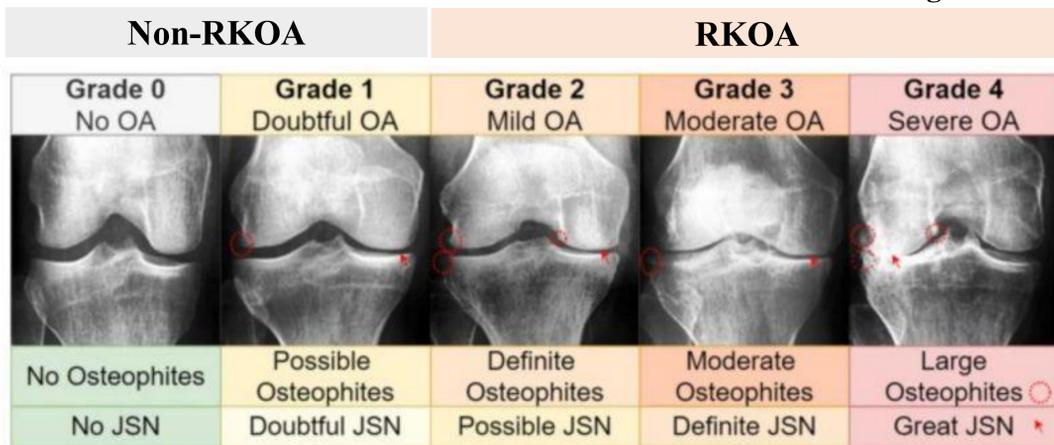**Figure: Schematic of Knee Anatomy(source-internet)**

Figure:Pictorial Representation of KL grades in KOA (Kellergen et al., 1957)

Challenges: 1) Irregularity of pathological structures, 2) uncertainties in delineating both inter- and intra- cartilage boundaries, 3) inconsistencies in capturing multi tissue context, (Ambellen et al., 2019, Kessler et al., 2022, Latif et al., 2021) 4) offline and cumber some implementations of post-processing stage. (Deng et al., 2021, Latif et al., 2021, Li et al., 2022)
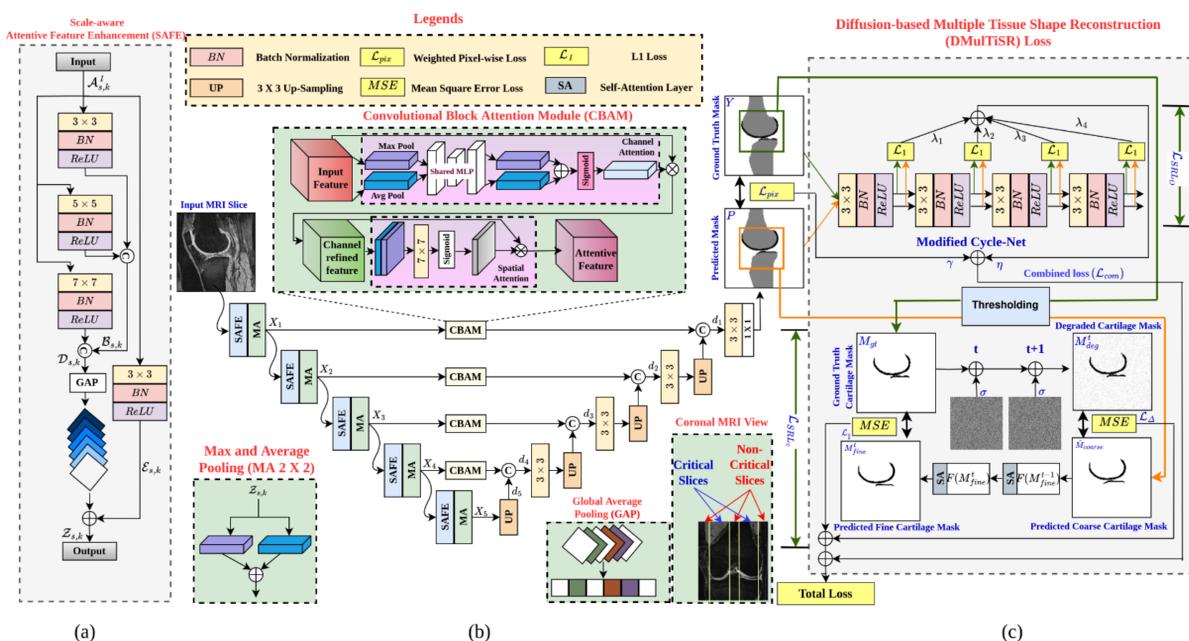
PROPOSED SCHEME

Figure: Schematic of (a) SAFE module and (c) DMultiSR loss function in MiSA-Unet model

Contributions

- **Multi-scale Attentive-Unet (MiSA-Unet) model** is end-to-end and single stage segmentation network unlike SOTA.
- **Scale-aware Attentive Feature Enhancement (SAFE) module:** To focus on multilevel spatial and channel context for accounting relevant local and global information.
- **Diffusion-based Multiple Tissue Shape Reconstruction (DMulTiSR) loss:** To address structural inaccuracies in the tibiofemoral bone and cartilages

EXPERIMENTS

Dataset Details

Dataset Size is 507 tibiofemoral segmentation maps for each MRI scan constituting of 160 slices with 3D DESS sequence.

Experimental Setup

Model is trained on NVIDIA A100 80 GB GPU for 100 epochs, 150*150 slice size, 150 batch size with learning rate of 0.03 and Adam optimizer.

Key Findings

- **For Critical MRI slices,** excellent results for FC and TC are obtained which are **nearly 4.5 % higher for DSC than modified cGAN.**
- **For all MRI slices,** average minimum improvement in DSC, VOE and HD are 0.24 % 9.85 % and 17.31 % respectively.
- Excellent results are obtained for FB and TB even **in presence of soft-tissue inflammation.**
- Cartilage performance if higher at **cartilage-cartilage interface which is critical for assessing the KOA subjects.**

Architecture	Metrics	FC	TC	FB	TB
Knee MRI Segmentation					
2D and 3D CNN + SSM (Ambellan et al., 2019)	DSC (%) ↑	89.9	85.6	98.5	98.5
	VOE (%) ↓	18.1	24.9	2.8	2.9
	HD (mm) ↓	5.35	6.35	2.93	3.16
*Modified cGAN (Kessler et al., 2020)	DSC (%)	89.5	83.9	98.5	98.5
	VOE (%)	18.92	27.55	–	–
2D-3D ensemble Unet (Latif et al., 2021)	DSC (%)	90.3	86.5	98.6	98.8
	VOE (%)	17.5	23.6	2.8	2.4
*Modified Unet++(Deng et al., 2021)	DSC (%)	90.9	85.8	99.1	98.2
nnUnet + Entropy Distance Maps (Li et al., 2022)	DSC (%)	89.8	86.4	98.6	98.6
	HD (mm)	5.22	4.70	11.82	5.30
Unet-S (Woo et al., 2022)	DSC (%)	89.7	89.8	98.7	98.7
	HD(mm)	5.58	4.74	4.05	3.82
*Modified Source-free UDA (Li et al., 2024)	DSC (%)	74.7	59.4	93.7	94.7
Other Network Architectures					
Unet (Ronneberger et al., 2015)	DSC (%)	88.6	87.0	98.3	98.3
	VOE (%)	20.06	22.41	3.34	3.29
	HD (mm)	6.69	5.23	6.12	4.05
Attention Unet (Oktay et al., 2018)	DSC (%)	88.7	87.1	98.3	98.2
	VOE (%)	19.62	22.16	3.33	3.24
	HD (mm)	6.88	5.56	6.00	6.46
HRnet (Wang et al., 2020)	DSC (%)	88.9	86.5	98.2	98.2
	VOE (%)	18.67	22.11	3.19	3.78
	HD (mm)	6.28	5.94	7.10	6.99
SAMed (Zhang et al., 2023)	DSC (%)	89.0	87.1	98.6	98.5
	VOE (%)	17.89	22.89	2.12	2.90
	HD (mm)	5.28	3.94	5.90	3.64
Proposed MiSA-Unet (Critical Slices Only)	DSC (%)	89.8	88.0	98.5	98.5
	VOE (%)	18.76	20.94	2.76	3.08
	HD (mm)	6.41	4.95	5.47	3.89
Proposed MiSA-Unet ⊖ (All Slices)	DSC (%)	90.4	90.1	98.7	98.6
	VOE (%)	17.22	18.97	4.09	2.9
	HD (mm)	4.74	3.11	2.54	4.32

● The best and second best results are denoted in red and blue colors, respectively. The * indicates the architectures specifically utilized for the knee MRI segmentation task, and The ⊖ indicates the model's testing on both critical and non-critical slices with the post-processing stage (similar to Deng et al.[1]).
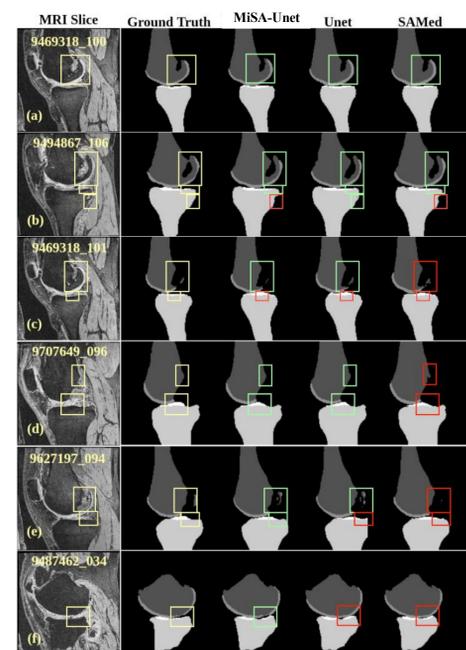
Figure and Table: Comparison of proposed MiSA-Unet with SOTA

Our Team

Prof. Arijit Sur, CSE, Project PI

Prof. Subramani Kanagaraj, ME, Project PI

Mr. Akshay Daydar Interdisciplinary Research Scholar (ME, CSE)

Mr. Alik Pramanick Research Scholar, CSE

Selected References

- Kellgren, J. H., & Lawrence, J. S. (1957). Radiological assessment of osteo-arthrosis. *Ann Rheum Dis*, 16(4), 494-502.
- Ambellan, F., Tack, A., Ehlke, M., & Zachow, S. (2019). Automated segmentation of knee bone and cartilage combining statistical shape knowledge and convolutional neural networks: Data from the Osteoarthritis Initiative. *Medical image analysis*, 52, 109-118.
- Deng, Y., You, L., Wang, Y., & Zhou, X. (2021). A coarse-to-fine framework for automated knee bone and cartilage segmentation data from the Osteoarthritis Initiative. *Journal of Digital Imaging*, 34(4), 833–840.
- Kessler, D. A., MacKay, J. W., Crowe, V. A., Henson, F. M. D., Graves, M. J., Gilbert, F. J., & Kaggie, J. D. (2020). The optimisation of deep neural networks for segmenting multiple knee joint tissues from MRIs. *Computerized Medical Imaging and Graphics: The Official Journal of the Computerized Medical Imaging Society*, 86(101793), 101793.