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THE PROBLEM

Molecular fingerprinting is in the Fingerprint Visualisation Manual edited by the Defence Science and Technology Laboratory/Home Office¹ and is being used in Police casework. It encompasses the application of Matrix Assisted Laser Desorption Mass Spectrometry Imaging (MALDI MSI), for the provision of biometric information, through generating multiple molecular images of a given fingerprint, alongside contextual (molecular) information, thus substantially exceeding the capabilities of conventional forensic fingerprinting.² However, its wider operational adoption has been limited by the absence of dedicated, user-friendly software capable of efficiently processing and analysing fingerprint MS imaging datasets. Whilst both advanced freeware and proprietary MSI data analysis software exist, they are mostly built to process biological tissue imaging data and need expert users to be adapted to forensic application. Therefore, we developed iFIS (intelligent Fingerprint Imaging Software): a novel IT platform specifically designed for molecular fingerprinting. Critically, iFIS incorporates a machine learning algorithm automatically grading and finding fingerprint images of the highest quality within seconds, without manually having to inspect the entire mass range.

1. Bandey H, editor. Fingerprint visualisation manual. 2nd ed. Dstl and Home Office; 2022. 2. S. Francese, C. Heaton, Emerging Technologies: Use of Matrix Assisted Laser Desorption Ionisation Mass Spectrometry for the Analysis of Fingerprint and Blood Evidence, Royal Society of Chemistry, 2023. <https://doi.org/10.1039/BK9781837671922-00159>



First, vendor-neutral fingerprint MS imaging dedicated software enabling automatic fingerprint quality grading for fingerprint database comparison and suspect identification

Two versions available: "iFIS" for non-MSI experts (e.g. Law Enforcement) and "iFIS Ultra" for MSI expert users, integrating more complex image retrieval processing functionality



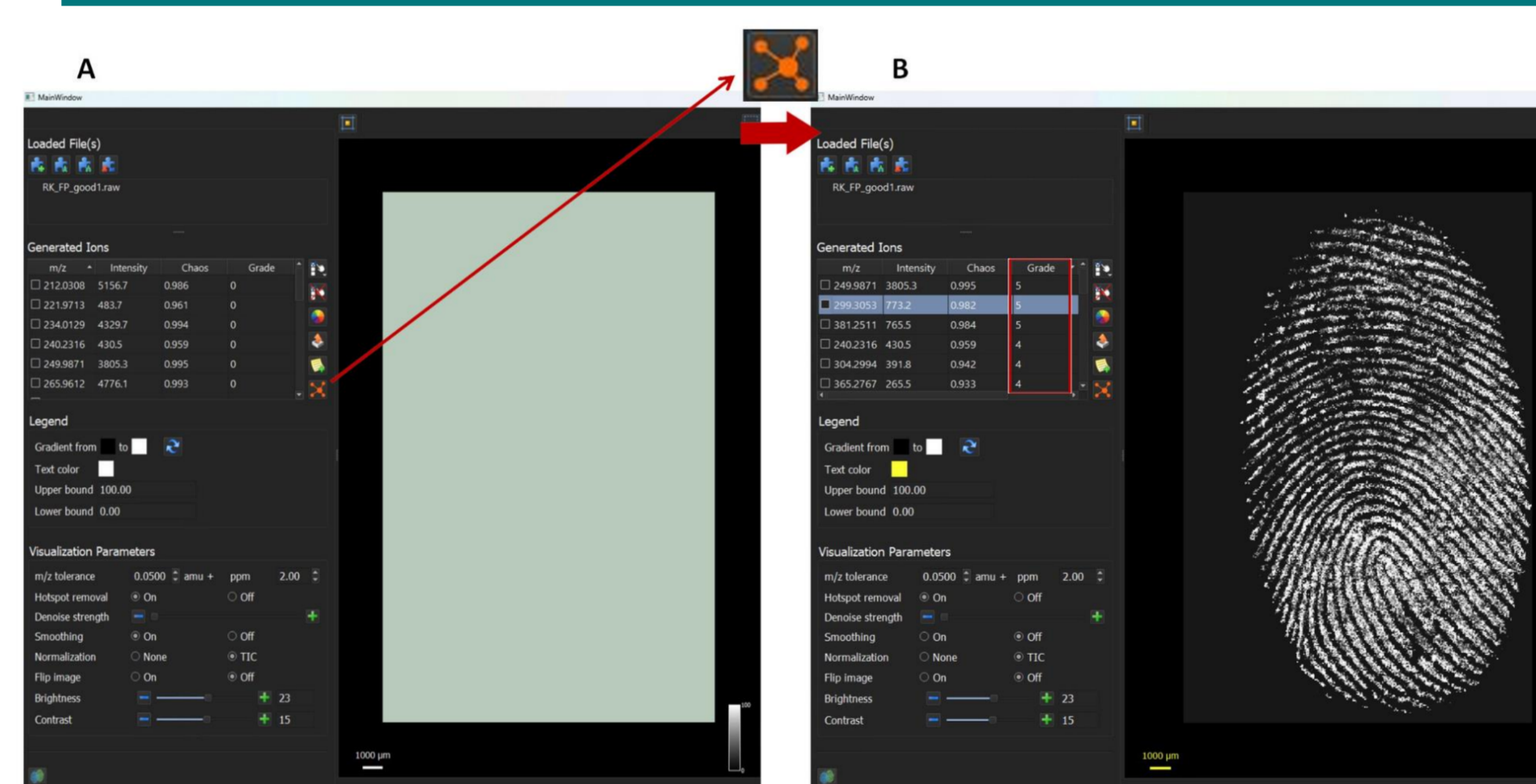
OUR SOLUTION: METHODOLOGY, RESULTS

- Fingerprint MALDI MS images were collected on glass, paper and aluminium, from 3 different digits for each donor, randomly to minimise data bias;
- Fingermarks were graded (i.e., scored from 0 based on ridge quality and the Scotland Yard System (SY) by West Yorkshire Police (UK));
- An AI model was trained to learn to categorize a subset of the total 663 fingerprint images collected according to the SY 5-point scale system. A range of deep feature extraction techniques and classification algorithms were explored, and the most proficient combination was to utilize deep visual features associated with Resnet50 pre-trained model along with selection of local compatible images for Support Vector Machine to classify a subset of (test) images, achieving 86% overall grading accuracy. Noteworthy, the machine learning grading can be trained/updated with newly acquired fingerprint imaging data;
- iFIS was designed and developed to be vendor neutral and comprehensive, integrating advanced MSI image analysis tools, statistical analysis for the seamless separation of overlapping fingermarks, and the machine-learning model that grades fingerprint images in seconds, enabling image selection and export into a "Law Enforcement-formatted report".



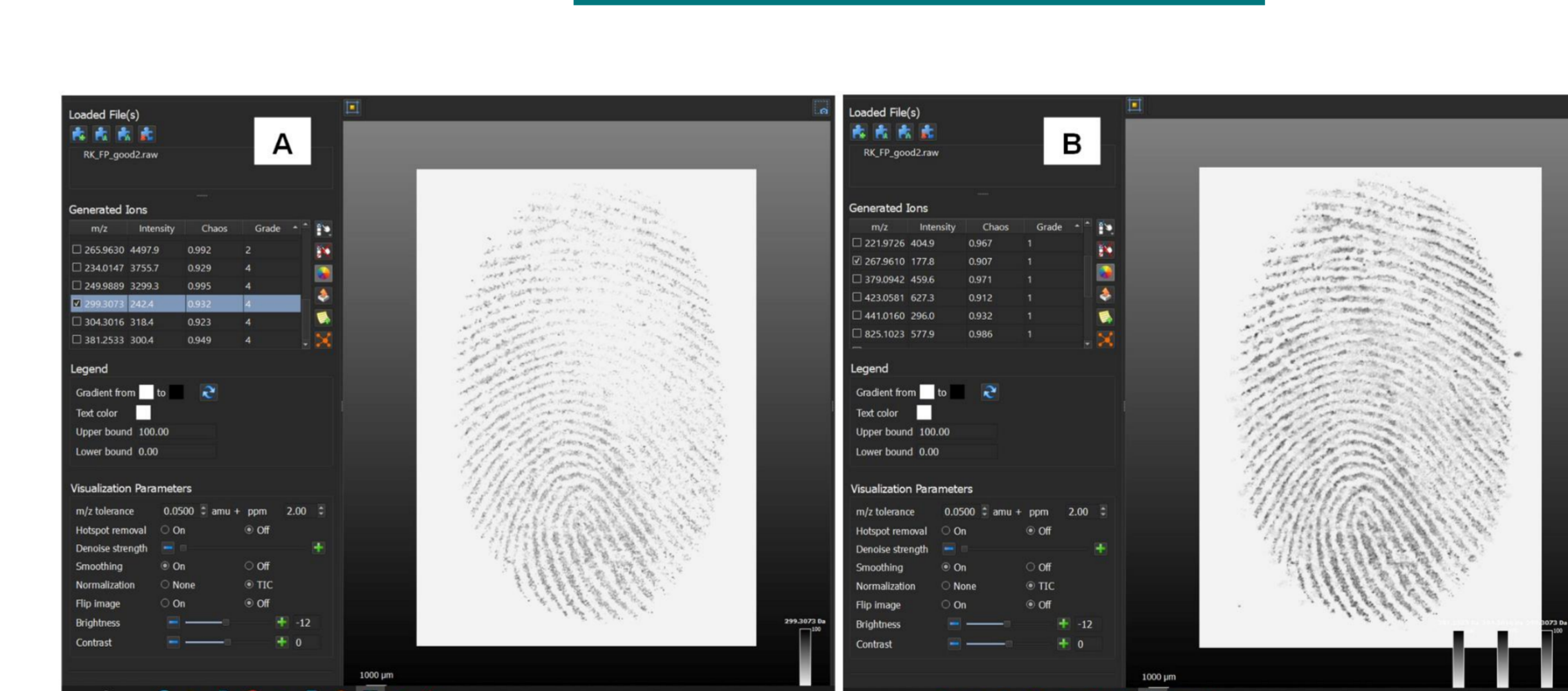
MSI METHODS: Fingermarks were matrix spray-coated using the HTX M3+™ Sprayer (HTX Technologies, USA) and imaged on a SELECT SERIES MRT MALDI mass spectrometer (Waters Corporation, UK) in positive mode. LipostarMSI (Mass Analytica, ES) - used as the skeleton to build iFIS - generated 663 images which were graded according to the 5-point scale Scotland Yard system machine learning model. The ML algorithm utilised a range of deep features based on the Resnet50 architecture corresponding to the visual characteristics of the fingerprint (minutiae and texture features). These were then fed to a Support Vector Machine-based classification algorithm for categorizing fingerprints into five distinct categories. The overlapping fingerprints dataset was imaged on a MALDI qTOF Synapt G2 HDMS (Waters Corp., Wilmslow, UK) system equipped with a neodymium: yttrium aluminium garnet (Nd:YAG) laser operated at 1 kHz. The laser power was set at 100 a.u., the sample plate voltage at 0 V, the extraction voltage at 10 V. The automatic quadrupole profile was selected and the data acquisition was made in the mass range 50 - 1200 Da in TOF (sensitivity) mode with a 0.2 sec scan time and at 100 µm pixel size.

FINGERPRINT ION IMAGE GRADING BY THE AI MODEL



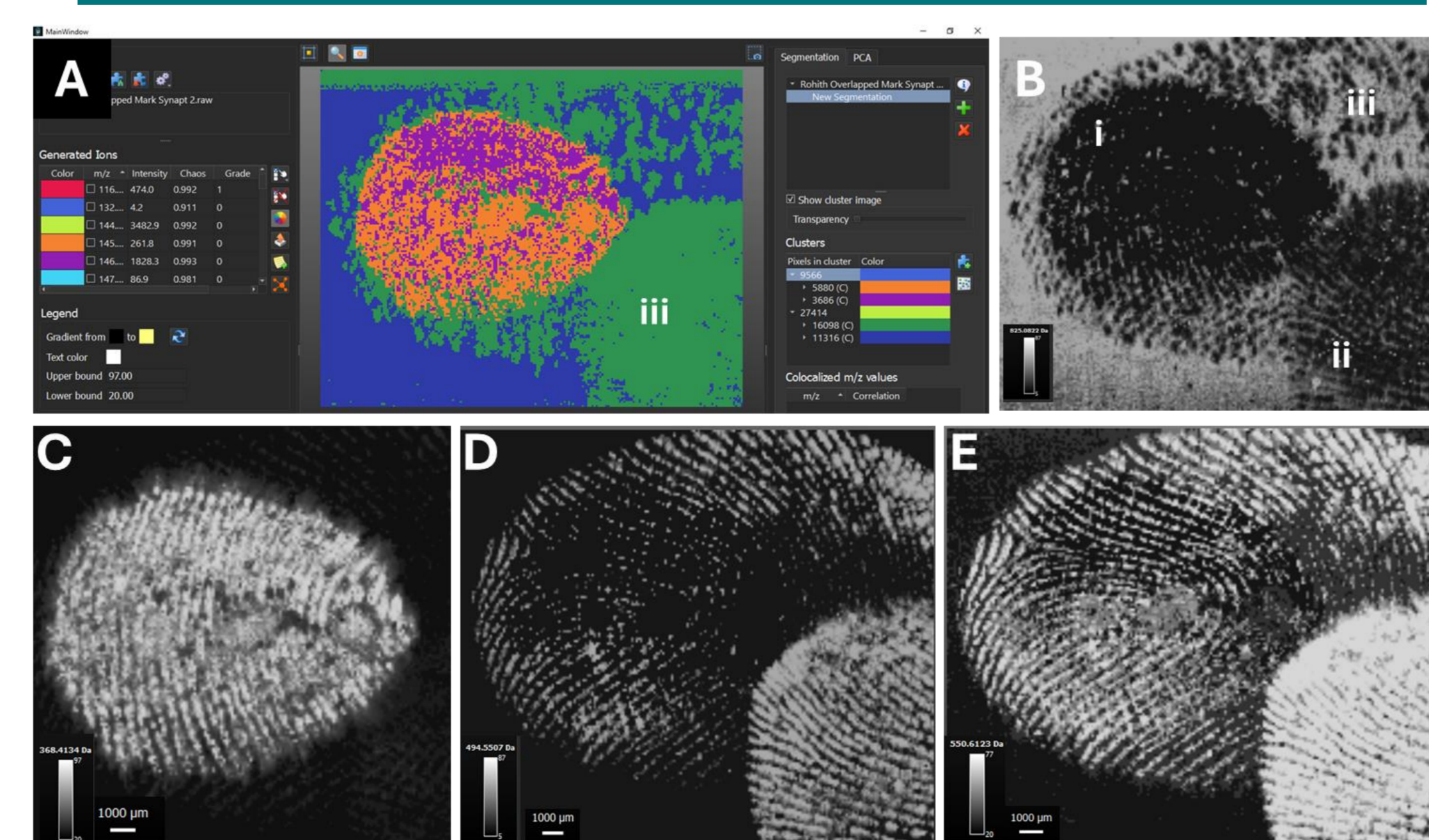
Panels A and B illustrate the interface when activating the grading algorithm function, yielding a grade for all the ions reported in the Table (panel B red square). Panel B shows the selection of the ion image that was scored 5 by the algorithm, according to the SY system.

MALDI MSI IMAGE OVERLAY



Panel A: ion image at m/z 299.3053; Panel B overlay of ion images at m/z 267.9610, 299.3053, 304.3016 and 381.2511.

SEGMENTATION ANALYSIS OF OVERLAPPING FINGERMARKS



Segmentation analysis of MALDI MSI of overlapping fingerprints. Three fingerprints could be distinguished in A (cluster image) and B (m/z 825.0822). The three marks are labelled in panel B as i-iii. Partial separation and recovery of ridge detail were achieved when imaging the cluster ions at m/z 368.4134 (C, mark i, complete separation), m/z 494.5507 (D, mark ii) and m/z 550.6123 (E, mark iii).

EXPORT INTO A "LAW ENFORCEMENT-FORMATTED REPORT"

