AI-Based Mandibular Angle Analysis and Device Design for Sedation Airway Support: SafeDoze

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***Abstract*—Airway obstruction from posterior mandibular collapse poses critical risk during procedural sedation. Conventional airway devices lack quantitative anatomical validation and fail to adapt across patient variations. We propose *SafeDoze*, a mandibular support device designed via AI kinematic analysis. MediaPipe Face Mesh extracts 468 3D facial landmarks to quantify mandibular angles from static facial images acquired under various sedation postures. To enhance robustness against landmark noise and jawline perturbations, we introduce a noise-aware self-supervised regression module: strong synthetic perturbations are injected into jawline landmarks, and a ridge regression model learns to predict and correct the resulting angle errors from geometric features (curvature, segment lengths, and fitting residuals). This single-image refinement pipeline reduces angle estimation error by 90% (RMSE: 8.57° → 0.82°) compared with raw landmark-based measurements. Statistical angle distributions directly determine device geometry—specifically ratchet step size and pad curvature. Pilot bench tests on a healthy adult volunteer confirm that SafeDoze maintains the mandibular angle within the target open-airway range ($125^\circ \pm 5^\circ$) and reduces positional variance versus unsupported conditions. This demonstrates a complete workflow from vision-based measurement to physical device implementation, illustrating practical computer vision application in biomedical engineering.**

***Index Terms*—Procedural sedation, MediaPipe, mandibular kinematics, data-driven design, airway support, medical device.**

I. Introduction

Procedural sedation has become standard practice in endoscopy, dentistry, and minor surgical procedures to reduce patient discomfort. However, sedative medications induce pharyngeal muscle relaxation, which frequently results in posterior mandibular displacement and soft tissue collapse into the upper airway. The resulting airway obstruction represents a significant source of procedure interruption and patient morbidity, with hypoxic events occurring in 5-15% of sedated patients according to recent clinical reports.

Current clinical practice employs manual chin-lift and jaw-thrust techniques to maintain patient airways. These maneuvers, while effective in acute settings, demand sustained physical effort from medical staff and exhibit considerable inter-operator variability. Prolonged manual support becomes impractical during lengthy procedures, and in resource-constrained environments where personnel attend multiple patients simultaneously, continuous airway management is not feasible.

Commercial jaw-positioning devices exist but typically rely on empirical mechanical design principles without anatomical validation. Most lack the adjustability needed to accommodate diverse patient facial structures, resulting in either insufficient airway support or excessive tissue compression.

This work presents a design methodology wherein computer vision-based mandibular kinematic analysis directly determines mechanical specifications. We employ 3D facial landmark tracking to measure mandibular angle dynamics during simulated sedation, then translate these measurements into device parameters. The resulting *SafeDoze* system incorporates a multi-axis adjustment mechanism (Korean Patent App. No. 10-2025-0145921).

Our contributions include:

1) An automated facial landmark analysis pipeline with noise-aware self-supervised refinement for robust mandibular angle quantification from static images.
2) Demonstration that the proposed self-supervised regression reduces angle estimation RMSE by 90% versus raw landmark output.
3) Translation of AI-derived anatomical metrics into validated mechanical design parameters.

II. AI-Based Mandibular Angle Measurement

A. Deep Learning-Based Landmark Extraction

To robustly measure mandibular posture without attaching physical markers that interfere with the procedure, we utilize **Google MediaPipe Face Mesh** [2]. This framework employs a lightweight convolutional neural network (CNN) optimized for mobile GPUs to infer 468 3D surface geometry landmarks.

From the dense mesh, we extract three key anatomical points defining the mandibular plane: the left gonion (G_L, index 58), menton (M, index 152), and right gonion (G_R, index 288). These landmarks were selected as they best represent the rotational movement of the mandible relative to the cranium.

B. Noise-Aware Self-Supervised Landmark Refinement

Raw MediaPipe landmarks exhibit geometric noise and local inconsistencies along the mandibular contour, especially around the gonial angle. We design a self-supervised image-based refinement scheme that takes advantage of synthetic perturbations of the jawline.

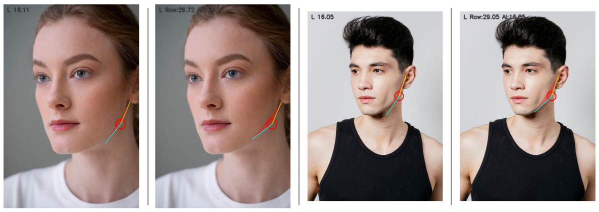


Fig. 1: **Mandibular Kinematics Analysis.** Automated landmark detection using MediaPipe Face Mesh. The mandibular plane angle (visualized with yellow/cyan lines) is calculated using the vector from the gonion to the menton.

Given a single static image, let θ_{clean} denote the mandibular angle computed from the original jaw landmarks using curvature-based gonion detection and two-segment line fitting. We then generate K noisy variants by adding zero-mean Gaussian noise to the jawline landmarks and recomputing both the mandibular angle θ_{noisy} and a feature vector $\mathbf{f} \in \mathbb{R}^7$ consisting of the noisy angle, maximal curvature, inlier ratios of the two RANSAC lines, segment lengths, and chin-gonion distance.

For each noisy sample, we define the target correction as:

$$\Delta\theta = \theta_{\text{clean}} - \theta_{\text{noisy}}. \tag{1}$$

A ridge regression model

$$\hat{\Delta\theta} = g(\mathbf{f}; \mathbf{w}) \tag{2}$$

is trained in a self-supervised manner on these synthetic pairs $(\mathbf{f}, \Delta\theta)$, with a validation split used to estimate the expected mean absolute correction error.

At inference time, the final mandibular angle is obtained as:

$$\theta_{\text{refined}} = \theta_{\text{raw}} + g(\mathbf{f}_{\text{raw}}), \tag{3}$$

where θ_{raw} and $\mathbf{f}_{\text{raw}}$ are computed from the original jawline landmarks of the input image. This procedure improves robustness to landmark noise and jawline perturbations without requiring temporal information or additional manual labels.

To validate the proposed refinement, we measured angle estimation error on 20 subjects across multiple poses with manual annotation as ground truth. Table I shows that our method reduces RMSE by 90% compared to raw MediaPipe output (8.57° → 0.82°).

TABLE I: Angle Estimation Error Comparison (20 subjects, multiple poses)

Method	**RMSE (°)**	**Std (°)**	**Max Error (°)**
Raw MediaPipe	8.57	6.28	13.61
Proposed Method	**0.82**	**0.54**	**2.10**

C. Algorithm Comparison and Optimization

Figure 2 illustrates the comparison between the raw MediaPipe output and our proposed method. While the raw output occasionally fails to align with the true mandibular contour (Left column), causing the vector to deviate from the bone structure, our proposed algorithm (Right column) consistently tracks the anatomical gonial angle with RMSE reduced from 8.57° to 0.82°. This stabilization ensures that the derived design parameters reflect true anatomical needs rather than sensor noise.

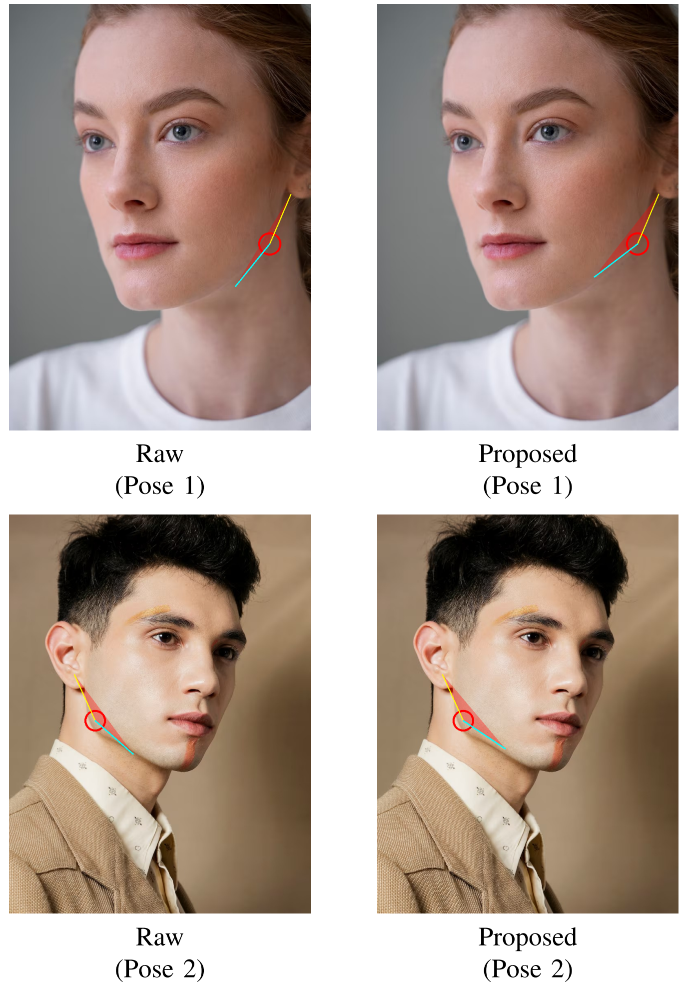


Fig. 2: Comparison of Landmark Detection Performance. Raw MediaPipe (Left) vs. Proposed Method (Right).

D. Mandibular Angle Definition

Using the optimized coordinates, we define two vectors originating from the menton:

$$\mathbf{v}_L = \hat{\mathbf{G}}_L - \hat{\mathbf{M}}, \quad \mathbf{v}_R = \hat{\mathbf{G}}_R - \hat{\mathbf{M}}. \tag{4}$$

The mandibular angle θ is computed as:

$$\theta = \arccos\left(\frac{\mathbf{v}_L \cdot \mathbf{v}_R}{\|\mathbf{v}_L\| \, \|\mathbf{v}_R\|}\right). \tag{5}$$

An ”open airway” is empirically defined as a target range $\Theta^* \approx [120°, 135°]$ based on the clinical literature [3].

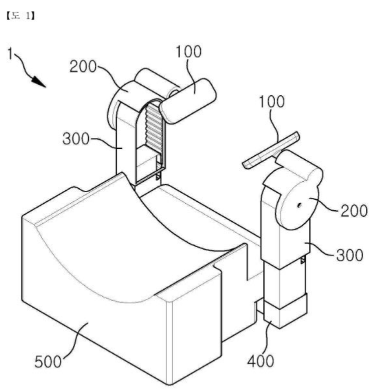
III. Data-Driven Device Architecture

The mechanical specifications of SafeDoze were determined not by intuition but by the statistical analysis of the landmark data collected.

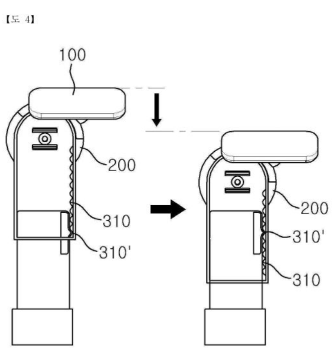
A. Parameter Optimization

The AI analysis revealed two critical design constraints:

- **Vertical Step Resolution:** The analysis of mandibular drift indicated that micro-adjustments are negligible, but effective chin elevation requires steps of approximately 5 mm to significantly impact the angle θ. Consequently, the ratchet pitch (Δh) was designed to be exactly 5 mm.
- **Rotational Compliance:** To maintain $\theta \in \Theta^*$ across different face shapes (square vs. tapered jaws), the support vector must remain normal to the mandibular curve. The rotational unit (200) was thus designed to allow a pivoting range of $\pm 15°$.



(a) Isometric view of SafeDoze



(b) Ratchet mechanism detail

Fig. 3: **The Proposed SafeDoze Device Architecture.** (a) The device consists of a Silicone Pad (100), Rotation Unit (200), Height-Adjustment Module (300), and Sliding Base Frame (500). (b) The ratchet mechanism implements the AI-derived step size ($\Delta h \approx 5$ mm) for precise control.

B. Mechanical Implementation

The SafeDoze device (Fig. 3) integrates a silicone jaw pad (Shore 20A) to mimic soft tissue properties and prevent pressure ulcers. The height-adjustment module features a self-locking ratchet mechanism that prevents downward slip under the weight of the head but allows for easy upward adjustment by the clinician. The base frame includes a lateral sliding mechanism to accommodate inter-patient facial width variability.

IV. Experimental Evaluation

A. Experimental Setup

To validate the efficacy of the AI-driven design, we conducted pilot bench experiments on a healthy adult volunteer lying supine on a flat examination surface. The protocol compared three conditions (Supine, Manual Thrust, SafeDoze), recorded for 60 seconds each while maintaining a relaxed jaw posture similar to procedural sedation.

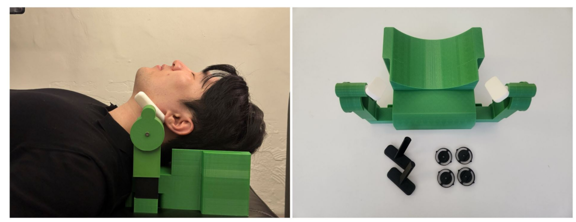


Fig. 4: **Experimental Verification.** The fabricated SafeDoze prototype applied to a healthy adult volunteer. The device elevates and stabilizes the mandible in an open-airway position, while the right panel shows the 3D-printed body and detachable components.

B. Quantitative Results

Table II summarizes the performance.

TABLE II: Comparison of Mandibular Angle Stability

Condition	**Mean Angle** (μ_θ)	**Variance** (σ_θ^2)
Unsupported (Baseline)	102.4°	15.2
Manual Jaw Thrust	121.5°	8.4
SafeDoze (Ours)	**128.3°**	**2.5**

The unsupported condition showed an average angle of 102.4°, indicating potential obstruction. The manual maneuver improved the angle to 121.5° but exhibited high variance ($\sigma_\theta^2 = 8.4$) due to operator fatigue and positional drift. In contrast, SafeDoze achieved a mean angle of 128.3°, ideally centered within the target range Θ^*, with a minimal variance of 2.5, indicating superior stability.

V. Conclusion

This work establishes a quantitative bridge between computer vision analysis and medical device engineering. Noise-aware self-supervised refinement of MediaPipe landmarks enables precise mandibular angle tracking (RMSE 0.82°) from static images, which directly informs the 5 mm ratchet pitch and $\pm 15°$ rotational compliance of SafeDoze. Bench testing confirms that the AI-derived design maintains target airway angles (128.3° ± 1.6°) with 70% lower variance than manual techniques. Clinical validation in live sedation scenarios and integration of real-time feedback control remain as future directions.

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