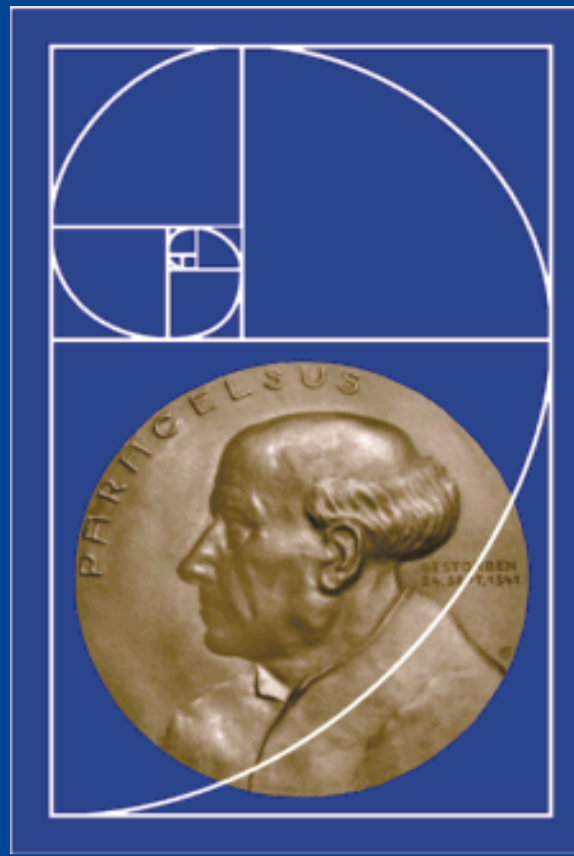


DO AUTOMATED, U-NET-BASED CARTILAGE SEGMENTATIONS FROM MRI BENEFIT FROM MANUAL QUALITY CONTROL AND CORRECTION? - DATA FROM THE IMI-APPROACH PROJECT

¹ Maschek S, ¹ Wisser A, ² Jansen M, ² Marijnissen AC, ² Lafeber F, ³ Lalande A, ² Weinans H, ⁴ Blanco FJ, ⁵ Berenbaum F, ⁶ Kloppenburg M, ⁷ Haugen IK, ⁸ Ladel CH, ⁹ Roemer FW, ¹ Eckstein F, ¹ Wirth W



¹Chondrometrics GmbH, Freilassing, Germany & Paracelsus Med. University, Salzburg, Austria, ²University Medical Center Utrecht, Utrecht, Netherlands, ³Servier, Suresnes, France, ⁴INIBIC-Universidade de A Coruña (UDC), A Coruña, Spain, ⁵Sorbonne University, Inserm, APHP Hôpital Saint-Antoine, Paris, France, ⁶Leiden University Medical Center, Leiden, Netherlands, ⁷Diakonhjemmet Hospital, Oslo, Norway, ⁸Consultant, ⁹University Hospital & University of Erlangen, Erlangen, Germany & Boston University School of Medicine, Boston, MA



Currently, quality-controlled manual cartilage segmentation is considered the “gold standard”, but automated, U-Net-based cartilage segmentations have been reported to provide a high accuracy, and sensitivity to cartilage thickness loss [1]. Still, the agreement between automated and manual segmentation is imperfect, particularly in knees with established radiographic osteoarthritis (OA).

OBJECTIVES

- 1) To evaluate the performance of automated, U-Net-based cartilage segmentations from MRI with and without additional manual quality control and correction (QC&C), and the time effort required for QC&C (Fig.1).
- 2) To compare automated segmentation with and without QC&C vs. the manual “gold standard” cross-sectionally as well as longitudinally, with change measured over 24 months.

METHODS

- Training and validation of 2D U-Nets:**
 - ✓ 2D U-Nets trained separately for the medial (MFTC) and the lateral (LFTC) femorotibial compartment of the knee using manual segmentations from 3D MRIs (IMI Approach Data)
 - ✓ Training set n = 100; validation set n = 25
- Application of the U-Net to:**
 - ✓ 26 knees with accelerated MFTC cartilage thickness loss over 2 years (BL and FU) according to manual segmentations
 - ✓ 16 knees without cartilage thickness loss according to manual segmentations
 - ✓ Age 67.2±6.8 years; 57% female
- Manual QC&C (Fig. 1):**
 - ✓ QC&C by 7 experienced readers
 - ✓ additional expert quality control
 - ✓ documentation of the time required for QC&C, of severe segmentation errors (U-Net), and of the consistency of U-Net segmentation across visits
- Statistics:**
 - ✓ DSC (Dice Similarity Coefficient) for agreement of automated vs. manual segmentation before and after QC&C
 - ✓ Cohen's D for the effect size of differences in cartilage change between manual- and U-Net-based segmentations without and with QC&C
 - ✓ Standardized Response Mean (SRM) for the sensitivity to change

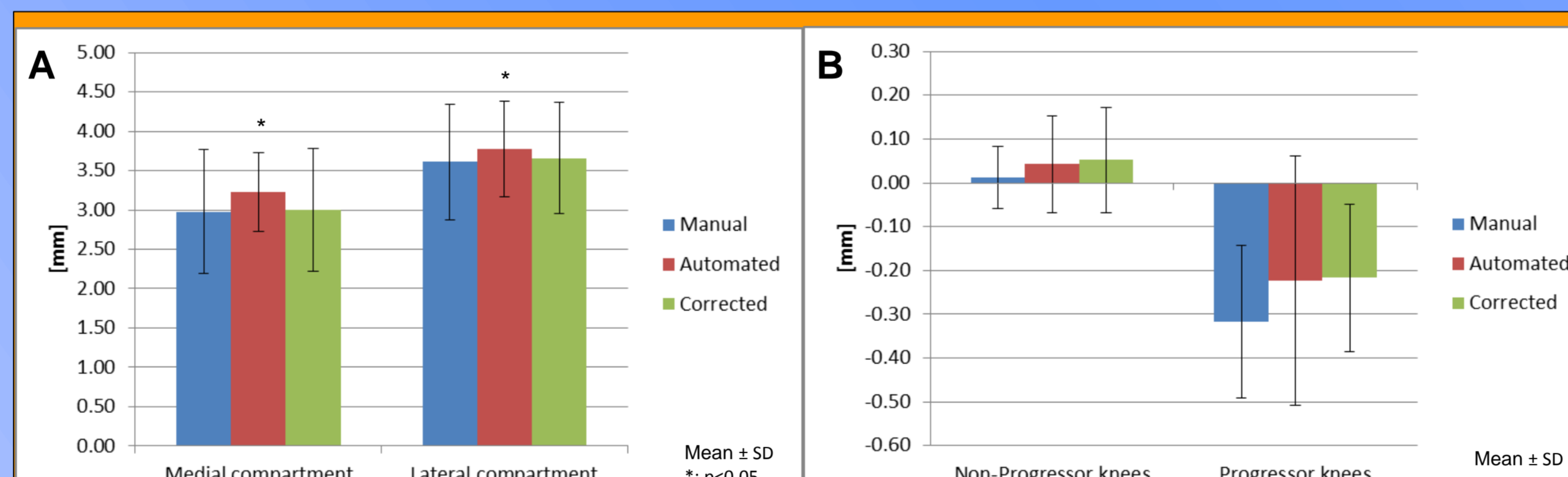
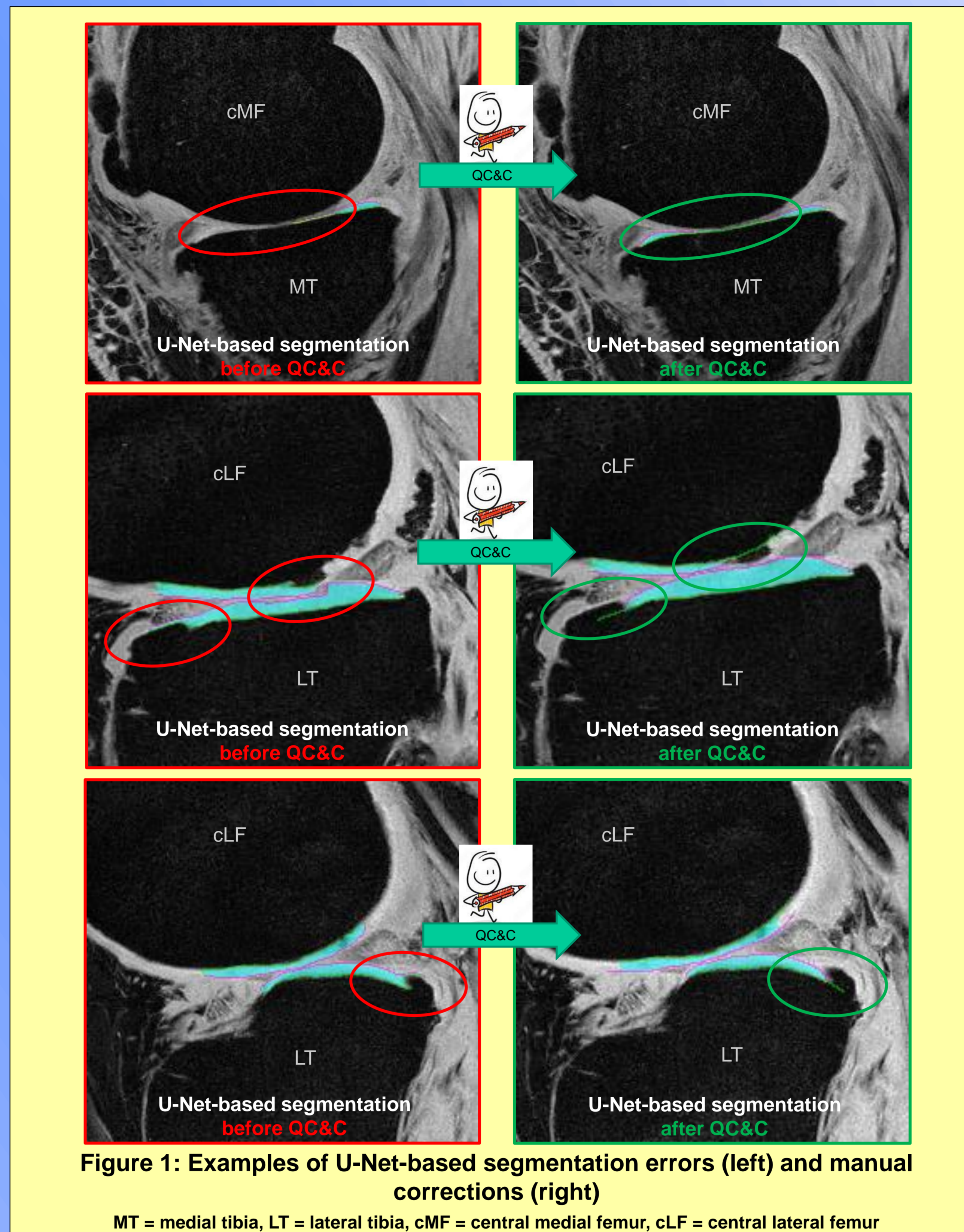


Figure 2: Baseline cartilage thickness entire sample (A) and 2-year cartilage thickness change (B) in the medial femorotibial compartment (MFTC)

1A: Effect size (Cohen's D) for differences in change (knees with vs. without cartilage loss)		1B: Sensitivity to change (SRM) in progressor knees in the MFTC	
Manual Segmentation (reference)	2.28	Manual Segmentation (reference)	-1.83
U-Net-based Segmentation before QC&C	1.13	U-Net-based Segmentation before QC&C	-0.78
U-Net-based Segmentation after QC&C	1.78	U-Net-based Segmentation after QC&C	-1.30

Table 1A: Effect size (Cohen's D) for differences in cartilage thickness change
Table 1B: Sensitivity to change (SRM=standardized response mean) in progressor knees in the medial femorotibial compartment (MFTC)

	Baseline cartilage thickness in the MFTC and LFTC					
	Manual segmentation		U-Net before correction		U-Net after correction	
	Thickness (mm)	Mean±SD [95% CI]	Thickness (mm)	Mean Diff. (mm) [95% CI]	Thickness (mm)	Mean Diff. (mm) [95% CI]
MFTC	2.98±0.79 [2.73, 3.22]	3.23±0.50 [3.07, 3.39]	0.25 [0.13, 0.38]	3.00±0.78 [2.76, 3.25]	0.03 [-0.03, 0.09]	
LFTC	3.61±0.74 [3.38, 3.84]	3.78±0.61 [3.59, 3.97]	0.17 [0.09, 0.25]	3.66±0.70 [3.44, 3.88]	0.05 [0.00, 0.10]	

	2-Year cartilage thickness change in the MFTC					
	Manual segmentation		U-Net before correction		U-Net after cCorrection	
	Thickness change (mm)	SRM	Thickness change (mm)	SRM	Thickness change (mm)	SRM
MFTC w/o cartilage loss	0.01±0.07 [-0.03, 0.05]	0.17	0.04±0.11 [-0.02, 0.10]	0.38	0.05±0.12 [-0.01, 0.12]	0.43
MFTC with cartilage loss	-0.32±0.17 [-0.39, -0.25]	-1.83	-0.22±0.29 [-0.34, -0.11]	-0.78	-0.22±0.17 [-0.28, -0.15]	-1.30

Table 2: Baseline cartilage thickness and 2-year cartilage thickness change observed from manual and U-Net-based segmentation before and after QC&C

RESULTS

- QC&C required approx. 60% of the time of fully manual segmentation but was subjectively reported to be quite tedious
 - The agreement (DSC) of manual segmentation vs. U-Net-based segmentation ranged from 0.83±0.12 to 0.89 ± 0.05 before and from 0.89 ± 0.06 to 0.92 ± 0.03 after QC&C
 - Before QC&C, baseline cartilage thickness was greater for U-Net-based than for manual segmentations in the MFTC (3.23 ±0.50mm vs. 2.98±0.79mm) and the LFTC (3.78±0.61mm vs. 3.61±0.74mm); After QC&C, cartilage thickness was closer to that from manual segmentations (Fig.2)
 - 2-year cartilage thickness loss in knees with MFTC cartilage loss tended to be lower both before and after QC&C than for manual segmentations (Fig.2B, Tab.2)
 - The effect size (COHEN's D) for differences in knees with vs. without cartilage thickness loss and the sensitivity to change (SRM) was greatest for manual segmentation followed by U-Net segmentations with QC&C (Table 1).

CONCLUSIONS

- The lower change observed with U-Net segmentations may partially be caused by a regression to the mean effect (selection of knees for greatest cartilage thickness loss derived from manual segmentations).
 - QC&C improved the agreement of automated vs. manual segmentations, but required a substantial amount of time.
 - QC&C also resulted in a greater effect size and a greater sensitivity to change for differences in cartilage thickness loss when compared to fully automated segmentations (without QC&C).

REFERENCES

[1] Eckstein et al., Arthritis Care & Res. 2022. 74(6),929-36

FUNDING

EU/EFPIA Innovative Medicines Initiative Joint Undertaking (grant n° 115770)

CONTACT

maschek@chondrometrics.de