A TBP DICOM format for total-body scanner-independent lesion evolution detection

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ABSTRACT

Total-body photography (TBP) has the potential to revolutionize early detection of skin cancers by monitoring minute changes in lesions over time. However, there is no standardized Digital Imaging and Communications in Medicine (DICOM) format for TBP. In order to accommodate various TBP data types and sophisticated data preprocessing pipelines, we propose three TBP //Extended Information Object Definitions// (IODs) for 2D regional images, dermoscopy images, and 3D surface scans. We introduce a comprehensive pipeline integrating advanced image processing techniques, including 3D DICOM representation, super-resolution enhancement, and style transfer for dermoscopic-like visualization. Our system tracks individual lesions across multiple TBP scans from different imaging systems and provides cloud-based storage with a customized DICOM viewer. To demonstrate the effectiveness of our approach, we validate our framework using TBP datasets from multiple imaging systems. Our pipeline and proposed IODs enhance TBP interoperability and clinical utility in dermatological practice, potentially improving early skin cancer detection.

Keywords: DICOM, Total Body Photography, AI

1. INTRODUCTION

Early detection of melanoma remains critical for patient survival, with five-year survival rates exceeding 99% when detected in localized stages. ive-year survival rates decline precipitously to 74% for regional stages and further deteriorate to 35% in cases of distant stages, underscoring the crucial importance of early diagnostic intervention.[1] Total Body Photography (TBP) has emerged as an essential tool for skin lesion surveillance, enabling systematic documentation and early detection of changing lesions.[2] As a clinical tool, TBP facilitates a structured imaging workflow from initial capture to long-term monitoring, as illustrated in Figure 1. The rapid progress in technology underscores the importance of developing standardized formats for TBP and ensuring its interoperability for lesion evolution detection.

Commercial TBP systems have evolved along two distinct technological approaches: image-based and 3Dmesh-based systems. Image-based systems, represented by ATBM master (Fotofinder Systems GmbH) and MelanoScan,[3,4] employ multiple synchronized cameras for high-resolution surface documentation. 3D-meshbased systems, exemplified by the Canfield Vectra 360,[5] utilize textured mesh representations for enhanced temporal monitoring. While image-based approaches generally offer superior texture detail, 3D-mesh-based systems, advanced by developments from Zhao *et al.*, and Huang *et al.*,[6,7] excel in accommodating variations in patient positioning while maintaining accurate lesion tracking capabilities. These developments have enhanced longitudinal lesion

monitoring through advanced multi-view imaging techniques and spatial registration methods, enabling more accurate tracking of lesion changes over time.

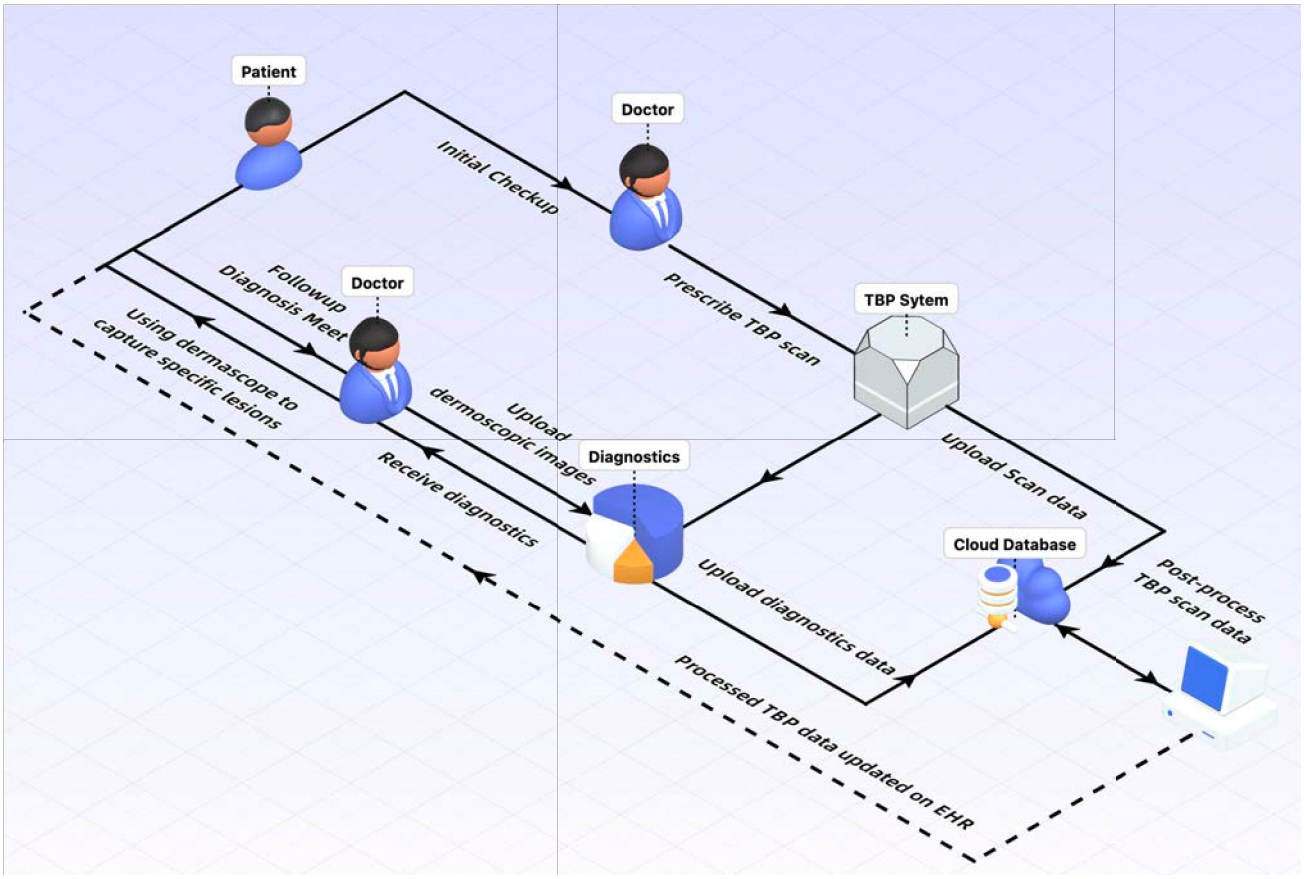


Figure 1: Sequence diagram of TBP data acquisition workflow in clinical practice.

Despite these technological advances, the field faces significant challenges in data standardization and interoperability, particularly for lesion tracking across different systems. While the Digital Imaging and Communications in Medicine (DICOM) standard has successfully standardized many medical imaging modalities, TBP presents unique challenges that current implementations do not fully address.[8] Although DICOM has made progress in standardizing various imaging types, three critical challenges persist: accurate inter-system alignment between different imaging sessions, preservation of temporal relationships in longitudinal lesion monitoring, and crosssystem compatibility of 3D surface meshes with traditional 2D imaging. Commercial systems' use of proprietary formats exacerbates these challenges, creating significant barriers to data exchange between healthcare providers and hampering the development of automated lesion analysis tools.

Addressing these challenges requires a standardized approach to maintaining lesion identity across different scanning systems and sessions. Traditional DICOM standards provide mechanisms for annotating regions of interest (ROI) within single imaging sessions, but lack robust support for tracking lesion evolution across multiple systems and timepoints. Current approaches often rely on manual correlation or system-specific identifiers that don't translate across platforms. While some solutions exist for tracking lesions in specific imaging modalities, such as RECIST measurements in oncological follow-up.[9] These frameworks are typically designed for radiological imaging and don't address the unique requirements of dermatological surface lesions. What's needed is a vendorneutral approach that can maintain lesion identity and correspondence regardless of the scanning system used.

To address these fundamental challenges, we propose establishes a comprehensive DICOM framework for TBP that enables seamless integration of multiple imaging modalities while facilitating cross-system compatibility and

data exchange. In DICOM, medical imaging information is organized hierarchically, with Information Object Definitions (IODs) serving as templates that define how specific types of medical data should be structured and stored. Each IOD consists of multiple modules that contain related data elements. Our framework introduces

three IODs: the TBP Extended 2D Regional Image IOD, the TBP Extended Dermoscopy IOD, and the TBP Extended 3D Encapsulated IOD. These IODs work in concert to provide a standardized representation of multimodal TBP data while maintaining crucial spatial relationships and clinical context.[10] Furthermore, we enhance the clinical utility of this framework through an advanced visualization pipeline that integrates super-resolution and style transfer techniques, improving image quality and interpretation capabilities.

Our work makes three contributions to the field:

1. A novel DICOM-based framework for TBP data standardization that addresses current interoperabilitychallenges through specialized Information Object Definitions for organizing data within individual scans.
2. A practical implementation strategy that integrates with existing dermatological workflows while maintaining lesion identity across different TBP systems and scanning sessions, enabling consistent tracking of lesion evolution over time.
3. An advanced visualization pipeline that applies super-resolution and style transfer techniques. It significantly improves image quality and interpretation while supporting comprehensive clinical analysis tools.

2. METHODS

2.1 DICOM Framework Architecture

Our framework extends current DICOM standards through carefully designed Information Object Definitions (IODs) and module relationships that preserve both backward compatibility and cross-system interoperability. As illustrated in Figure 2, the architecture implements three specialized IODs, each addressing specific aspects of TBP data management while maintaining strict DICOM compliance and supporting existing clinical workflows.

2.1.1 TBP Extended 2D Regional Image IOD

The TBP Extended 2D Regional Image IOD builds upon the existing Visible Light (VL) Photographic Image IOD to enable comprehensive dermatological imaging, thereby establishing spatial relationships among twodimensional regional images, three-dimensional surface meshes, and dermoscopic images. This IOD adheres the DICOM Composite Information Entity-Relationship Model, implementing essential modules including Patient, Study, Series, Frame of Reference, Equipment, and Image, with the Image IE serving as the primary container below the Series IE. The VL Image Calibration Module incorporates photogrammetric parameters such as focal lengths, principal point coordinates, and distortion coefficients, while the Extended VL Photographic Acquisition Module captures critical acquisition parameters including focus distance and camera-specific configuration settings.

The General Reference Module facilitates bidirectional linkages through Referenced Image Sequence *(0008,1140)* for linking regional images to dermoscopic images, and Referenced Instance Sequence *(0008,114A)* for linking regional images with 3D surface meshes. These reference mechanisms, combined with standardized calibration parameters, enable precise spatial registration between different imaging modalities and support accurate tracking of lesion evolution over time. The modular structure ensures compatibility with existing DICOM architectures while providing the specialized functionality required for essential to TBP practices.

2.1.2 TBP Extended Dermoscopy IOD

The TBP Extended Dermoscopy IOD addresses the specialized requirements of dermoscopic imaging in total body photography, accommodating images acquired by various methods, including direct dermatoscope capture, macro photography with consumer-grade cameras, and algorithmically segmented crops from TBP regional images. This IOD adheres to the DICOM Composite Entity–Relationship Model and implements essential modules such as Patient,

Study, Series, Frame of Reference, Equipment, and Image, while also introducing the TBP Dermoscopic Module that manages critical spatial relationships among dermoscopic crops, corresponding regional images, and 3D surface meshes. The designated modality is DMS (External-camera Photography), which distinguishes these specialized dermoscopic captures from standard photographic images.

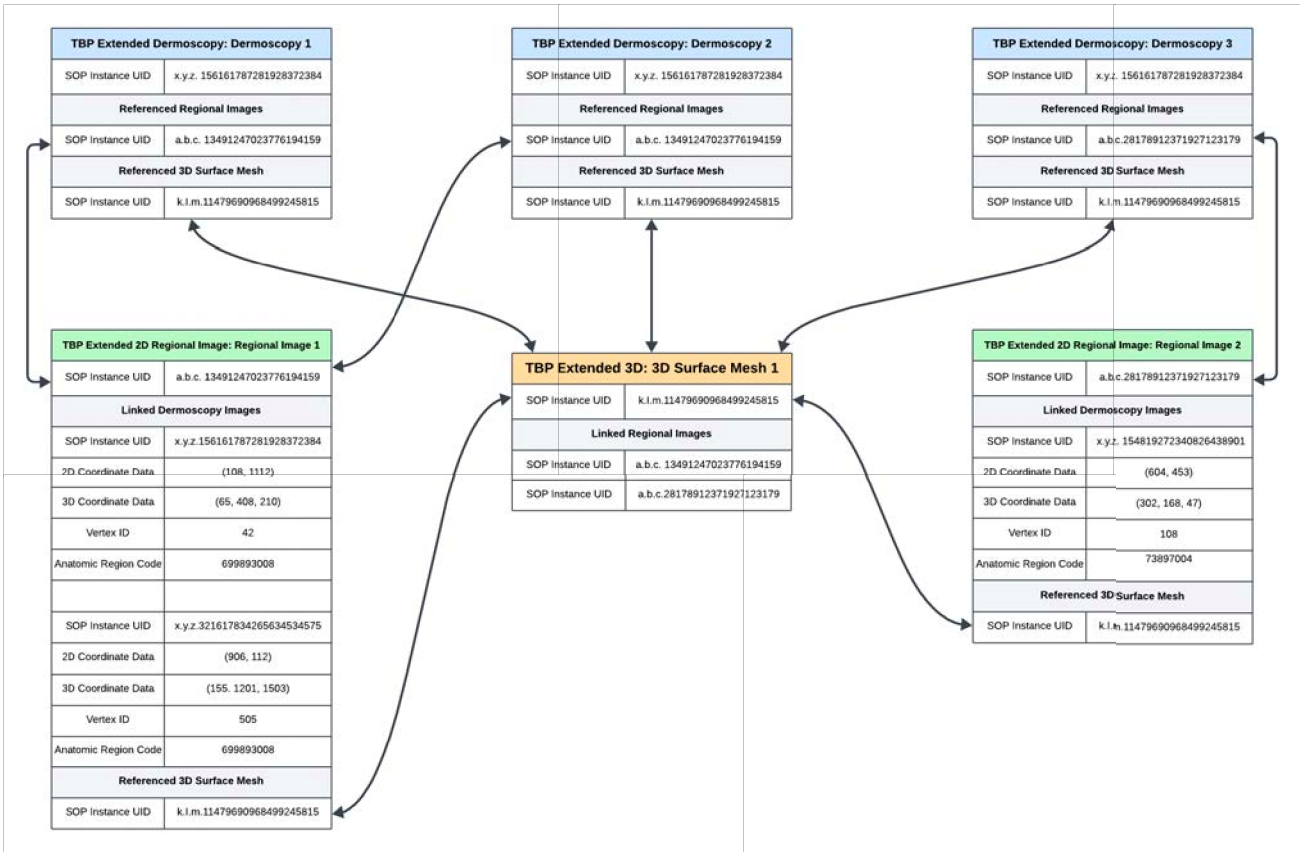


Figure 2: Illustration of the relationships between TBP Extended IODs, showing how dermoscopy images, regional images, and 3D surface mesh data are interconnected.

The TBP Dermoscopic Module introduces several crucial attributes, including Lesion ID for unique identification, 2D and 3D coordinate data for precise spatial localization, and optional parameters such as Triangle ID and Barycentric Coordinates for accurate mesh surface registration. These parameters enable robust linking of dermoscopic images to their source locations within in both 2D regional images and 3D surface meshes through the Referenced Image Sequence and Referenced Instance Sequence, respectively. This comprehensive reference system facilitates precise tracking of individual lesions across multiple imaging modalities and supports the longitudinal monitoring of lesion evolution.

2.1.3 TBP Extended 3D Encapsulated IOD

The TBP Extended 3D Encapsulated IOD provides a framework for managing three-dimensional surface mesh data in total body photography, with the modality designated as M3D. Adhering to the DICOM Composite Entity–Relationship Model, this IOD implements key modules including Patient, Study, Series, Frame of Reference, and Equipment, while also introducing the specialized TBP 3D Module for the comprehensive capture of acquisition parameters and surface mesh characteristics. The TBP 3D Module records essential attributes such as TBP Capture Procedure for documenting the acquisition method, Body Coverage percentage, Missing Body Parts for identifying uncaptured anatomical regions, Reconstruction Error metrics, and Reconstruction Algorithm specifications.

Moreover, it incorporates the Photogrammetry Module to store vital parameters related to 3D reconstruction, including focal length, exposure settings, aperture values, and the overlap percentage between consecutive captures. Through the General Reference Module, the IOD maintains bidirectional connections with regional images via Referenced Image Sequence, enabling accurate spatial registration between 3D surface meshes and corresponding 2D images. This reference system, combined with comprehensive acquisition parameters, supports

reliable spatial localization and facilitates longitudinal tracking of anatomical features across multiple imaging modalities while maintaining compatibility with current DICOM infrastructure.

2.2 Lesion Tracking Across TBP Systems

TBP systems face significant challenges in maintaining consistent lesion identity across multiple imaging sessions and different scanning platforms. Figure 3 illustrates the complete workflow of our lesion tracking framework, from initial patient imaging through various tracking scenarios. Our framework addresses these challenges through a standardized DICOM-compliant approach that supports both 2D image-based and 3D mesh-based lesion documentation.

2.2.1 Standard lesion identification approach

For each imaging session in the proposed framework, the system generates a DICOM JSON file containing acquisition parameters, patient positioning data, and temporal reference information. This file serves as the primary index for the imaging session and maintains a registry of all detected lesions, accommodating both planar and volumetric representations.

For 2D image-based scans, each lesion observation is initially assigned a Tracking Identifier, serving as a temporary marker during the initial detection phase. The framework processes overlapping image regions through a sequential analysis pipeline that employs the skin lesion matching methodology proposed by Korotkov *et al.*[11] This approach handles the challenges of correlating lesions across different viewing angles and anatomical curvatures, enabling reliable identification of identical lesions captured in multiple images.

For 3D mesh-based representations, the framework extends lesion documentation to include surface mesh coordinates, texture mapping information, and volumetric characteristics. The system stores mesh vertices, faces, and UV mapping coordinates associated with each lesion, thereby enabling precise spatial localization on the three-dimensional body surface. This 3D lesion data maintains consistency with the DICOM mesh storage specification while preserving the relationship between surface geometry and lesion appearance.

When the system confirms multiple observations of the same physical lesion across different images or mesh regions, it generates and assigns a Tracking Unique Identifier to that lesion. This standardized approach ensures consistent lesion identification while maintaining the flexibility to accommodate various imaging modalities and system-specific implementations.

2.2.2 Intra-System Lesion Tracking

Maintaining a continuous record of each lesion within the same TBP system is vital for evaluating the evolution of skin lesions. When a subsequent scan is performed on the same TBP system, its DICOM JSON file is analyzed in conjunction with files from previous sessions to establish temporal lesion correspondence. For each detected lesion, the system first attempts to match it with historically documented lesions using coordinates and identifiers stored in previous JSON files. Upon successful correlation, the system updates the lesion's reference chain by appending new observation data, creating a continuous record that enables tracking of individual lesions across multiple sessions.

For 3D mesh-based systems, the temporal tracking mechanism follows a similar principle while accommodating the additional complexity of mesh-based coordinates. The framework matches lesions across sessions using mesh vertex indices and barycentric coordinates, maintaining a continuous record of each lesion's position across sequential 3D scans. This approach ensures reliable lesion tracking regardless of minor variations in patient positioning or mesh topology between scanning sessions.

2.2.3 Inter-System Tracking with Uniform Data

When patients undergo imaging across different TBP platforms, the framework employs a vendor-neutral approach to maintain consistent lesion tracking while preserving system-specific data formats. For 2D image-based systems, this is achieved through a standardized DICOM JSON structure that establishes correspondence between lesion observations from different platforms. The lesion mapping can be performed either manually by

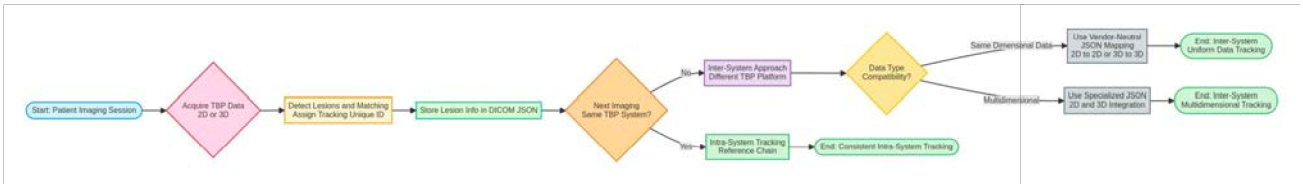


Figure 3: Complete workflow of the lesion tracking framework

clinical experts or through machine learning-based methods, depending on institutional preferences and requirements. Each observation maintains its native coordinates and identifiers within its original system, while the DICOM JSON model provides the necessary cross-referencing to track lesions across platforms.

The framework extends this vendor-neutral mapping strategy to 3D mesh-based systems by incorporating mesh-specific parameters in the JSON structure. Similar to 2D systems, the correspondence between 3D lesion representations can be established through expert annotation or automated matching algorithms. This approach enables cross-platform lesion tracking without requiring complex mesh topology conversions between different scanning systems. By maintaining each vendor's native mesh format while providing standardized mapping references, the framework ensures reliable lesion correspondence across diverse 3D scanning implementations and preserving the fidelity of system-specific data.

2.2.4 Inter-System Tracking with Multidimensional Data

Cross-dimensional lesion tracking addresses the challenge of maintaining lesion identity correspondence between 2D image-based and 3D mesh-based TBP systems through a specialized DICOM JSON structure. The mapping between 2D and 3D representations can be established either through expert clinical annotation or automated dimensional correspondence algorithms. For each cross-dimensional pair, the JSON structure stores both the 2D planar coordinates with their anatomical region identifiers and the corresponding 3D mesh vertex indices with surface parameters, creating a comprehensive bidirectional reference system. This unified mapping approach enables healthcare providers to track lesions consistently across dimensional boundaries while preserving each system's native data format. Whether a patient's follow-up examination uses the same or different capture technology, the framework maintains reliable lesion identification through its flexible cross-dimensional reference system, supporting seamless transitions between 2D and 3D modalities in clinical workflows.

2.3 Enhanced Visualization Pipeline

The enhanced visualization pipeline integrates image processing techniques within the DICOM framework. As illustrated in Figure 4, our system processes three types of imaging data: 3D mesh data, 2D regional images, and dermoscopic images, each stored in corresponding DICOM formats and enhanced through specialized visualization techniques.

2.3.1 Super-Resolution Enhancement Framework

Super-resolution enhancement in medical imaging enables the extraction of high-resolution details from standard clinical images, which is particularly valuable in dermatological applications where fine features can indicate significant clinical findings. For example, when examining melanocytic lesions, enhanced resolution can reveal subtle changes in border irregularity or structural patterns that might otherwise be unclear in standard resolution images.[12] For reliable algorithmic detection and analysis, lesions must occupy at least 20×20 pixels, requiring a spatial resolution of approximately 0.075 mm/pixel for a 1.5 mm diameter lesion.[13] In clinical practice, longitudinal

monitoring often involves comparing images from different capture devices with varying resolutions, creating challenges in maintaining consistent feature analysis across patient visits.

Our implementation integrates the pretrained SwimIR super-resolution model[14] directly into the DICOM workflow, automatically enhancing images while preserving their quantitative color values. In clinical practice, this enhancement enables clearer visualization of critical features such as color variations within lesions, textural patterns, and border definitions. The system processes images automatically upon retrieval from storage, preserving the original DICOM attributes and relationships without disrupting workflows.

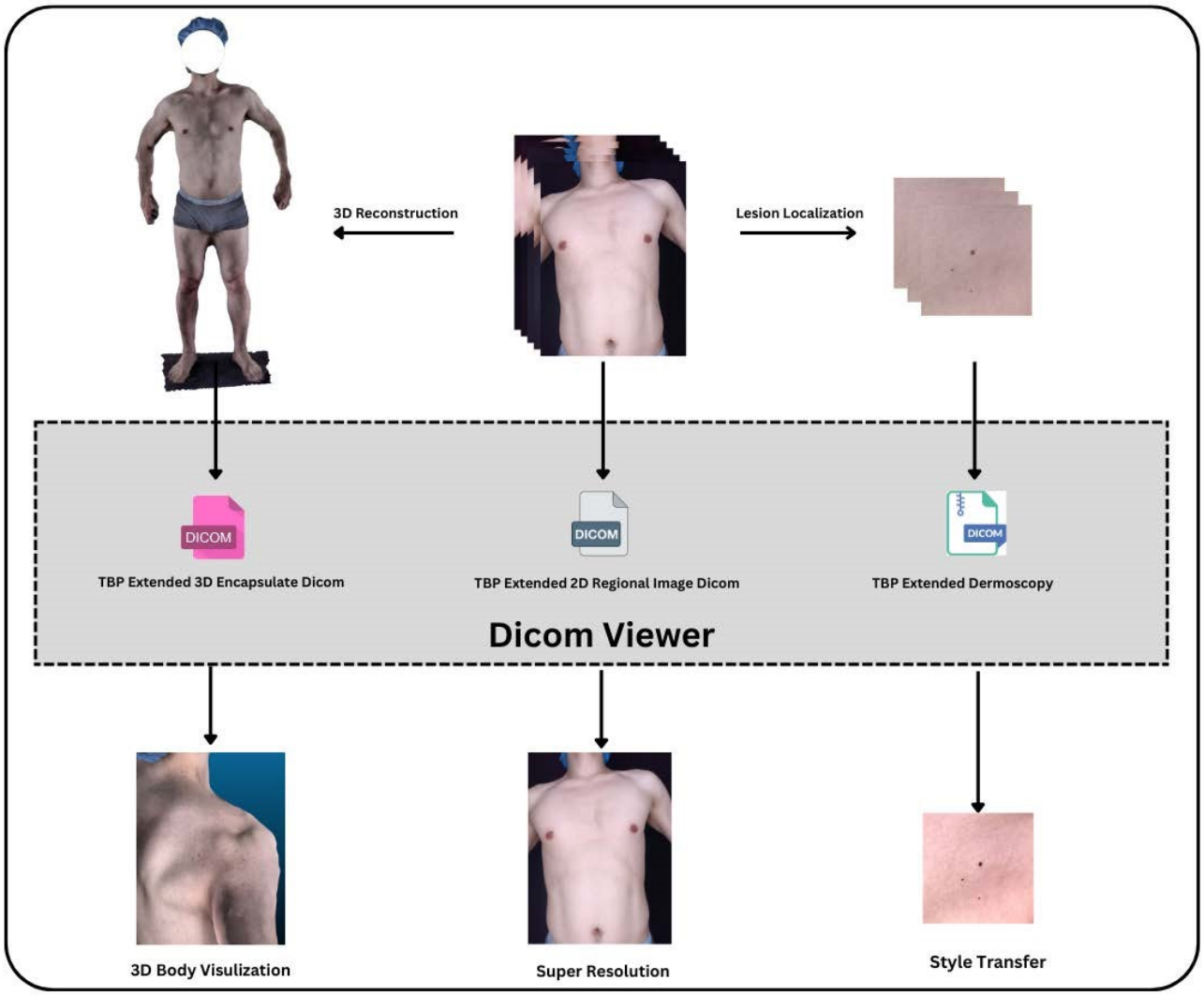


Figure 4: Enhanced visualization pipeline demonstrating the integration of 3D reconstruction, super-resolution, and style transfer processing within the DICOM framework.

2.3.2 Style Transfer Implementation

Style transfer technology in medical imaging addresses the challenge of standardizing image appearance across different capture devices and imaging conditions. The ability to harmonize different imaging sources is essential not only for accurate diagnostic evaluations but also for long-term patient monitoring. For instance, when tracking a patient's lesions across multiple visits and employing different devices, style transfer helps ensure a uniform visual presentation despite variations in the capture equipment.

Our system employs CycleGAN for style transfer between dermoscopic images and clinical photographs.[15] The network was trained on the public Derm7pt dataset, which contains paired clinical and dermoscopic images of skin lesions annotated with standardized dermoscopic criteria.[16] During training, we applied data augmentation techniques, including random cropping, rotation, and brightness adjustments, to improve the model's robustness. We implemented a custom weighted loss function that prioritizes the preservation of lesion boundaries and color distributions while allowing texture enhancement from clinical photographs. The trained model processes dermoscopic images to generate enhanced visualizations that maintain diagnostic features and incorporate complementary visual information from clinical photographs.

2.3.3 Clinical Visualization Tools

Modern dermatological practice faces the challenge of efficiently managing and comparing multiple images across different modalities and time points. Our visualization framework, built as a plugin for the Open Health Imaging Foundation (OHIF) DICOM viewer, addresses this challenge through an integrated suite of tools that enable side-by-side comparison of temporal sequences, simultaneous viewing of clinical and dermoscopic images, and rapid switching between body sites.[17]

Our viewer presents images in a hierarchical, clinician-friendly manner. The viewer first shows a full-body overview of the patient. When the clinician selects a region of interest on this overview, the viewer transitions to a corresponding image with the best viewing quality, determined by the imaging distance and viewing angle. The viewer also allows a detailed examination of a single lesion by zooming in on the corresponding image. Additionally, the implementation organizes images in a clinically intuitive hierarchy, allowing seamless transitions between full-body overviews and detailed examinations of specific lesions. Figure5 illustrates how our visualization framework integrates 2D and 3D perspectives within the OHIF DICOM viewer.

By leveraging cloud-based data management, our implementation can be adopted widely in clinical settings. The system uses encrypted storage and transmission protocols to maintain DICOM compatibility and ensure authorized access to complete patient imaging histories. The framework's cloud infrastructure further enhances its clinical utility through sophisticated data management capabilities. Even when distributing TBP DICOM data across healthcare facilities, it upholds DICOM standards and restricts data access to authorized personnel only. Through our custom OHIF plugin development, intelligent caching and synchronization mechanisms optimize performance in distributed healthcare environments. This approach enables efficient retrieval of longitudinal imaging data while maintaining HIPAA compliance.

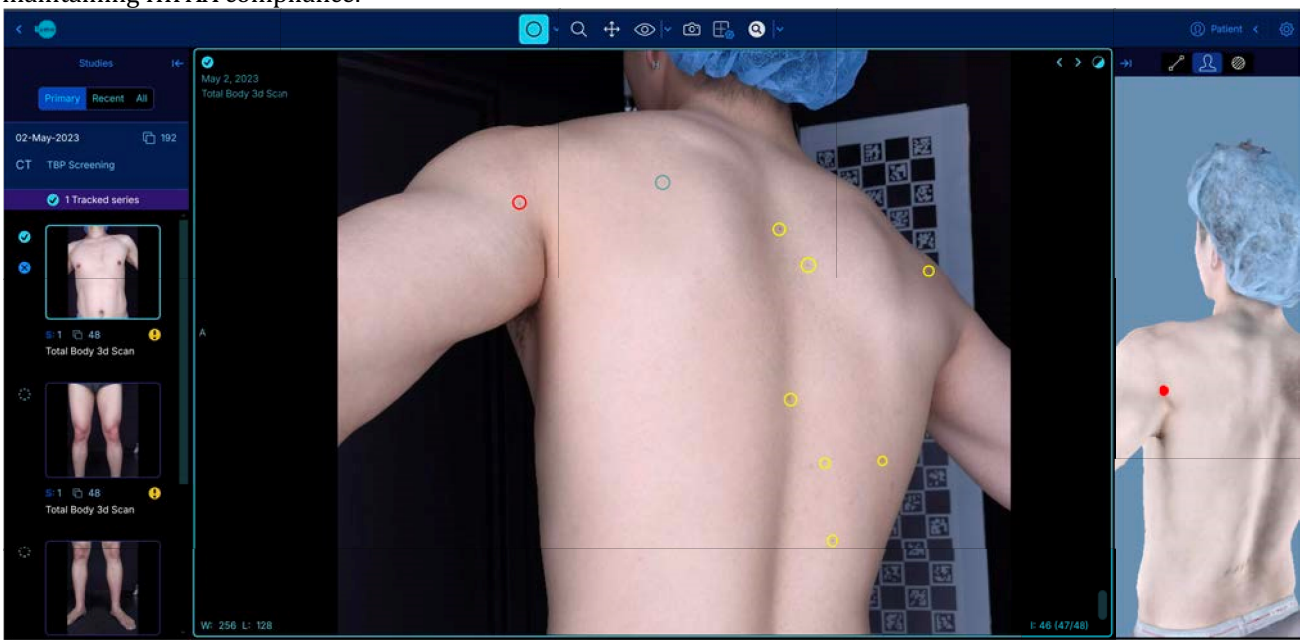


Figure 5: Screenshot of our integrated DICOM viewer. The left panel provides a thumbnail series of whole-body images, the center panel displays a high-resolution view with annotated lesions, and the right panel shows a 3D reconstruction for spatial context.

3. EXPERIMENTS

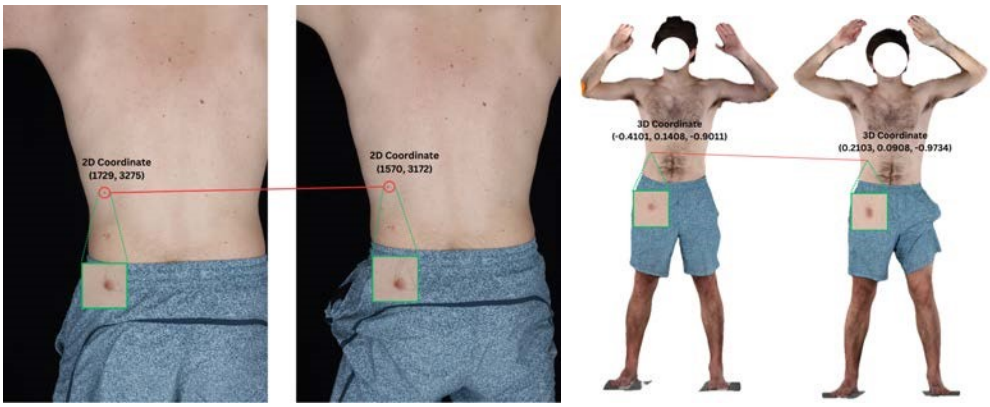
We evaluated our framework through a comprehensive registration system implemented on two different TBP setups. Our primary system consists of five DSLR cameras (Canon EOS 90D) arranged vertically with 30%-50% overlap in the field of view, installed on a motorized rotary beam with LED light panels. The system captures images at 114 angular positions. The image resolution is 4640 × 6960. The second system has 7 smartphone cameras (Huawei P50 Pro with a focal length of 6 mm and aperture of f/1.8) on a 360-degree rotary beam. During a scan, the system performs a 360-degree rotation at varying speeds - 9°/sec for anterior/posterior regions and 3°/sec for lateral regions, capturing images at 48 angular positions. The image resolution is 8192 × 6144.

To obtain a textured 3D surface mesh, we adopted a photogrammetry-based reconstruction approach. We first applied incremental Structure from Motion to estimate camera poses and a sparse point cloud of the subject using OpenMVG.[18] We then used multi-view stereo to reconstruct the surface mesh from the sparse point cloud and texturized the mesh using OpenMVS.[19]

To validate our tracking framework across different dimensional representations and systems, we conducted two experiments: intra-system temporal tracking and cross-system lesion correspondence. Our evaluation used real patient data captured using both systems with informed consent.

We recruited one patient with at least 15 distinctive nevi distributed across different body regions. Using our primary system (5-camera DSLR setup), we performed three sequential imaging sessions at one-month intervals. During each session, both 2D photographs and 3D reconstructed meshes were generated following our standard acquisition protocol at 114 angular positions.This protocol enabled us to validate the framework's ability to maintain consistent lesion identification across multiple imaging sessions within the same system. Figure 6a shows the temporal tracking results for most representative lesion in 2D case, displaying their successful identification and mapping across the 2 timepoints. The 3D lesion tracking maintained in our DICOM JSON structure accurately preserved lesion identity despite minor variations in patient positioning between sessions, as evidenced by the consistent lesion labeling shown in Figure 6b.

To evaluate cross-system compatibility, we conducted imaging sessions of the same patient using both our primary DSLR system and the smartphone-based system. This experiment assessed both uniform data tracking between different 2D imaging systems and multidimensional tracking between 2D images and 3D reconstructed meshes. The protocol involved capturing complete body surface documentation using both systems, generating standardized DICOM JSON files, and creating vendor-neutral mapping structures to establish lesion correspondence. This setup allowed us to validate our framework's ability to maintain accurate lesion identification across different imaging platforms and dimensional representations while preserving the native characteristics of each system's data format. Figure 7 demonstrates the successful mapping of lesions between our DSLR and smartphone-based systems. The left panel shows lesion identification in the DSLR system's images, while the right panel displays the corresponding lesions captured by the smartphone system, with our JSON mapping structure maintaining correct correspondence.



(a) 2D to 2D (b) 3D to 3D

Figure 6: Intra-System Lesion Tracking Result

The experimental validation demonstrates that our calibrated registration pipeline successfully handles all three registration scenarios while maintaining spatial consistency and anatomical relationships. The framework's ability to establish accurate correspondences across different imaging modalities and sessions supports its practical application in clinical TBP systems.

(a) 2D to 2D (b) 3D to 3D (c) 2D to 3D

Figure 7: Inter-System Lesion Tracking Result

4. CONCLUSION

We introduced a concise DICOM-based TBP framework that standardizes how 2D regional images, dermoscopic image, and 3D surface meshes are captured and stored for dermatological applications. By integrating superresolution and style transfer techniques, our approach unifies diverse imaging modalities and preserves consistent lesion tracking across multiple platforms. The framework demonstrated robust intra-system and inter-system lesion identification, which supports earlier and more reliable detection of evolving lesions. Its DICOM compliance and cloud-enabled architecture make it a scalable solution for improving melanoma surveillance in clinical practice. In future work, we plan to use new vision technologies to enhance visualization in TBP systems. We also intend to introduce new validation mechanisms to improve lesion matching accuracy, particularly in complex clinical scenarios. Extending cross-institutional data sharing and evaluating the framework on larger patient populations will help drive real-world adoption and improve early melanoma detection.

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