Skeleton ID

by Panacea Cooperative Research

What is it today?

The software structure & methods

Skeleton ID

Game-changing paradigm: digital analysis and comparison of 2D and 3D antemortem/postmortem data

Only requires a photo, an x-ray or dental records of the deceased as input data.

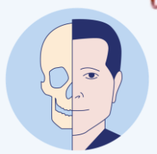
Full automation reduces effort **from hours/days to minutes**.

Makes large scale application possible (e.g. search on entire databases)

Up to 99,9% accuracy

CORE + VIRTUAL LAB

SUPPORTED IDENTIFICATION METHODS



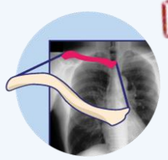
PATENTED

Craniofacial Superimposition



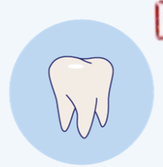
PATENTED

Biological Profile (only CORE)



PATENTED

Comparative Radiography



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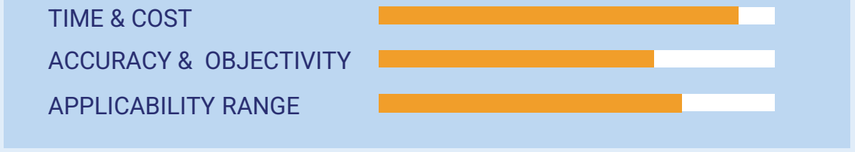
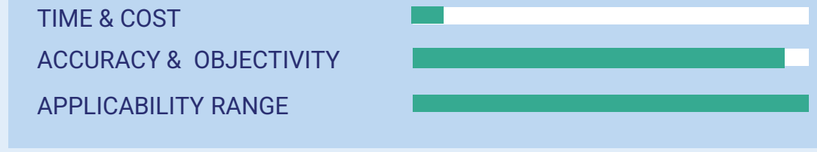
Dental Comparison (only CORE)



MANUAL
Skeleton-based Identification

VS

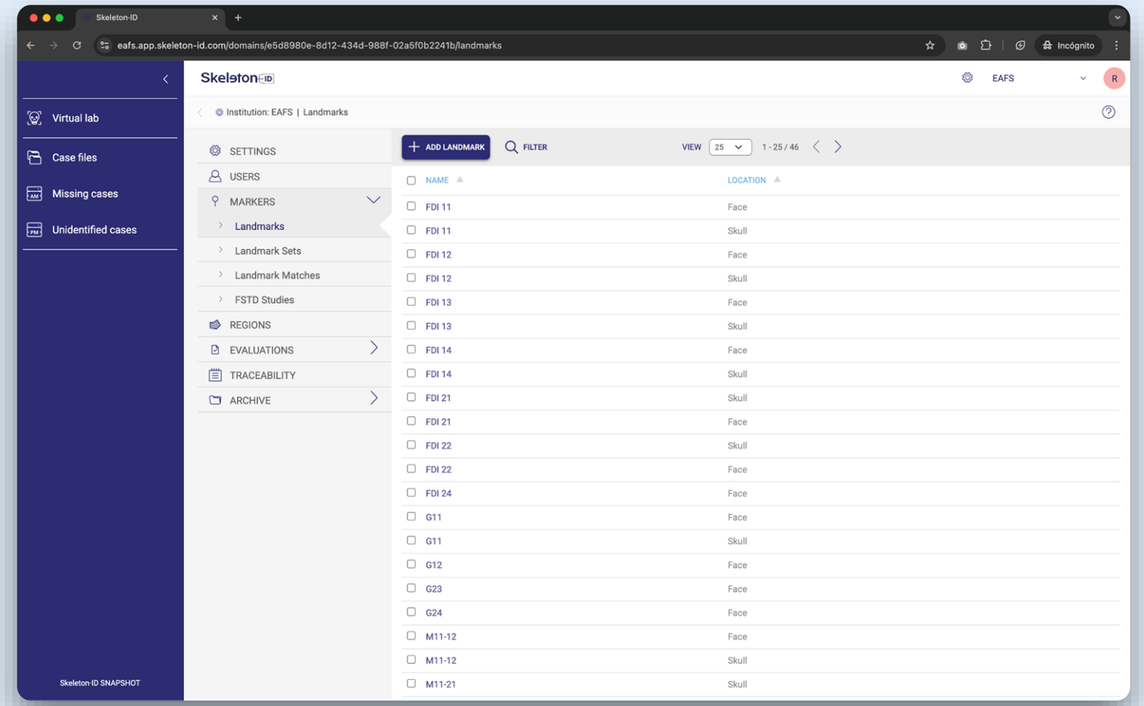
AUTOMATED
Skeleton-ID



Core

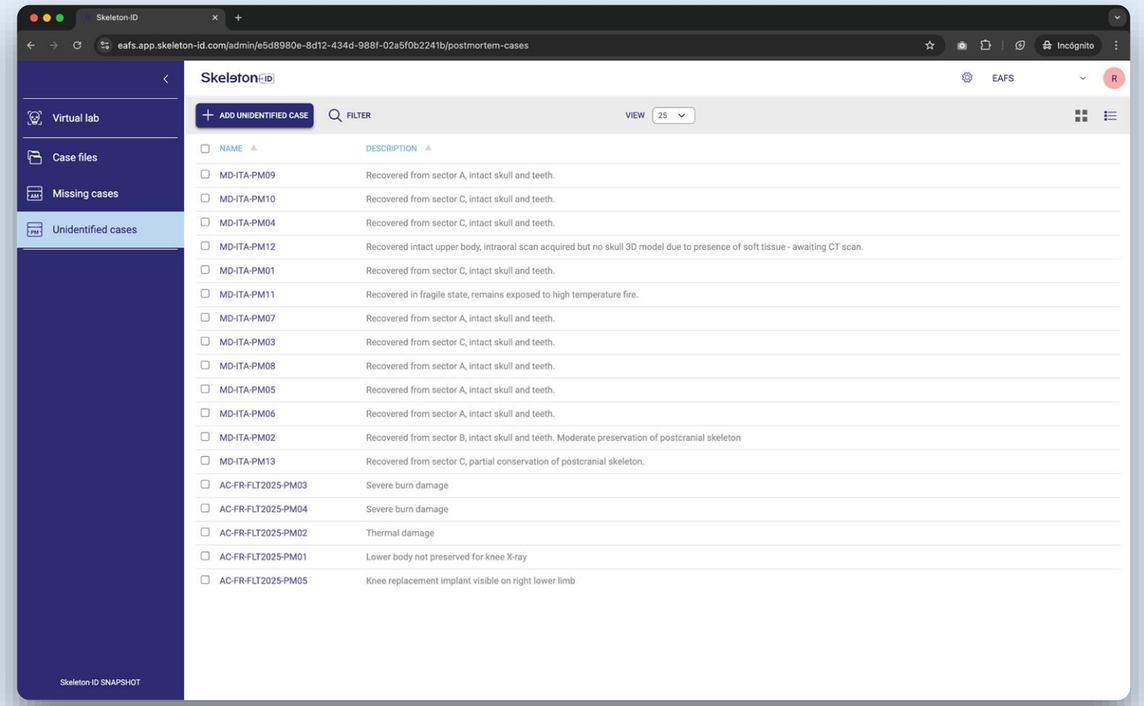
Skeleton ID Administration Panel allows:

- users and institution management;
- interface language (currently, English and Spanish);
- configuration of different menus;
- definition and selection of different criteria for the different ID techniques



Skeleton ID Databases allows:

- management missing persons, unidentified and case files (events) records;
- including all data of interest for the reconciliation / ID process (as in Interpol forms), including 2D and 3D images, body, skeleton or odontology description, belongings, etc.



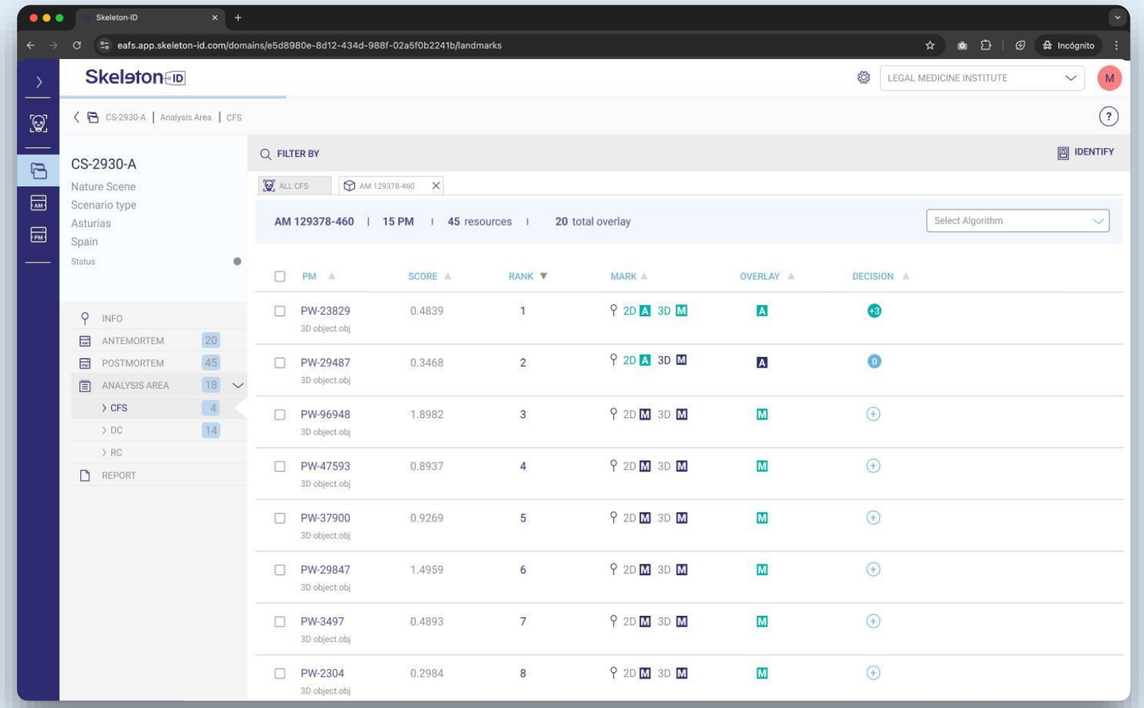
Core

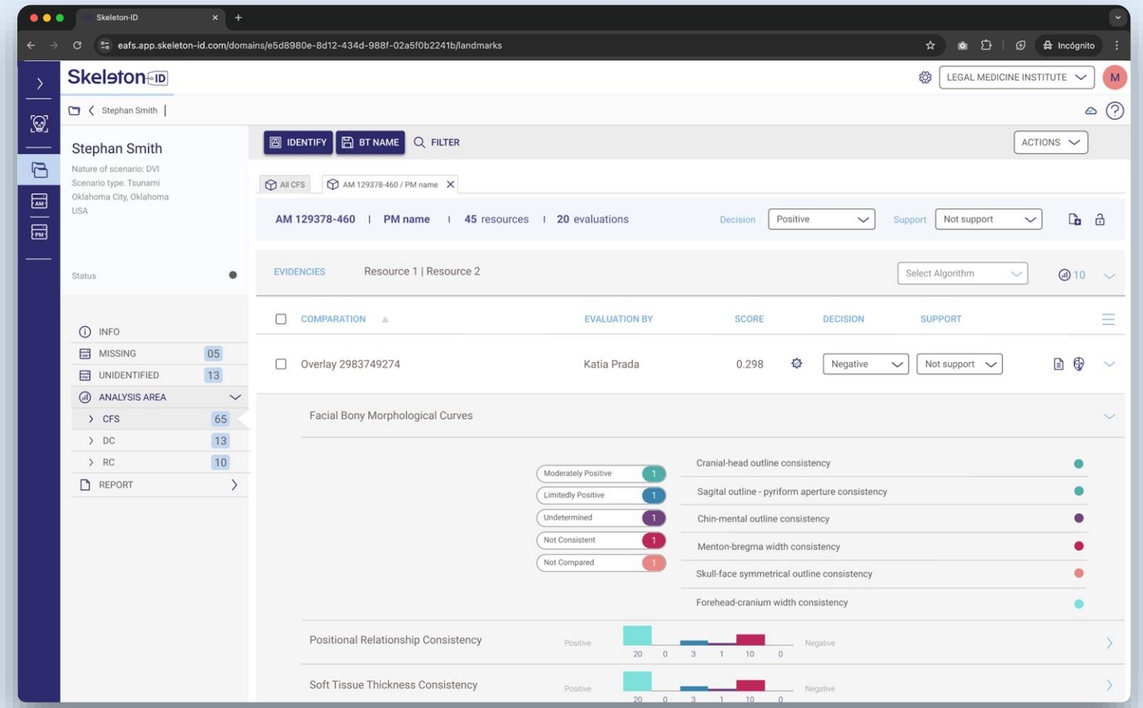
Skeleton ID Analysis Area allows:

- searching and filtering AM-PM cases (by age, sex, stature, population affinity, moment and location of disappearance);
- automatic multiple comparisons and ranking using different ID techniques.

Skeleton ID Evaluation Area allows:

- the fulfilment of standards / best practices by presenting a complete list of criteria to be evaluated and facilitate decision making at different hierarchical levels;
- writing reports for each ID technique as well and attach external reports and generate an integral report;
- close, download and edit reports outside Skeleton-ID





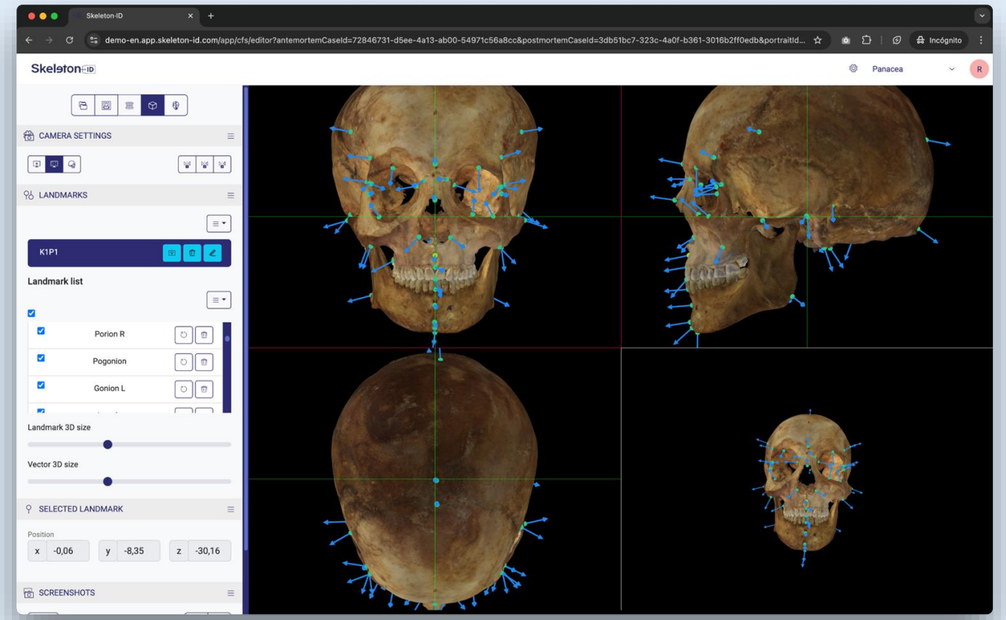
Skeleton ID

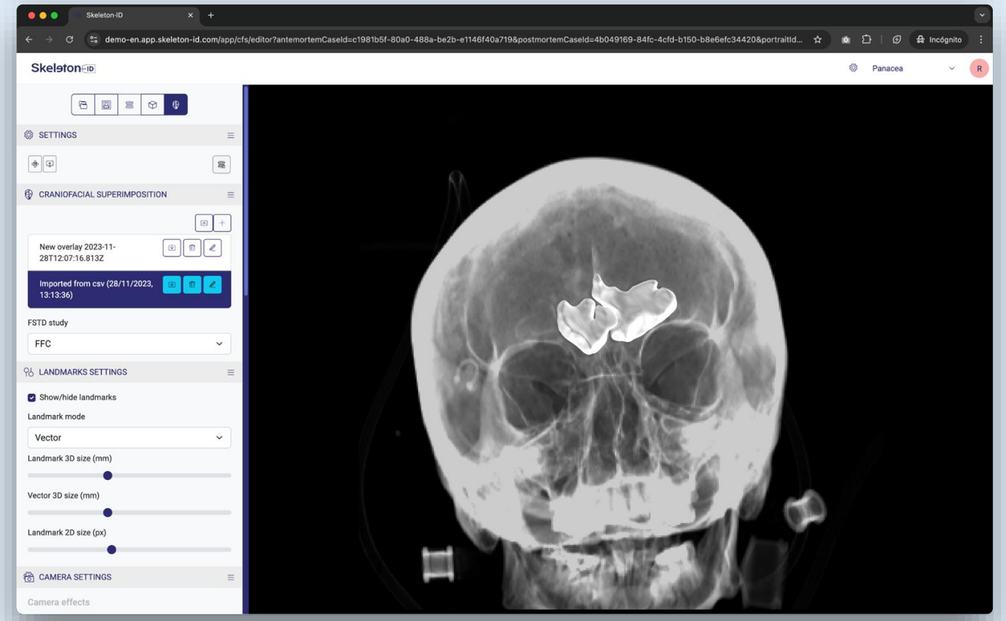
Panacea COOPERATIVE RESEARCH

The Virtual Lab

A unique web-based graphical engine with tools specifically designed for AM-PM evidence comparison

- 2D image handling: zoom, pan, landmark location, draw contours and regions
- 3D image handling: meshes and volumetric, set reference plane, multi-camera view, rotation-translation, landmark location
- 3D-2D scenes: 3D to 2D projection with different camera models, ad-hoc camera operations (photography, radiography, panorama), 3D-2D registration/overlay, transparency and sweep.
- Obtain and save screenshots, work with different tabs, autosaving, change colors, size and name of landmarks / regions, change sensitivity of the mouse, etc.









Biological Profile Estimation

Biological Profile Estimation

SKELETON-ID MODULE

Introduction of quantitative variables

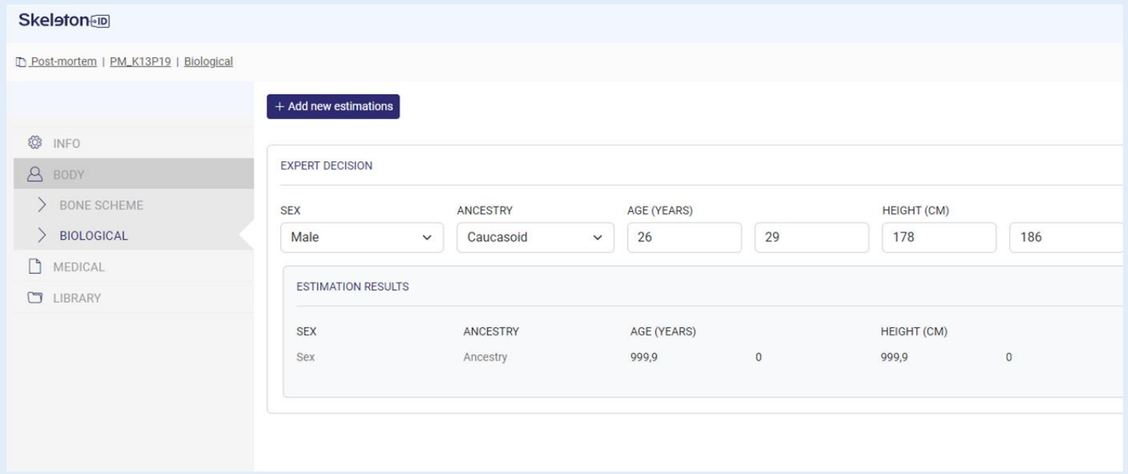
Linear measurements, perimeters or volumes and automatic calculation of indices

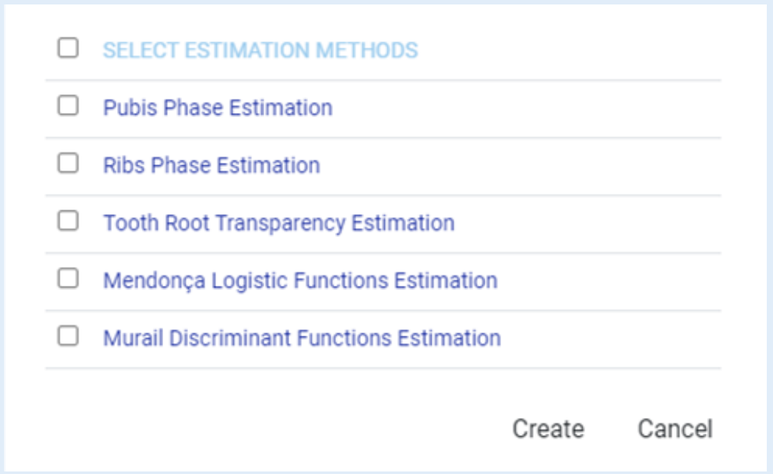
Drop-down forms for entering qualitative variables

Stages of development or degeneration, presence or absence of bone characteristics, suture closure processes, etc.

Viewing and analyzing images and X-rays

Morphological analysis
Delimitation of surfaces and analysis of their relationships
Location of morphological features
Manual comparison with photographic models and developmental atlases







Dental Comparison

Dental Comparison

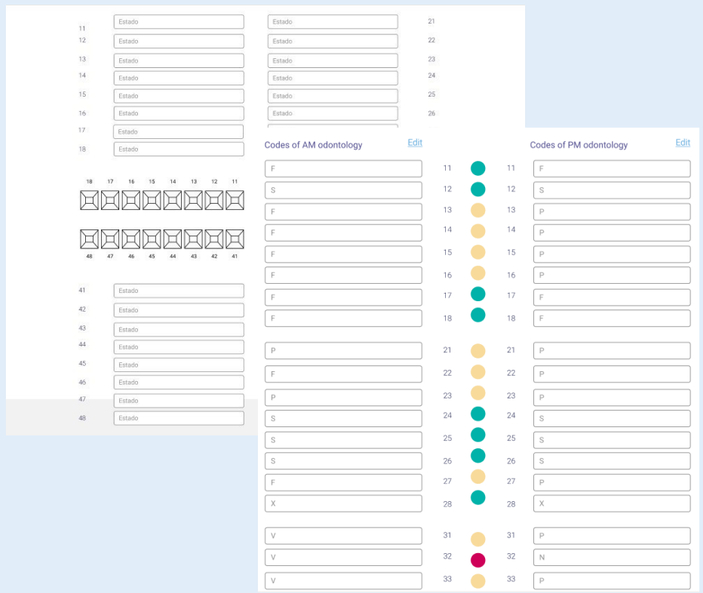
SKELETON-ID MODULE

Dental charts

Form to introduce AM and PM dental charts using FDI, Universal, Haderup or Palmer standards

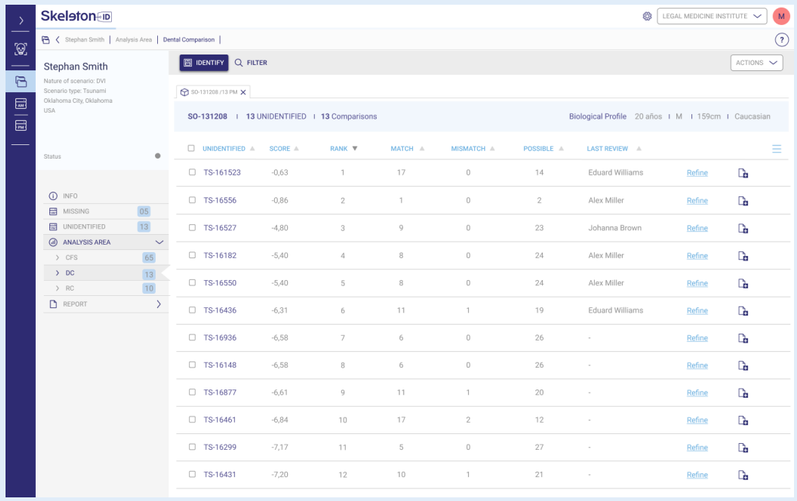
Simplified coding systems using only 7 dental codes

In the future other codification sets will be included: Interpol (41)



Automatic comparison and ranking

It allows to automatically compare large amounts of AM-PM dental records in a matter of seconds. It provides a ranking based on the number of consistent codes, explainable inconsistencies, and not explainable inconsistencies.
It also features a "traffic light" view to analyze (and refine if necessary) each AM-PM comparison.
Mean average ranking (where the positive case is ordered in mean) = 2.
Scientific publication pending, results presented in AAFS 2024 (Denver).



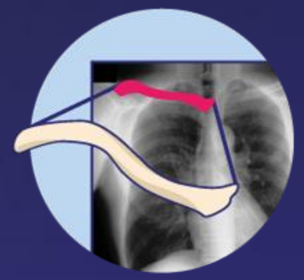
Automatic Dental Superimposition of facial photos and 3D dental models (intraoral scans)

Mean average ranking (using dental landmarks) = 1.6

Mean average ranking (using dental contours) = 1.1

Scientific publication pending, results presented in EAFS 2025 (Dublin)





Comparative Radiography

Comparative Radiography

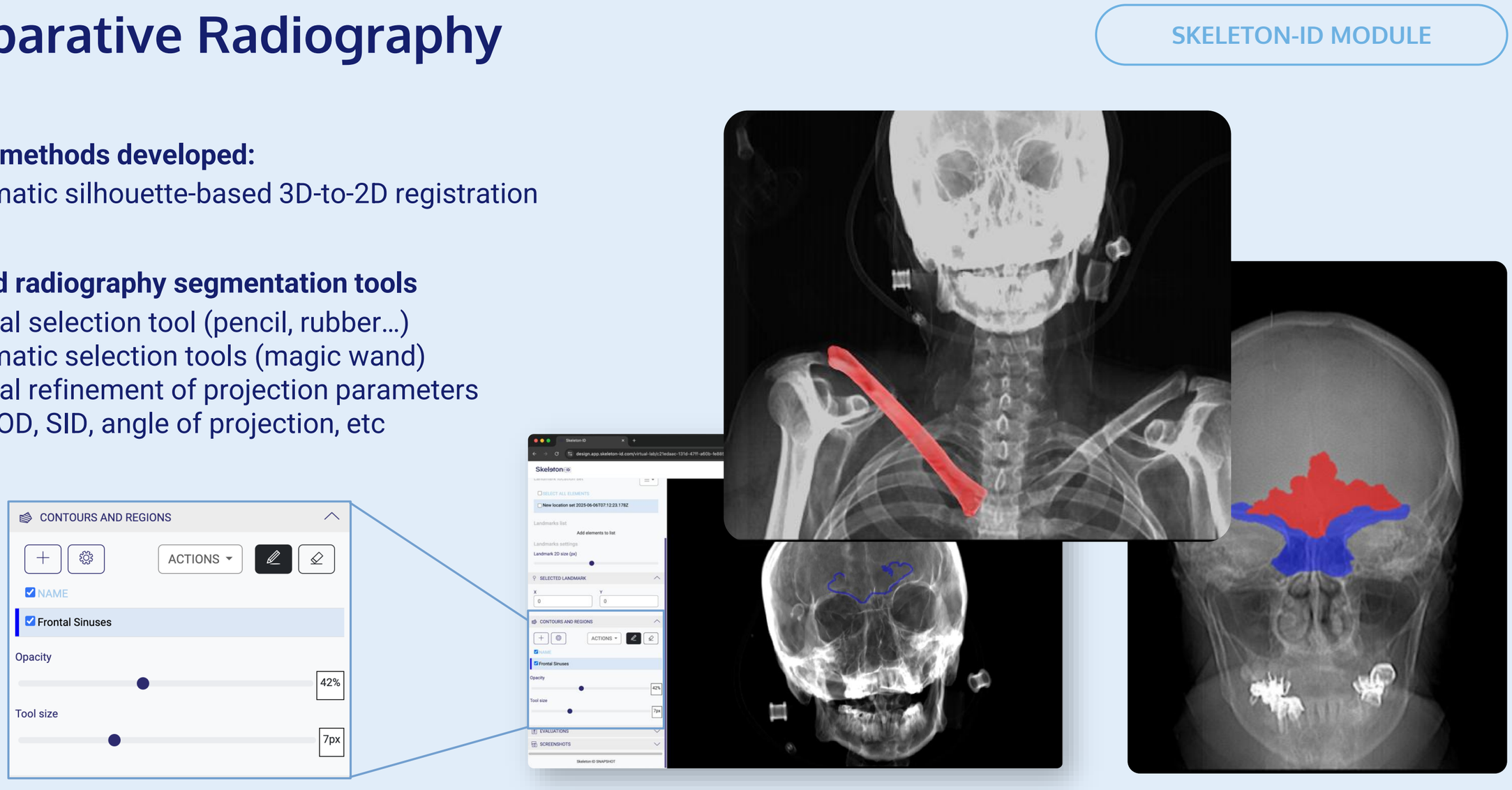
SKELETON-ID MODULE

AI-based methods developed:

- Automatic silhouette-based 3D-to-2D registration

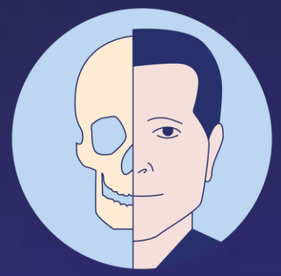
Integrated radiography segmentation tools

- Manual selection tool (pencil, rubber…)
- Automatic selection tools (magic wand)
- Manual refinement of projection parameters
  - SOD, SID, angle of projection, etc



O. Gómez, P. Mesejo, O. Ibáñez et al. **Evaluating artificial intelligence for comparative radiography**. International Journal of Legal Medicine 138, 307–327 (2024).
O. Gómez, P. Mesejo, O. Ibáñez et al. **Deep architectures for high-resolution multi-organ chest X-ray image segmentation**. Neural Computing & Applications 32, 15949–15963 (2020).

O. Gómez, P. Mesejo, O. Ibáñez, O. Cordón. **Deep architectures for the segmentation of frontal sinuses in X-Ray images: towards an automatic forensic identification system in comparative radiography.** Neurocomputing, 456 (2021), 575-585.



Craniofacial Superimposition

Skeleton ID

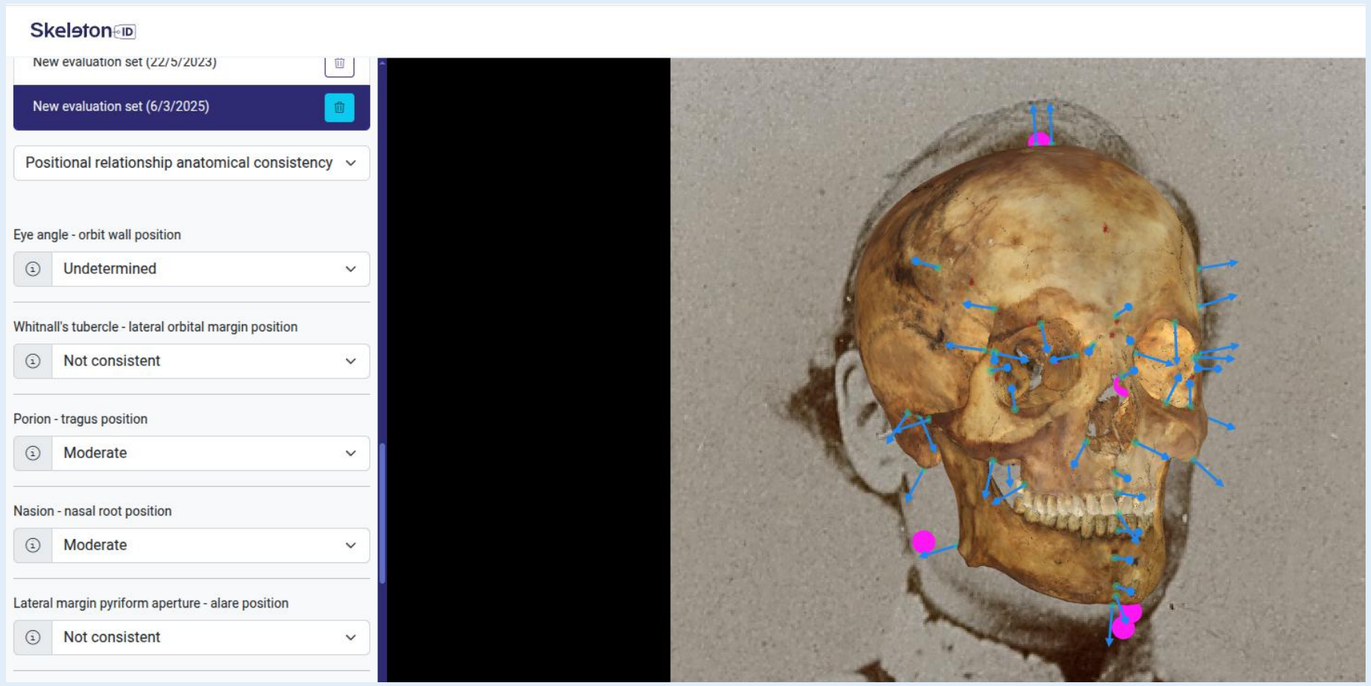
Panacea
COOPERATIVE RESEARCH

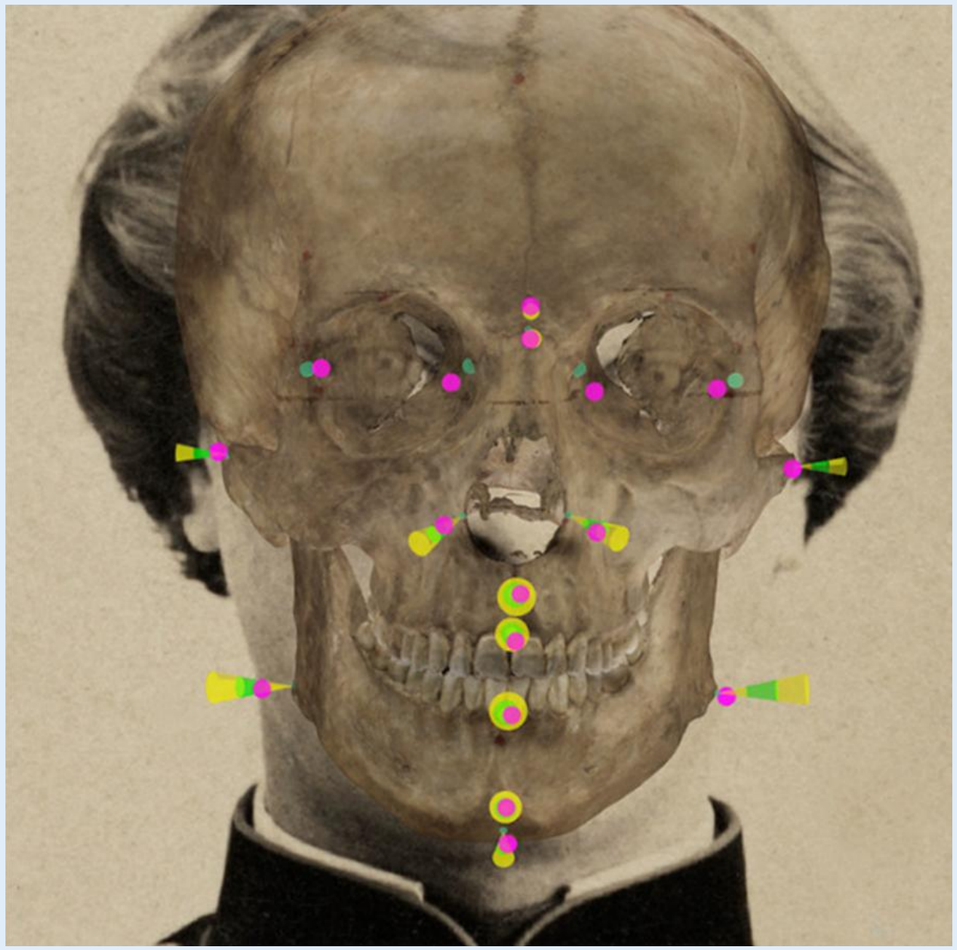
Craniofacial Superimposition

SKELETON-ID MODULE

Dedicated tools in the Virtual Lab to analyse, refine and evaluate skull-face overlays

- Automatic mandible-cranium attachment algorithm
- Mathematical modelling of TMJ roto-translation to simulate that in the facial photo
- List of anatomical correspondence criteria in the 3D-2D scene





Skeleton ID

Panacea COOPERATIVE RESEARCH

Craniofacial Superimposition

SKELETON-ID MODULE

AI-based methods developed and available in Skeleton-ID:

- Automatic location of 30 cephalometric landmarks in facial photographs
  With an error of 1.1% of the face width
- Automatic location of 58 craniometric landmarks in skull 3D models
  With error below the inter-observer error in 82% of cases
- Automatic 3D Skull- 2D Facial photo superimposition
  With an average error of 2.0 mm
- Automatic multi-comparison and ranking using the previous three algorithms
  With an average ranking of 2.2, i.e., the positive case is within the first 4 positions in 75% of the cases

Software tools and algorithms validated in two international validation studies:

- 25 Contemporary cases: rate of correct decisions ranging from 91.5% (overall average of ten analysts) to 100% (experienced analysts)
- 11 Historical cases: rate of correct decisions of 100% (experienced analysts)

G. Gomez-Trenado, P. Mesejo, O. Cordon. **Cascade of convolutional models for few-shot automatic cephalometric landmarks localization**. Engineering Applications of Artificial Intelligence, Volume 123, Part B, 2023

E. Bermejo, K. Taniguchi, Y. Ogawa, R. Martos, A. Valsecchi, P. Mesejo, O. Ibáñez, K. Imaizumi. **Automatic landmark annotation in 3D surface scans of skulls: Methodological proposal and reliability study.** Computer Methods and Programs in Biomedicine, Volume 210, 2021.

A. Valsecchi, S. Damas and O. Cordón, **A Robust and Efficient Method for Skull-Face Overlay in Computerized Craniofacial Superimposition**," in IEEE Transactions on Information Forensics and Security, vol. 13, no. 8, pp. 1960-1974, 2018

R. Martos, R. Guerra, F. Navarro, M. Peruch, K. Neuwirth, S. Valsecchi, R. Jankauskas, O. Ibáñez. **Computer-aided craniofacial superimposition validation study: the identification of the leaders and participants of the Polish-Lithuanian January Uprising (1863-1864)**. International Journal of Legal Medicine 2024;138(1):107-121.

R. Guerra, R. Martos, O. Ibáñez, A. Valsecchi, E. Bermejo, S. De Luca et al. **International validation study of AI-guided Craniofacial Superimposition in a contemporary population sample.** Submitted to Forensic Science International.

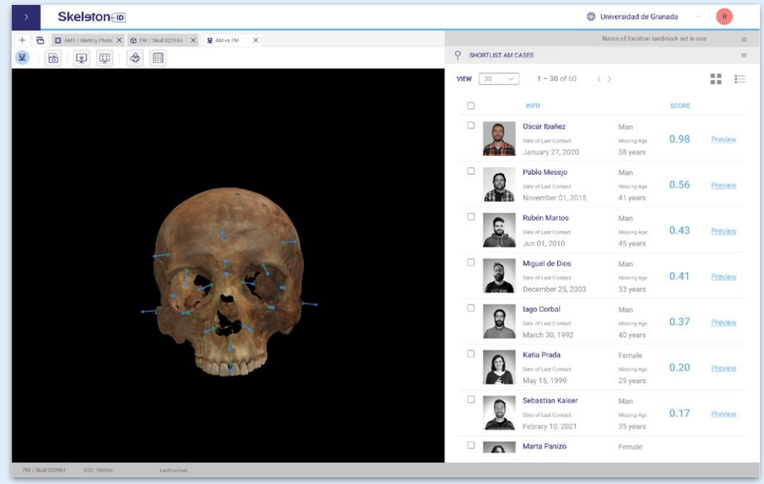
How it works?



3D scan of a skull
as comparison PM data

1

2



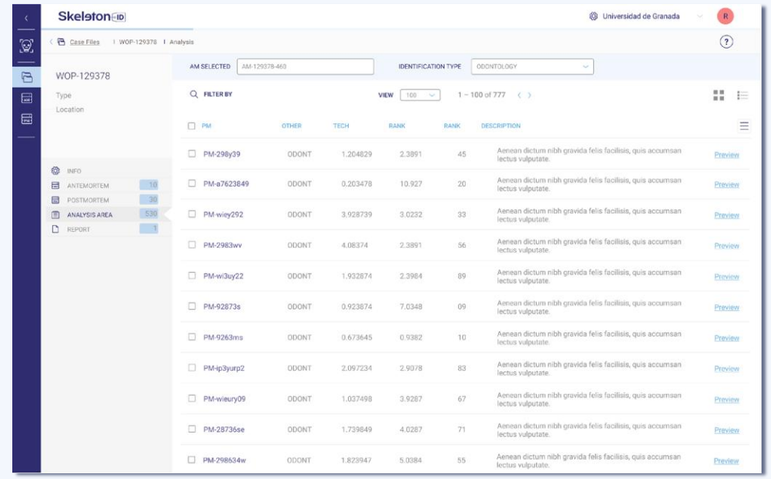
One or more photographs of the face as
data input

3

4



Automatic 3D-2D
craniofacial superimposition



AI creates a ranking of potential candidates
and provides a matching score

Skeleton ID

Skeleton ID

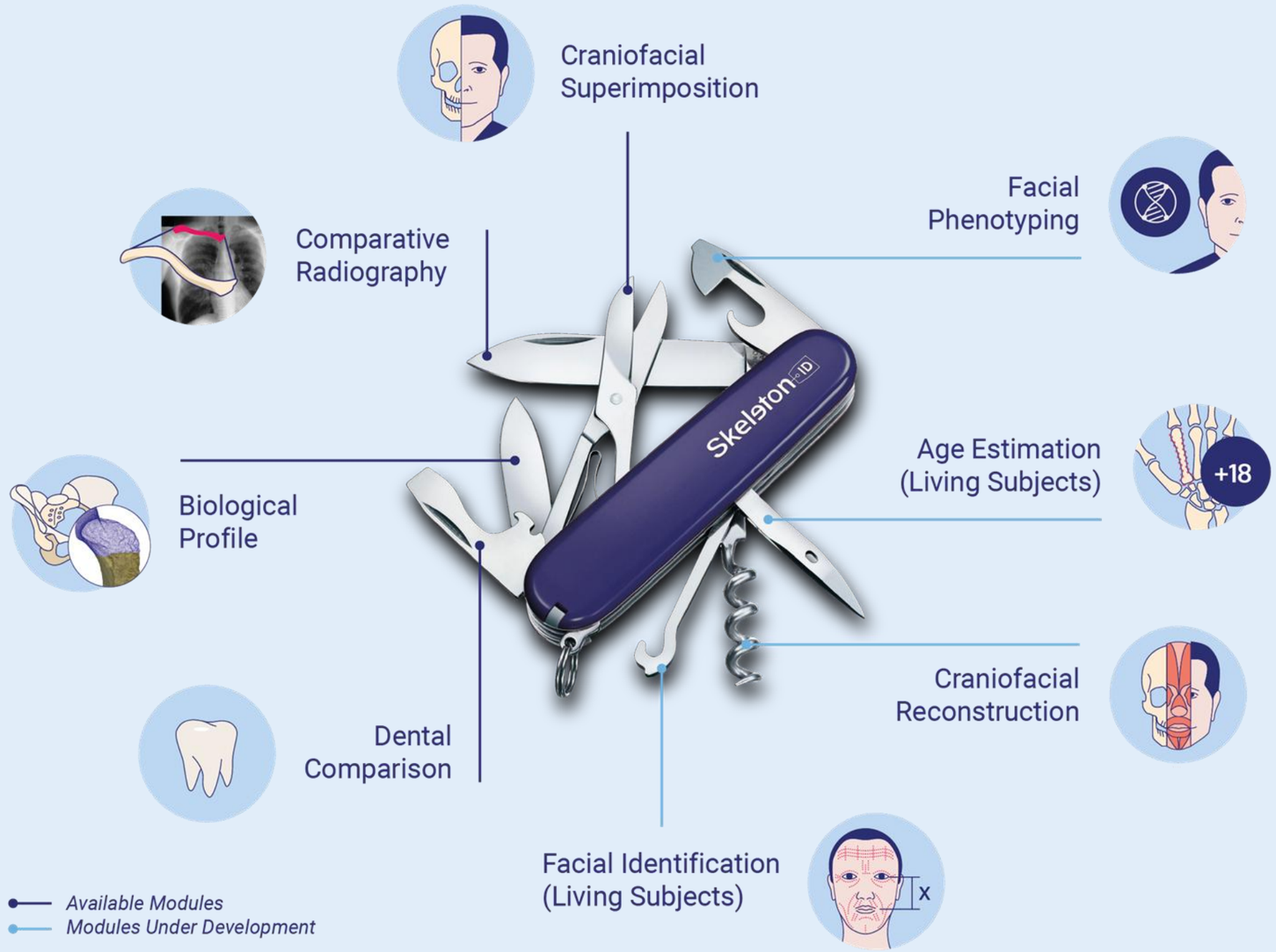
by Panacea Cooperative Research

What are we working on?

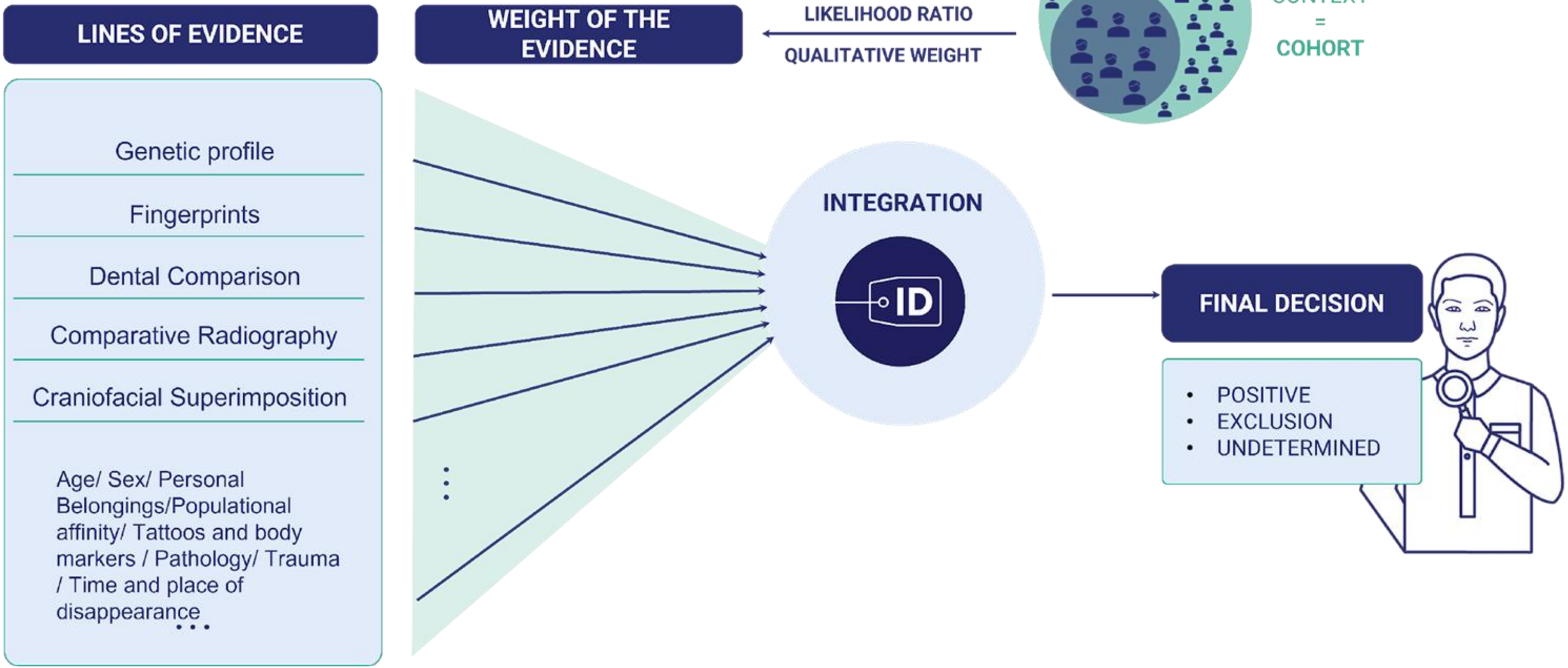
On-going Research / Future Vision

Combining AOF methods with AI allows us to apply these methods on a large scale and eliminate the limitations of manual application.

The technological advance is of similar importance to the development of automated fingerprint identification systems in the 1980s.



Integral support for the identification process: decision support



Biological Profile Estimation

SKELETON-ID MODULE

AI-based methods developed (not yet integrated in Skeleton-ID)

Explainable semi-automatic biological profile estimation

- Age based on macroscopic observations of the pubic symphysis (adults) MAE: 7.51 years
- Age based on up to 64 macroscopic observations of the entire skeleton (adults) MAE: 6 years

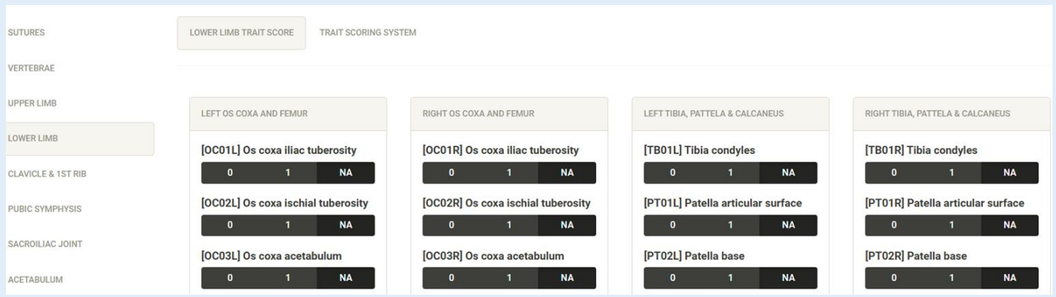
Fully automatic biological profile estimation from images

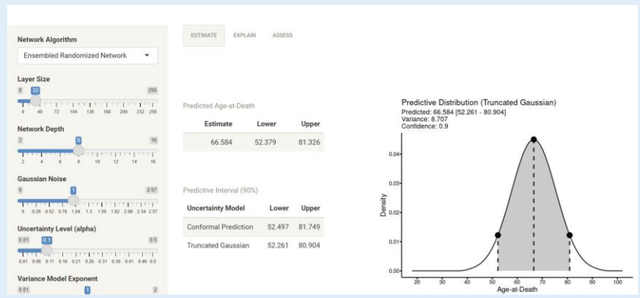
- Sex using one photo of the ilium (0-3 years) 59%
- Sex using one photo of the humerus (adults) 91%
- Age using one 3D model of the pubic symphysis (adults) MAE: 8.33 years

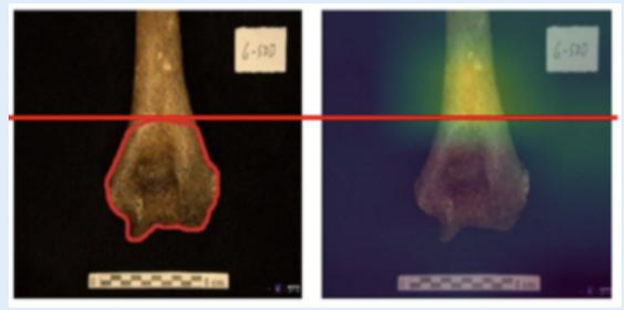
ONGOING RESEARCH

Development (collaborations with Universities of Granada, Coimbra and A Coruña) of automatic methods from:

- Photographs and 3D models of individual bones
- Multifactorial approach using images of different anatomical regions
- Explainable AI methods







E. Bermejo, A.D. Villlegas, J. Irurita, S. Damas, O. Cordón. **Explainable Machine Learning for Age-at-death Estimation from the Pubic Symphysis**. Expert Systems. 2025, 42:3

J.C. Gámez-Granados, J. Irurita, A. González, S. Damas, I. Alemán, O. Cordón. **Automating the decision-making process of Todd's age estimation method from the pubic symphysis with explainable machine learning**. Information Sciences (2021).

D. Navega, E. Costa, E. Cunha. **Adult Skeletal Age-at-Death Estimation through Deep Random Neural Networks: A New Method and Its Computational Analysis.** Biology (Basel) 2022, 11(4); 532.

J. Venema, D. Peula, J. Irurita, P. Mesejo. **Employing deep learning for sex estimation of adult individuals using 2D images of the humerus**. Neural Computing and Applications (2022).

R.F. Ortega, E. J. Estévez, J. Irurita. P. Mesejo. **Analysis of the performance of machine learning and deep learning methods for sex estimation of infant individuals from the analysis of 2D images of the ilium**. International Journal of Legal Medicine, 135-6 (2021), 2659-266.

A. Manzanares , M. Bello, P. Mesejo, O. Cordón**. Age-At-Death Estimation from 3D Models of the Pubic Symphysis by using a Deep Multi-View Learning Approach**. Submitted to Neurocomputing.

Skeleton ID

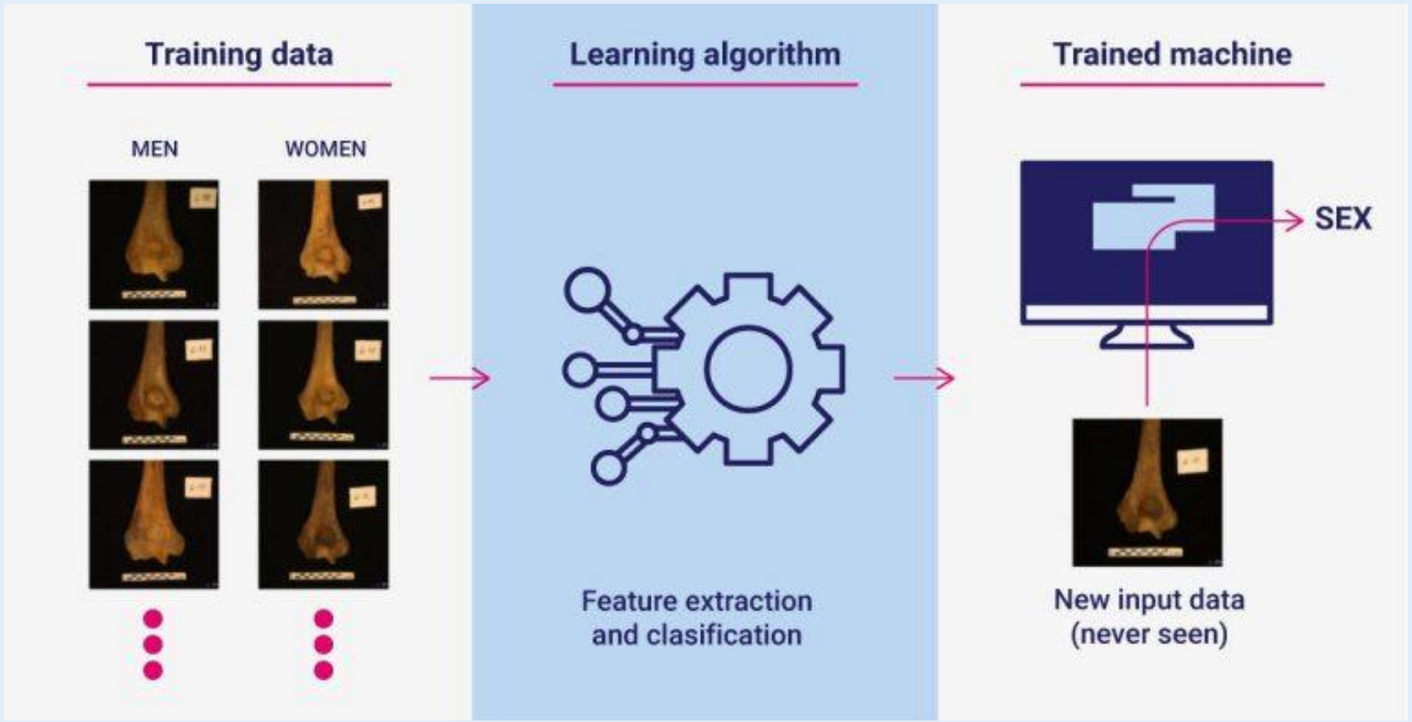
Panacea COOPERATIVE RESEARCH

Biological Profile Estimation

SKELETON-ID MODULE

ONGOING RESEARCH

AI-based methods developed (not yet integrated in Skeleton-ID)





El individuo es hombre con una probabilidad de 99.03%

Dental Comparison

SKELETON-ID MODULE

Automatic teeth segmentation, labelling and codification (paper to be written)

- Automatic segmentation and labelling algorithm finished
- Working on automatic coding according to Simplified Codification System

Automatic Dental Superimposition of panoramic x-rays and 3D dental models (close to submit a paper)

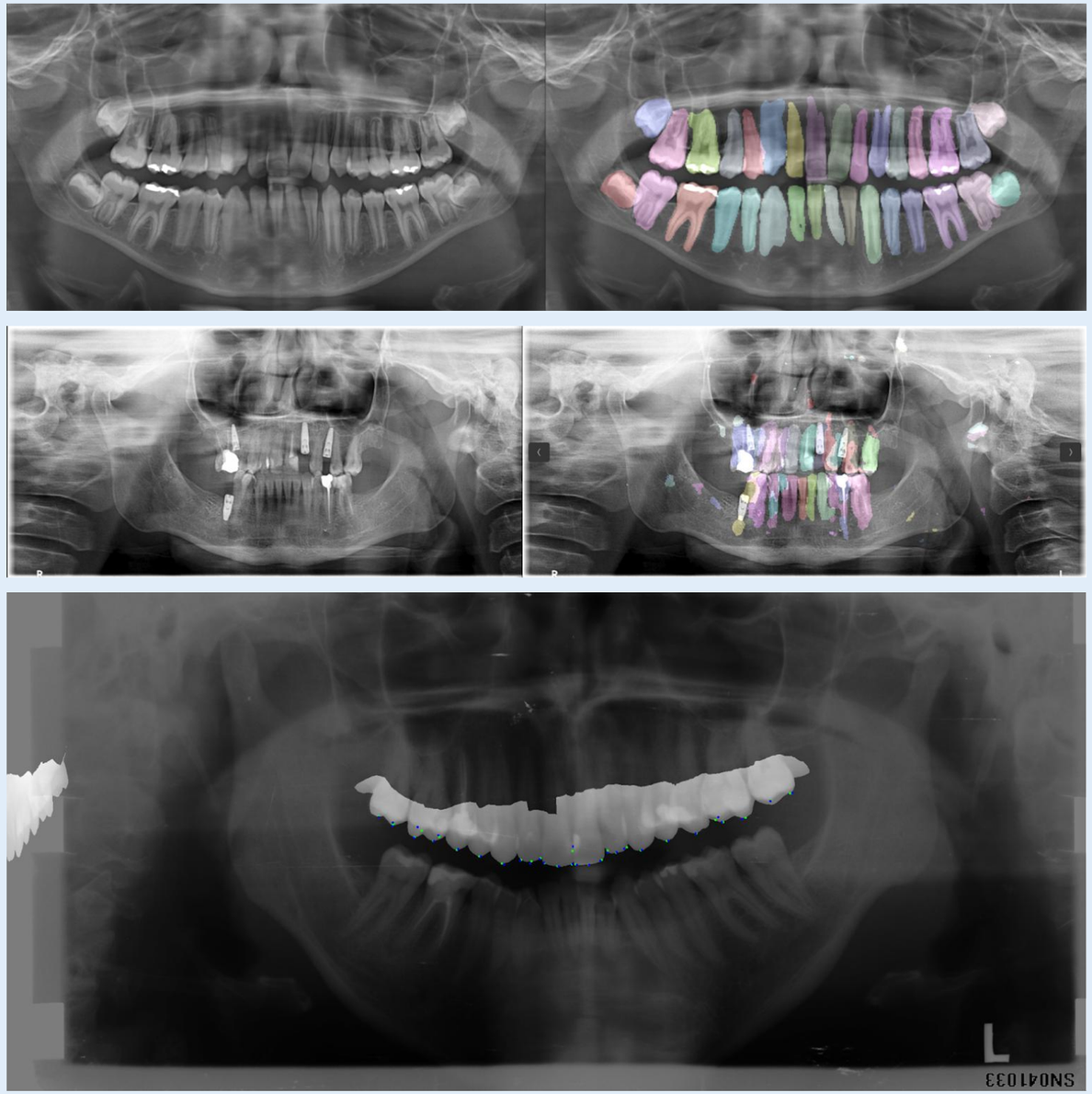
- Automatic algorithm already finished
- Pending a large multi-comparison experimentation to evaluate performance

Likelihood ratio evaluation framework (paper under review process)

- Calculate LR for each AM-PM evaluation and Cllr for the system

Robust Dental Superimposition using dental chart information

- Pending



Craniofacial Superimposition

SKELETON-ID MODULE

Ongoing research (collaborations with Universities of Granada, Coimbra and A Coruña) of fully automatic methods from

P. Martínez-Moreno, A. Valsecchi, P. Mesejo, Ó. Ibáñez, S. Damas. **Evidence evaluation in craniofacial superimposition using likelihood ratios.** Information Fusion, Volume 111, 2024.

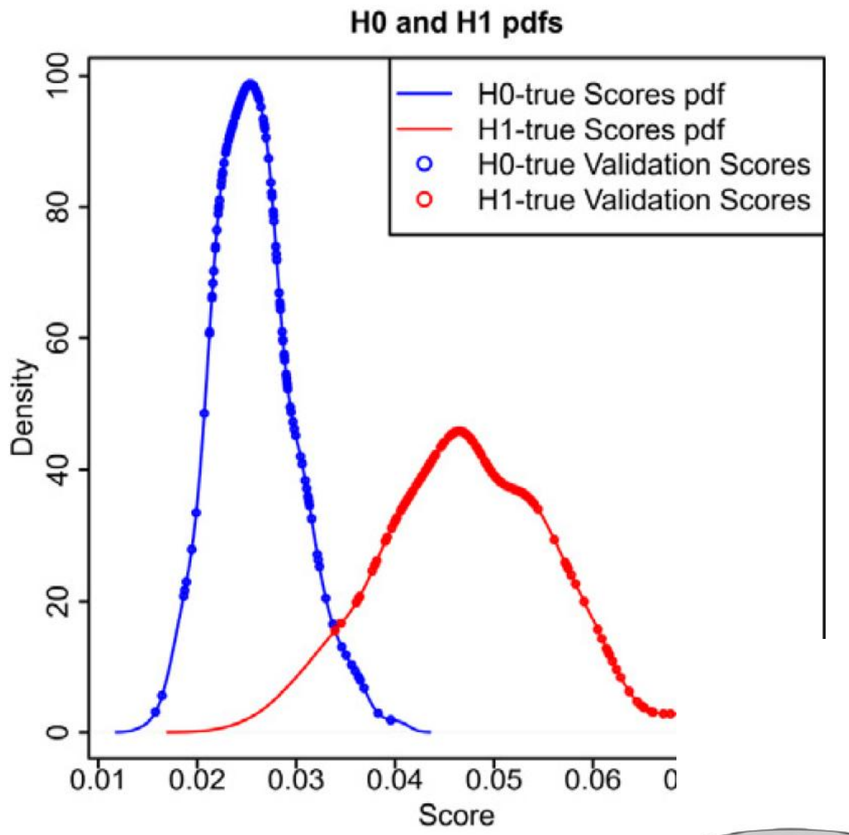
Facial Soft-Tissue study: 548 subjects (Korea, South Africa) including 3D direction of 49 landmarks. More data / populations: Chile, Portugal, Chec Republic, …

Massive reliablity studies: using synthetic landmark-based approaches (millions of cross-comparisons) and real cases (>40.000 cross-comparisons)

Lilium: novel skull-face overlay algorithm using a priori information about focal length, subject-to-camera distance, overall pose together with anatomical criterias (chin shape, forehead shape) and soft tissue statistical distribution.

Deep Lilium: fully automatic solution to assess anatomical consistency in a skull-face overlay

Likelihood Ratio (LR) in Craniofacial and Dental Superimposition



$H0$: "The subject in the reference facial photographs and the subject in the 3D skull model are the same person".

$H1$: "The subject in the reference facial photographs and the subject in the 3D skull model are different.".

Information Fusion 111 (2024) 102489

Contents lists available at ScienceDirect

Information Fusion

journal homepage: www.elsevier.com/locate/inffus

Full length article

Evidence evaluation in craniofacial superimposition using likelihood ratios

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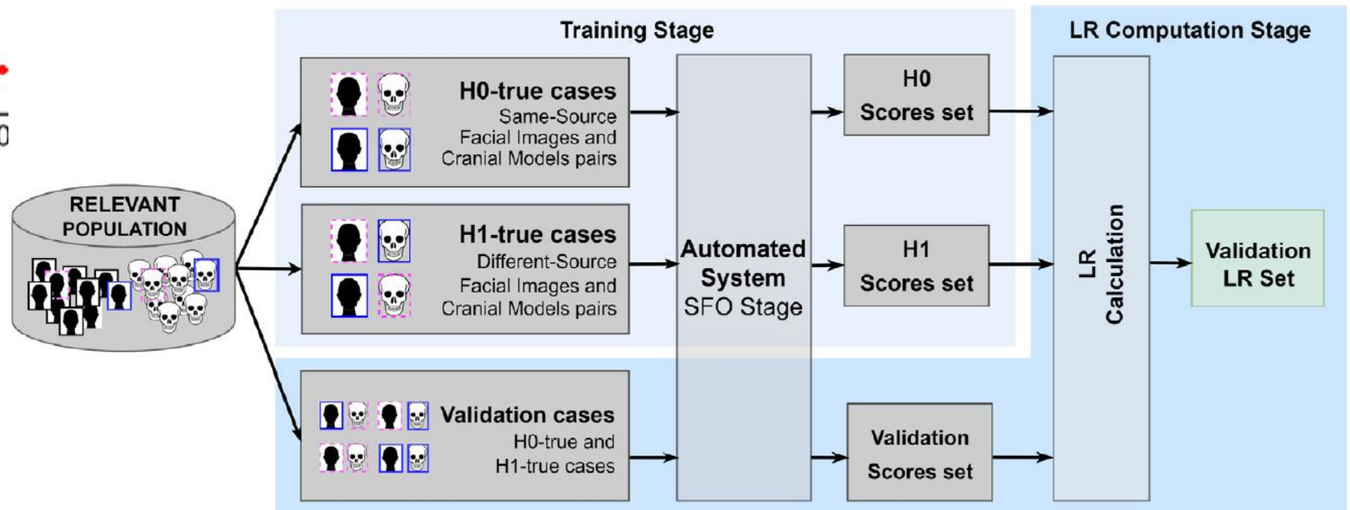
[b] Andalusian Research Institute in Data Science and Computational Intelligence, University of Granada, Granada, 18016, Spain
[c] Panacea Cooperative Research S. Coop., Ponferrada, 24402, Spain
[d] Faculty of Computer Science, CITIC, University of A Coruña, A Coruña, 15008, Spain



SCAN ME



Craniofacial Reconstruction

Reconstructive methods do not require reference data for comparison

FUTURE MODULE

ONGOING RESEARCH

Craniofacial Reconstruction (CFR) is the process of recreating the face of an unidentified subject solely from the skull, traditionally carried out through a combination of art, forensic science, anthropology, osteology and anatomy, by the manual work of experts forensic artists of very limited availability worldwide.

The European project **FACEGEN** uses Generative AI to make craniofacial reconstruction **accessible, scalable** and **trustworthy** while meeting the high **performance requirements of forensic applications**.

Future developments will include **multimodality** leveraging **DNA-based** inputs for **photorealistic** outputs.

FUTURE FUNCTIONALITIES

Missing persons DB searches: Reconstructed facial models can be massively compared against photo databases to narrow down candidate IDs.

Enhanced CranioFacial Superimposition: The **CFR** module can support the superimposition process, turning a face-to-skull comparison into a face-to-face comparison.

Trustworthy models: Objective metrics, explainability and counterfactual examples to support decision making and human agency.

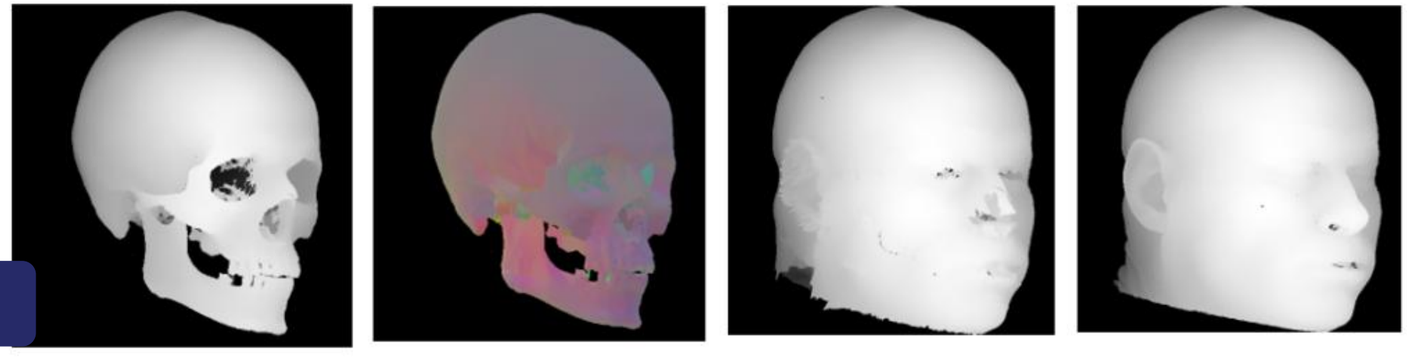
Fragmented skull reconstruction: End-to-end reconstruction starting with fragmented or even incomplete skull remains.





TRADITIONAL

FACEGEN





Facial Phenotyping

Reconstructive methods do not require reference data for comparison

FUTURE MODULE

ONGOING RESEARCH

Facial Phenotyping (FP) exploits out biological knowledge about the genetic basis of facial development to create models that can estimate the facial appearance solely from data extracted from DNA.

FP can classify into descriptive categories or can estimate quantitative features that are the basis for a filtering method that can rule out incompatible candidate identities in mass searches of photograph databases.

Furthermore, DNA-based estimations constitute additional evidence that can complement and reinforce other identification techniques in forensic casework, reducing bias and enhancing objectivity in multimodal investigative processes.

FUTURE FUNCTIONALITIES

Automated composite sketch: Generate a facial depiction to initiate an identity search, recognizable by potential relatives/acquaintances.

Mass DB searches: Comparison of estimated metrics/features from biological samples and photos in DBs to narrow down candidate IDs.

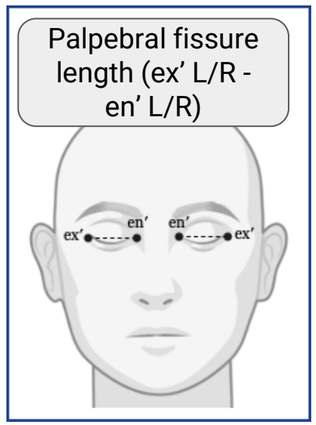
Enhanced CranioFacial Reconstruction: Complementing skull-derived information to generate photorealistic (pigmentation, texture) images.

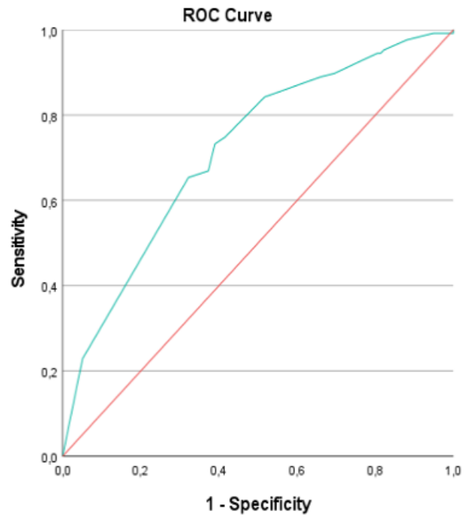
Facial regions with association to rs7167736



Navarro-López B, Wilke F, Suárez-Ulloa V, et al. Exploring the association between SNPs and facial morphology in a Spanish population..Sci Rep 2025 .

Multimarker classification model for Palpebral fissure length





AUC = 0.718 (95% CI: 0.654 - 0.781, p = 4.018E-09)

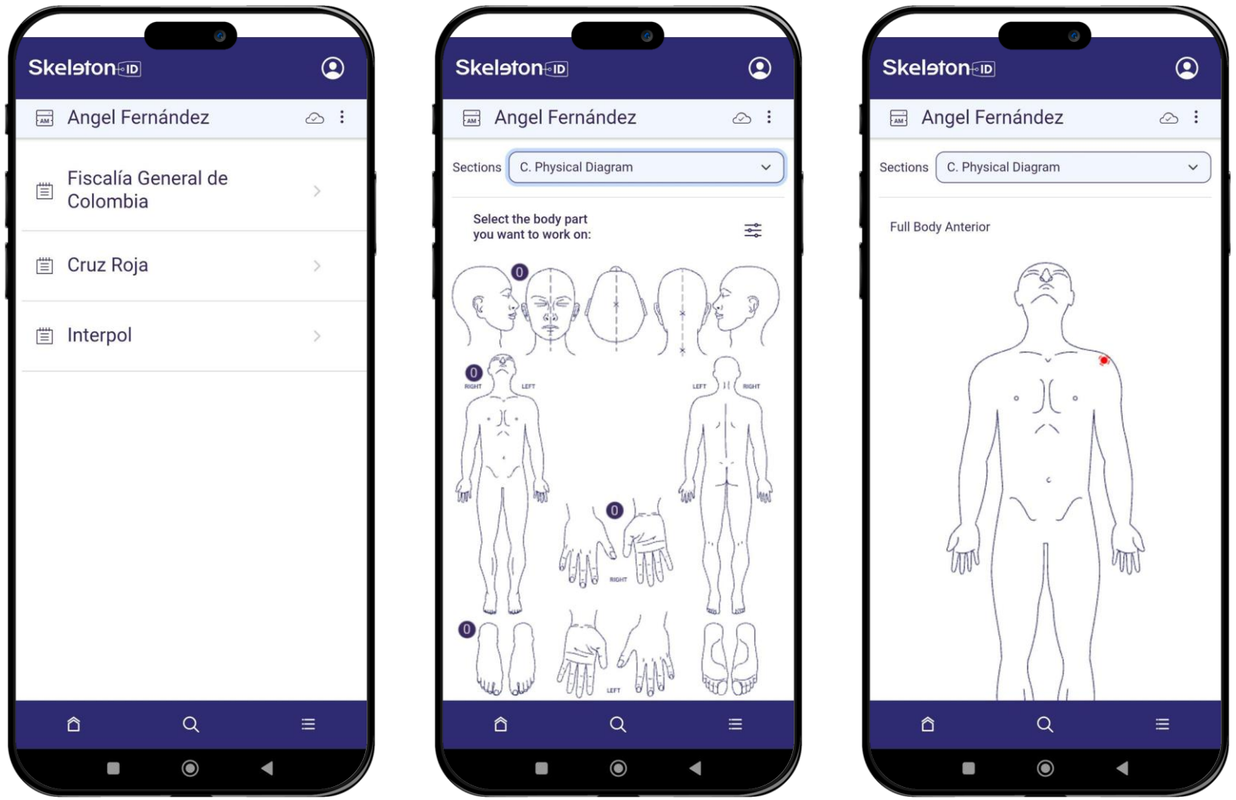
Skeleton ID

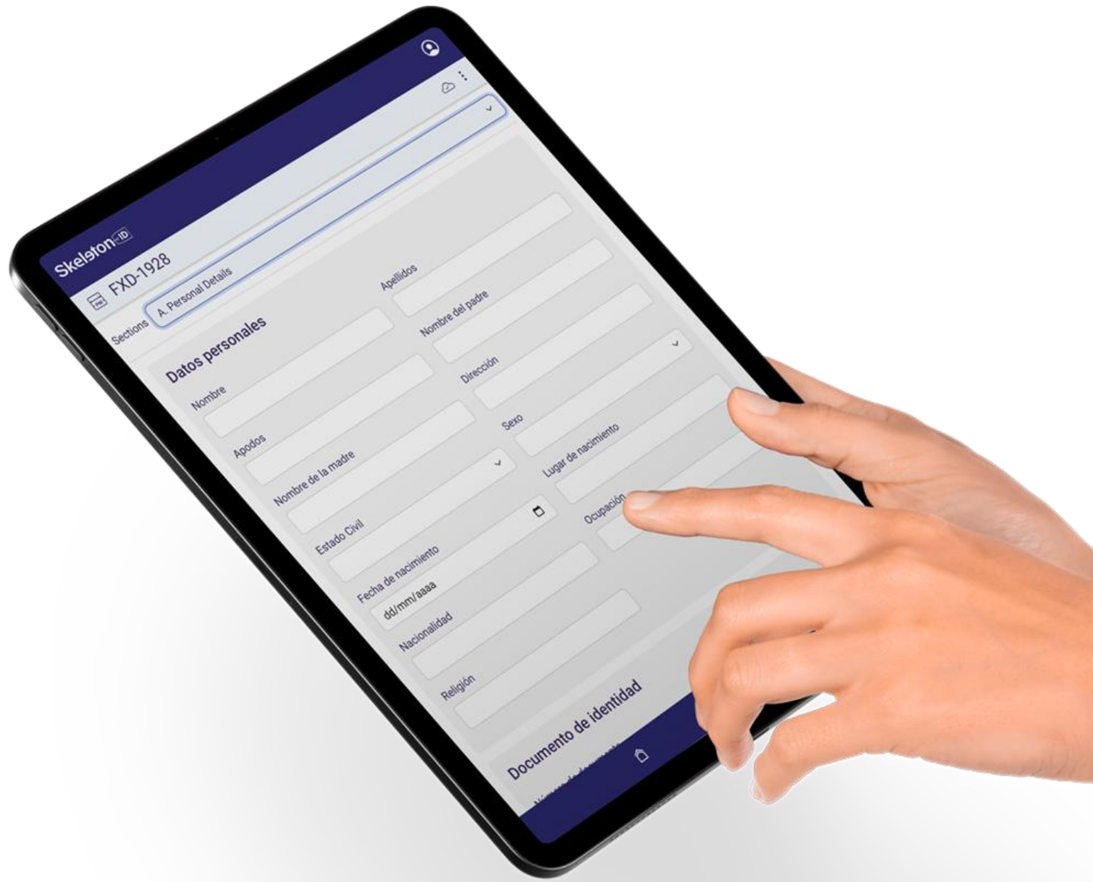
Panacea COOPERATIVE RESEARCH

Skeleton ID Mobile App

WEB-BASED APP

Skeleton-ID Mobile App is a standalone **app client for field data collection** (Internet is not needed). It offers the possibility to collect AM and PM information following national and international forms (ICRC, Interpol, Fiscalía General de la Nación, etc.). Easy and fast integration of new forms.



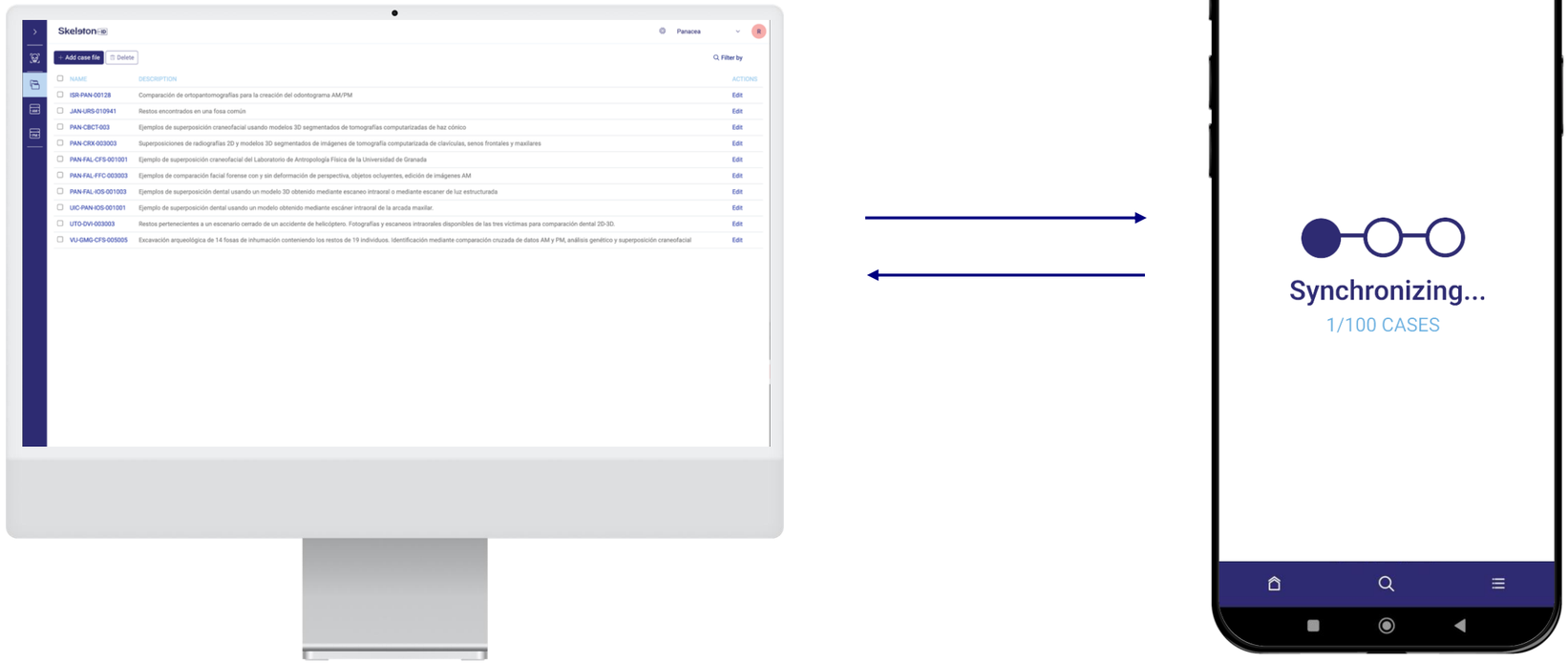


Panacea COOPERATIVE RESEARCH

AM-PM Data Synchronization

SKELETON ID MOBILE APP

We are working on a data synchronization with Skeleton·ID through API Rest to read and write data in Skeleton-ID Mobile App.



This will allow the users to collect data anywhere and synch with Skeleton·ID to store the data and work with it through the Administration Panel and the Virtual Lab.

Project Anima
Standardized and interoperable collection of AM and PM data

specific objectives

1. Development of a mobile application for the digitalization of AM/PM data collection process.

2. Creation of group of expert and collaborators.

3. Creation of an ontology of AM-PM forms.

4. Development of a universal converter for AM-PM forms.

5. Testing, validation and release of all components and tools (open source license)