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Research Article

Innovative Design of Dental Mouth Props: Exploring Functional Features and Material Enhancements for Improved Performance

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Abstract: Dentists play a crucial role in maintaining patients' oral health. However, prolonged dental procedures often cause discomfort, such as jaw muscle fatigue and anxiety. Dental mouth props are used to keep the mouth open during procedures, but they often lead to complaints regarding comfort, size incompatibility, and material elasticity. Therefore, product design improvements are necessary to enhance patient comfort and usage efficiency. This study aims to improve the design of Dental Mouth Prop using Quality Function Deployment (QFD) and Value Engineering (VE) methods. The first phase of QFD maps the technical traits, including mechanical strength, anatomical fit, and material elasticity, that shape performance. The second phase highlights the parts that required refinement, such as the central support and bite surface. VE then examines each component's function and cost to guide a more efficient and effective design. Through the VE process, the central support was replaced from silicone rubber (2–10 MPa flexural strength) to PMMA (92.44 MPa), and the bite surface from silicone rubber (1–10 MPa tensile strength, 1–10 MJ/m³ toughness) to thermoplastic elastomer (10–60 MPa, 20–60 MJ/m^3). Replacing the material results in a 20.6% material cost reduction, while the simulation results also show improved load distribution and increased structural stability, addressing key discomfort factors such as jaw fatigue and bite-surface pressure. This study demonstrates that the application of QFD and VE can yield a more efficient product, reduce costs, and improve product quality while maintaining user needs and comfort.

Keywords: Dental mouth prop; Product design; Quality function deployment; Value engineering

1. Introduction

Dentists play an important role in public health, but long procedures can cause jaw and neck fatigue, increasing the risk of TMJ pain and TMD, especially when the jaw opens beyond comfort limits (Srivastava et al., 2021; Seligman, 2017). Although most treatments are performed within an hour, longer surgeries significantly heighten patient discomfort (Uzumcugil et al., 2020). Dental Bite Blocks help reduce strain and improve access, yet many patients still report discomfort due to poor size compatibility, limited design options, and material issues (Sidana et al., 2024; Knezevic et al., 2023).

The current DMP often fits poorly, especially in smaller jaws, causing pressure, pain, and longer procedures. This leads to frequent breaks, which frustates both patients and practitioners and extends recovery time (LakshmiKumari et al., 2024). Furthermore, existing commercial DMPs commonly rely on silicone rubber, whose biocompatibility tends to degrade after repeated sterilization cycles, exhibits limited rigidity under sustained bite forces, and may lose its elasticity over time (Kaneko et al., 2019a). Fixed-size designs also restrict adaptability, creating

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pressure points for patients with smaller or atypical jaw anatomy. These material and structural shortcomings often result in discomfort, unstable positioning, and reduced procedural efficiency (Huang et al., 2020). Unlike other medical devices, dental tools, such as the DMP, have not experienced significant innovation.

Although some adjustable mouth props exist on the market, they typically rely on simple notched mechanisms, fixed-step ratchets, or multisize interchangeable blocks that lack continuous adjustability. These products provide only coarse adjustment, are prone to slipping, or require switching between sizes (LakshmiKumari et al., 2024). In contrast, no commercially available design currently incorporates a continuously adjustable mechanism, that offers finer control, a self-locking feature, and stable load distribution. This comparison highlights the engineering gap that our design seeks to address (Yamamoto et al., 2023).

Optimizing DMP design can reduce discomfort and improve procedural efficiency (Joung et al., 2019). This study proposes a width-adjustable DMP using a screw-jack mechanism that allows precise gap adjustment for different jaw sizes, providing better compatibility, enhanced usability, and improved comfort through a stable self-locking system. Most DMP studies focus on basic functionality but overlook patient anatomical variability and material optimization, highlighting the need for a more comprehensive approach that integrates user diversity and material performance into the redesign process (Sidana et al., 2024).

This study addresses the gap by introducing two key contributions: a width-adjustable design for diverse jaw anatomy and a more elastic, durable, and cost-efficient material combination. QFD and VE resolve performance and economic limitations, offering a clear engineering solution to persistent DMP usability issues. Furthermore, this study applies QFD to convert patient needs into technical requirements (Husal et al., 2024) and VE to optimize materials for comfort and cost efficiency (Hartanto et al., 2024). QFD ensures functionality, while VE improves value through function analysis (Duan, 2012; Younker, 2003), enabling resource optimization and supporting the development of a cost-effective, high-value DMP (Ginting et al., 2025; Ishak et al., 2020).

2. Research Methodology

2.1 Product Design

Product design theory focuses on creating products through iterative design, emphasizing user needs, ergonomics, and comfort (Ginting, 2022; Ulrich and Eppinger, 2015). The product life cycle encompasses stages from introduction to decline, guiding decisions on development, performance optimization, marketing, and innovation (Stark, 2021; Kusrini and Kartohardjono, 2019). Key considerations in medical product design include biocompatibility, safety, and regulatory compliance to minimize patient risk and ensure approval (Sharma and Luthra, 2023; Bernard, 2018; Schuh and Funk, 2018).

This study aims to improve DMP design and performance. Data were gathered from questionnaires, customer needs, technical traits, key part identification, product specs, and literature. The respondents were selected through judgment and quota sampling. The sample included experienced dentists who regularly use DMPs, supported by input from dental nurses familiar with their handling and patient comfort. Although their expertise strengthens the findings, the narrow expert-based sample is recognized as a limitation (Ntona et al., 2023).

2.2 Quality Function Deployment

QFD, which was developed in Japan in the 1960s, is a method for translating customer needs into technical specifications and is now applied across various industries (Akao, 2024; Ficalora et al., 2022). Phase I of QFD focuses on translating customer needs into product characteristics, while Phase II takes these characteristics and translates them into specific module and component specifications, ensuring the design fulfills the technical requirements (Ginting, 2016; Yeh, Huang, and Wu, 2011). QFD has proven effective across various sectors, including

healthcare (Ginting et al., 2025), where it has improved service quality, safety, and overall process efficiency (Gremyr and Raharjo, 2013).

2.2.1 Phase 1 of QFD: Product Planning

QFD Phase I develops a House of Quality (HoQ) that links Customer Requirements (CR) with Technical Characteristics (TC). CR are gathered through questionnaires and prioritized, TC are defined and their relationships with CR are evaluated, and the Planning Matrix and Technical Matrix are then used to translate priority needs into technical actions (Sukma et al., 2022; Yeh, Huang, and Yu, 2011). The technical matrix for this phase is determined based on performance measures derived from the HoQ, consisting of three main aspects: level of difficulty (D) using formula (1), degree of importance (I) using formula (2), and estimated cost (C) using formula (3).

$$D_j = \frac{\sum_{i=1}^{m} R_{ij}^{\mathrm{TC,TC}}}{\sum_{i,j} R_{ij}^{\mathrm{TC,TC}}} \times 100\% \tag{1}$$

$$I_j = \frac{\sum_{i=1}^{m} R_{ij}^{\mathrm{TC,CR}}}{\sum_{i,j} R_{ij}^{\mathrm{TC,CR}}} \times 100\% \tag{2}$$

$$C_j = \frac{D_j}{\sum_{j}^{n} D_j} \times 100\% \tag{3}$$

In these formulas, $R_{i,j}$ represents the relationship weights, either between TCs or between TCs and CRs, while the values D_j, I_j , and C_j are each obtained by comparing the total relationship weight of a specific TC with the total weight of all relationships in their respective matrices. The TCs were identified through interviews with dental professionals and supported by relevant literature. The TC–TC and TC–CR matrices were then used to calculate the D_j, I_j, and C_j, integrating both engineering constraints and user needs. These results guided the QFD prioritization, from which the two highest-ranking TCs were selected for focused redesign.

2.2.2 Phase 2 of QFD: Part Deployment

The QFD Phase II process begins by identifying priority TC based on weighted difficulty, importance, and cost. The critical parts (CP) of the product are then identified, followed by the analysis of the relationships among CP and between TC and CP to assess their interdependence. Finally, the Technical Matrix is constructed using formulas (1), (2), and (3), with "TC" replaced by "CP" and "CR" by "TC" to match the design parameters (Sukma et al., 2022; Yeh, Huang, and Yu, 2011). Similarly, in QFD Phase II, the TC–CP matrix identifies the components with the highest priority values, highlighting which parts require focused redesign and material optimization.

2.3 Value Engineering

Value Engineering (VE) increases value by optimizing function while reducing cost (Ongbali et al., 2024; Younker, 2003). VE is particularly important in the medical product sector, where it helps reduce production costs while maintaining high functionality standards (Wibisana and Budiyanto, 2021; Younker, 2003). VE includes five stages: gathering information, generating alternatives, evaluating options, developing proposals, and implementing the selected solution (Husal et al., 2024; Muhammed et al., 2020; Rajiv et al., 2014).

2.4 Integration of the QFD and Value Engineering

The integration of QFD and VE, such as medical product design, helps align customer needs with technical specifications while reducing costs (Setti et al., 2021; Yekinni, 2015). This

approach has been effectively applied in several product designs, enhancing both functionality and cost-efficiency (Hartanto et al., 2024; Muhammed et al., 2020). A manufacturing case study showed that integrating QFD and VE improved functionality, reduced costs, and increased customer satisfaction (Rajiv et al., 2014). Figure 1 shows the methodological flowchart for this integration.

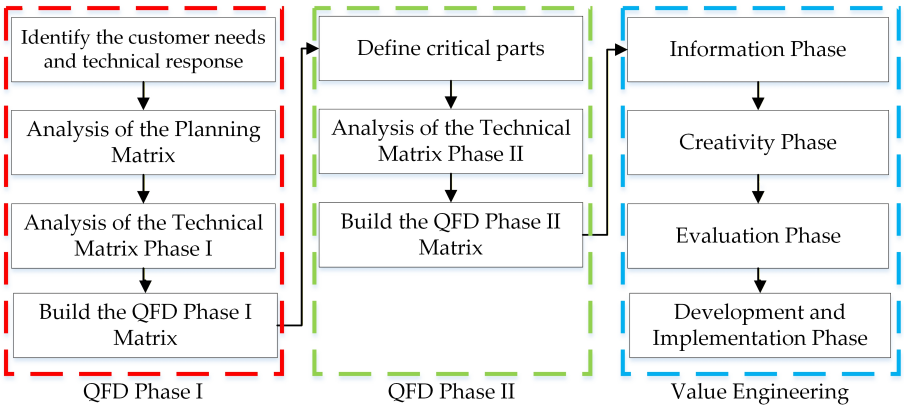


Figure 1 Research steps in the integration of QFD phases I, II, and VE

Previous studies on DMP have primarily focused on the tool's functional aspects without systematically translating user needs into technical specifications or optimizing cost (Knezevic et al., 2023; Sapate et al., 2021; Nagori et al., 2017). This study integrates QFD and VE to translate customer needs into technical characteristics and to assess design options by function and cost. Innovation centers on adjusting product dimensions to match jaw anatomy and choosing a more elastic, cost-efficient material.

3. Results and Discussion

3.1 Data Collection

Open-ended questionnaires were used to collect research data, which informed the development of closed-ended questionnaires using a 5-point Likert scale. The data validity and reliability of the data were tested before determining the importance level of customer requirements (Sullivan and Artino, 2013). Ordinal data were treated as interval data for a more precise analysis. This served as input for QFD Phase I, guiding product design to better meet customer expectations.

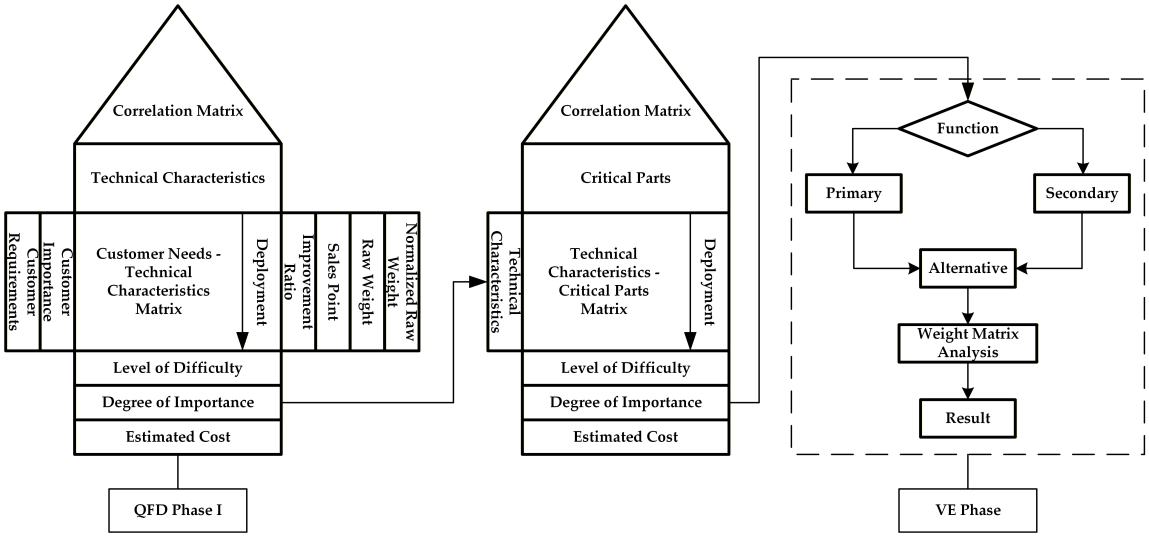


Figure 2 Flowchart of the research methodology for DMP design with intergrated methods

3.2 QFD Phase I

3.2.1 Determining the Importance Level of Variables

The importance of each variable was assessed using the mode value from the closed-ended questionnaire, based on the most frequent responses. Five key CR points were selected from 10 responses, reflecting consensus on key functional and comfort features. The CR values are summarized in Table 1.

Table 1 Importance level of each customer requirement

CR.	Customer requirement variable	Importance level
1	The DMP is designed with dimensions of $40 \times 14 \times 40$ mm.	2
2	The primary structural material utilized for the DMP is silicone rubber, selected for its durability and flexibility.	4
3	The surface material of the DMP that comes into direct contact with the teeth is thermoplastic elastomers, chosen for its biocompatibility and comfort.	4
4	The DMP undergoes sterilization using the autoclave method, ensuring effective disinfection for clinical use.	3
5	The DMP incorporates a width-adjustable feature, allowing for customization to accommodate different patient anatomies.	5

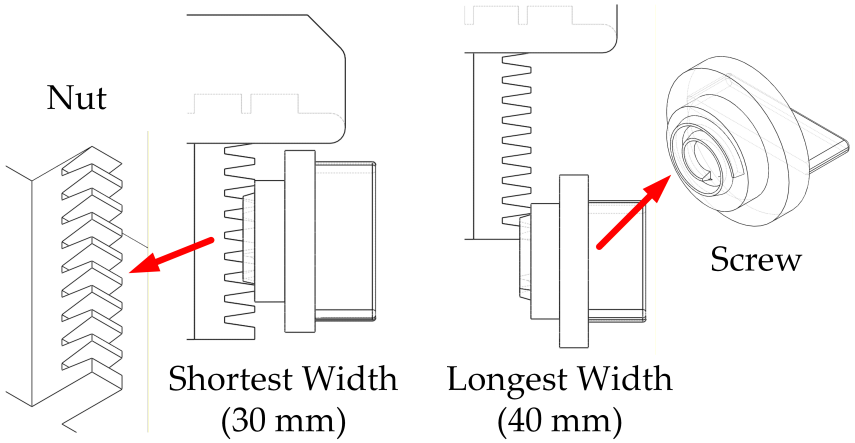


Figure 3 Proposed adjustable width function system

3.2.2 Analysis of the planning matrix

After determining CR, the necessary TCs are identified. A relationship analysis is then conducted to evaluate how the items interact using symbols such as V (strong positive), v, x, X (strong negative), and – (no relationship). Subsequently, the connections between TC and CR are quantified using 9 (strong), 3, 1, and 0 (no relationship) (Yeh, Huang, and Yu, 2011). The strength of these relationships helps assess the difficulty of the design process. The results are used in the Planning Matrix to prioritize product development strategies, based on difficulty and importance, as shown in Table 2.

Table 2 shows the importance level assessment for DMP product attributes, with the highest score 5 given to the "Width Adjustable" feature, followed by material and sterilization method attributes. This prioritization reflects consumer focus on comfort and functionality, leading to the inclusion of the width-adjustable feature via a screw jack system (Figure 3).

The opening gap interval was adjusted to match the smallest and largest sizes of similar products, ensuring optimal compatibility and usability (Dental Kart, 2023). The proposed width-adjustable system uses a screw-jack mechanism, in which a threaded screw converts a small rotational turn into a precise linear movement. This allows the mouth prop to open or close smoothly while providing high stability, and its self-locking feature ensures that the position remains secure without slipping during use (Borse et al., 2024).

3.2.3 Analysis of the Technical Matrix QFD Phase I

Identifying TCs was essential for translating user needs into engineering specifications. They were developed through interviews with professionals on comfort, safety, and usability, supported by journal references on dental device design, materials, and clinical ergonomics. These TCs consist of the following: (1) anatomical precision (Tan et al., 2022), (2) mechanical strength (Luo et al., 2023), (3) biocompatibility (Wuersching et al., 2022), (4) sterilization resistance (Almeida et al., 2022), (5) product weight (Vasudevan and Stahl, 2020), (6) Material Elasticity (Belli et al., 2017), and (7) slip resistance (Chaaben et al., 2020).

After identifying the TCs, we conducted weighting in two stages: the TC–TC matrix generated the Level of Difficulty, and the TC–CR matrix produced the Degree of Importance. These were combined with the estimated cost because higher difficulty typically increases production cost. Together, these values help QFD balance user needs, technical feasibility, and cost.

Additionally, the difficulty level (on a scale of 1 to 5) is assigned according to the following percentage ranges: 0-5% corresponds to scale 1, 6-11% to scale 2, 12-17% to scale 3, 18-23% to scale 4, and over 24% to scale 5 (Yeh, Huang and Wu, 2011).

Table 3 Technical matrix for phase I QFD

Criteria	TC-1	TC-2	TC-3	TC-4	TC-5	TC-6	TC-7
Level of difficulty	3	4	2	2	2	2	4
Degree of importance	13	16	11	11	12	15	22
Estimated cost	16	21	11	11	11	11	21

3.2.4 HoQ QFD Phase I

After evaluating importance levels, TC–CR relationships, and calculating the Planning and Technical Matrices, the results are consolidated into the Phase I House of Quality (HoQ), which highlights key design priorities and improvement areas (Figure 4). The highest-value TCs show which factors matter most for meeting user needs from the House of Quality results. This study limits the focus to the two top-scoring TCs to keep the redesign manageable and feasible. Mechanical strength (TC-2) and material elasticity (TC-7) were identified as the key TCs for further development. They are essential for ensuring the safety and stability of DMP under bite pressure and preventing slipping. Thus, to meet these requirements, QFD Phase II must prioritize material choice, structural design, and product strength.

3.3 QFD Phase II

3.3.1 Define critical parts

In Phase Iiof the QFD, critical parts (CP) are identified as key components essential for meeting the priority TC established in Phase I. These CPs are determined through surveys conducted with dental clinics. The CP for the DMP product is as follows: (1) central support, (2) bite surface, (3) frame, and (4) positioning slot. The identification of these CP will be followed by the calculation of the Technical Matrix, which is used to measure and evaluate the TC and the relationship between the CP and CR.

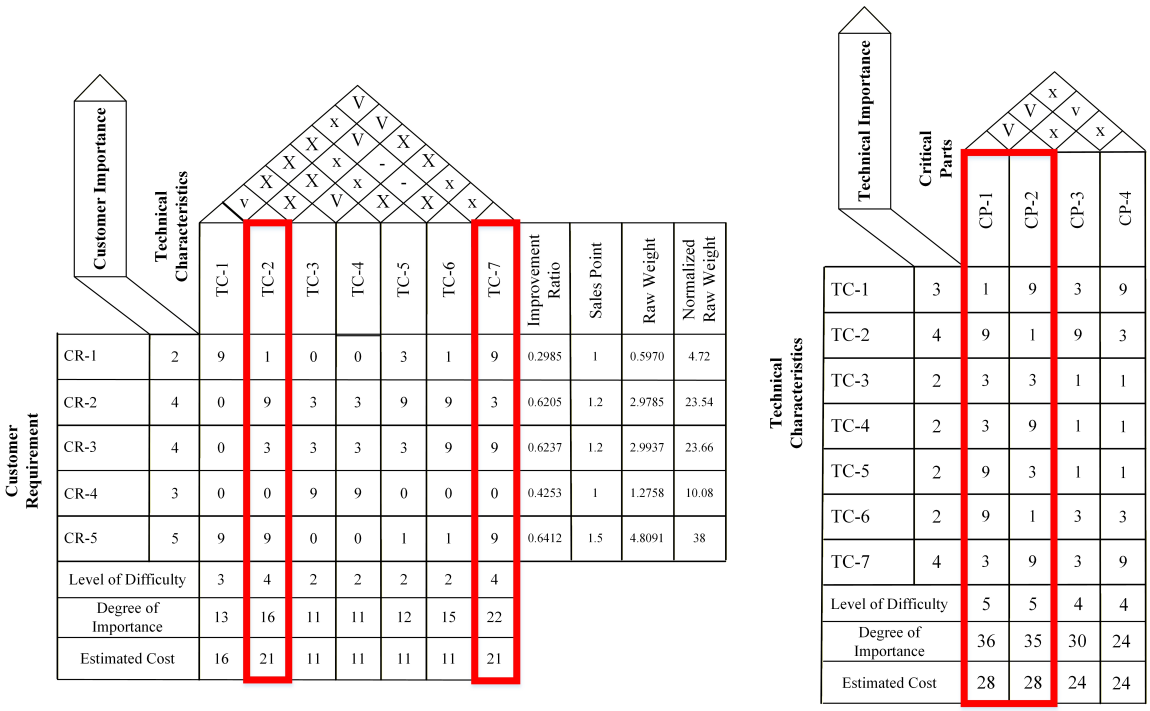


Figure 4 HoQ of QFD in Phases 1 and 2 of the initial DMP

3.3.2 Analysis of the QFD Technical Matrix Phase II

In Phase II, the Technical Matrix applies the same calculations as in Phase I, evaluating the difficulty, importance, and cost of the CPs. The resulting priorities indicate which components influence performance the most, as shown in the Phase II HoQ in Figure 4.

3.3.3 HoQ QFD Phase II

Similarly, in QFD Phase II, the product component prioritization is determined through the HoQ by analyzing the CP that obtains the highest parameter values within the TC-CP Matrix. These values indicate which CP most directly contributes to fulfilling the prioritized TC. As in the previous phase, the Central Support (CP-1) and Bite Surface (CP-2) were identified as the components with the greatest priority for further development and material optimization. The alignment between TC priorities from Phase 1 and CP priorities from Phase 2 will direct further product improvements, as shown in Figure 5.

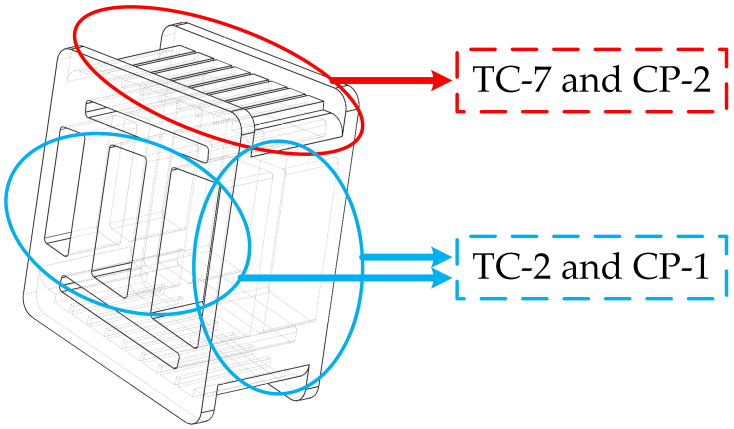


Figure 5 Prioritized product development based on QFD phases 1 and 2

3.4 Value Engineering

3.4.1 Information Phase

The General Phase defines key DMP functions and prioritizes improvements to the central support and bite surface using phase II QFD to enhance stability and comfort. The Information Phase then provides component and cost data, such as silicone rubber (1 kg at 6.25 USD, prone to degradation) and the DMP unit price (7–10 USD), to guide redesign decisions toward more durable materials without increasing cost (Kaneko et al., 2019a). The central support is identified as the primary function in the function determination phase, with the bite surface, positioning slot, and frame serving secondary functions. In value engineering, this classification guides efforts to improve essential functions and explore more efficient material or design alternatives without reducing quality (Younker, 2003), as shown in Table 4.

Table 4 Part, function, and level determination of initial DMP level

Part name	Function		Level		Description
	Verb	Noun	Primary	Secondary	
Central support	Support	Bite	Yes	–	–
Bite surface	Withstand	Teeth	–	Yes	Central support
Positioning slot	Position	Teeth	–	Yes	Central support
Frame	Stabilize	Product	–	Yes	Central support

3.4.2 Creativity Phase

In the creative phase, the Central Support and Bite Surface is identified as a component of the DMP that needs to be engineered, with Value Engineering used to select cost-effective material alternatives that meet medical safety standards (ISO 10993, USP Class VI, FDA Approval) (Sharma and Luthra, 2023; Sall et al., 2023; Bobo et al., 2016). The commonly used materials in the Table 5 show the key pros and cons of various materials used in DMP to assist in material selection.

The color of the DMP was changed from purple to orange and blue to improve visibility, recognition, and safety in clinical settings. Purple conveyed premium quality but lacked contrast. Orange offers high visibility, while blue conveys trust and cleanliness, making the product more suitable for medical use and more easily recognized against teeth and gums (Kauppinen-Räisänen and Luomala, 2010).

3.4.3 Evaluation Phase

In the material evaluation stage, the optimal material for each DMP component is determined using a pairwise comparison matrix (symbols X, 1, and 0), where 1 indicates superior performance, 0 indicates inferior performance, and X indicates self-comparison. The assessment is conducted separately for the three selection criteria, namely, flexibility, biocompatibility, and cost savings, with each criterion weight set at 40, 35, and 25, respectively, based on professional interviews and supporting journal evidence indicating their relevance to clinical comfort and safety.

Each material is compared pairwise under every criterion, and the total "1" scores form its raw index. The raw index is then normalized and multiplied by the weight of the criterion. Summing all weighted scores identifies the material with the highest overall value. Table 6 summarizes the results.

Based on the results of the matrix analysis, it can be concluded that the selected alternative material for the central support is polymethyl methacrylate and the bite surface is thermoplastic elastomer due to its highest weight index value compared to other alternatives. The mechanical

properties of silicone rubber were compared with those of PMMA and TPE to support the material substitution, as summarized in Table 7.

Table 5 Material properties and limitations for DMP

Alternative	Pros	Cons	Ref.
Silicone rubber	Comfortable and flexible; non-slip; hypoallergenic and biocompatible	Less stable under high pressure or prolonged use; potential for degradation	Silva and Masini, 2023; Cho et al., 2021; Kaneko et al., 2019b
Polycarbonate	Strong and durable; stable in position; resists long procedures	Rigid and hard feel; less comfortable without padding	Osswald, 2016
Ethylene vinyl acetate	Flexible and elastic; cheap and lightweight; suitable for disposable products	Not resistant to high-temperature sterilization; wears out quickly; easily deforms	Silva and Masini, 2023; Park et al., 2022; K. Wang and Deng, 2019
Polymethyl methacrylate	Stable and sturdy; can be made transparent; hydrophobic	Rigid and inflexible; brittle under uneven pressure; uncomfortable	Ramanathan et al., 2024; Ali et al., 2015
Natural rubber latex	Cheap and flexible; easily shaped; comfortable and hydrophobic	Allergy risk; not durable over time for long-term use	Barrera, 2023; Guerra et al., 2021
Polyurethane	Flexible and rubber-like feel; resists weathering, chemicals, and UV light; impact resistant	Degrades under UV exposure; poor heat resistance; can be costly for large-scale production	Backes et al., 2024; Neubauer et al., 2022; Kim et al., 2018
Thermoplastic elastomer	Flexible and rubber-like; resists weathering, chemicals, and UV light; non-toxic and biocompatible	Less durable under high stress; poor high-temperature resistance; more expensive than other plastics	Gong et al., 2021; Scholz and Gehringer, 2021; Spontak and Patel, 2000
Soft gel polymer	Highly flexible and comfortable; provides cushioning and impact absorption; smooth texture	Can deform over time; less durable than rigid materials; prone to degradation under heat or humidity	Z. Wang et al., 2022; Shi et al., 2020

Table 6 Results of Pairwise Matrix Analysis for Material Selection

Part	Alternative weight	Criteria			Total
		I (40)	II (35)	III (25)	
Central support	Silicone rubber	1/10	4/10	0/10	8
	Polycarbonate	3/10	2/10	1/10	21.5
	Ethylene vinyl acetate	2/10	2/10	3/10	22.5
	Polymethyl methacrylate	4/10	2/10	2/10	28
	Natural rubber latex	0/10	0/10	4/10	10
Bite surface	Silicone rubber	0/10	4/10	1/10	16.5
	Natural rubber latex	4/10	0/10	4/10	26
	Polyurethane	1/10	2/10	1/10	13.5
	Thermoplastic elastomer	2/10	2/10	3/10	22.5
	Soft gel polymer	3/10	2/10	1/10	21.5

Comparatively, PMMA provides far greater flexural strength and stiffness for load-bearing support than silicone rubber, while TPE offers much higher tensile strength and toughness for a more resilient, comfortable bite surface. Combined, they address structural rigidity and patient comfort more effectively than the original single-material silicone design (Al-Dwairi et al., 2023; Sbrescia et al., 2023; Persson and Andreassen, 2022; Sbrescia et al., 2021; Cho et al., 2021).

Silicone rubber was used for all parts of the original product. However, based on the results of the evaluation phase, the materials for the central support and bite surface be replaced with alternative materials. As a result, the proposed design features different materials for these two components. The material changes in these sections are illustrated in Figure 6.

Table 7 Mechanical properties of silicone rubber, polymethyl methacrylate (PMMA), and thermoplastic elastomer (TPE)

Central support			Bite surface		
Properties	Silicone rubber	PMMA	Properties	Silicone rubber	TPE
Flexural strength	2–10 MPa	92.44 MPa	Tensile strength	1–10 MPa	10–60 MPa
Stiffness	0.1–10 MPa	2085 MPa	Failure strain	150–900%	300–800%
Hardness	2 VHN	18.11 VHN	Young modulus	0.5–3 MPa	10–100 MPa
			Toughness	1–10 MJ/m^3	20–60 MJ/m^3

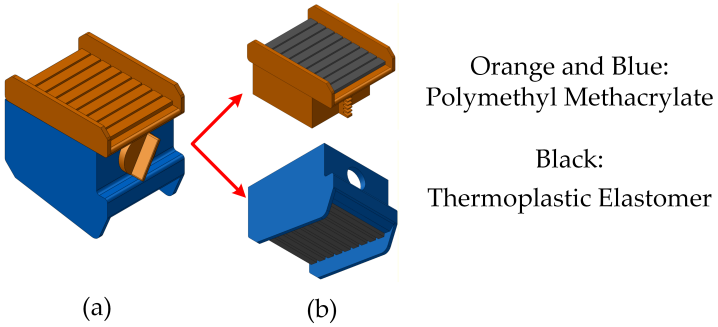


Figure 6 (a) New color scheme (b) material replacement

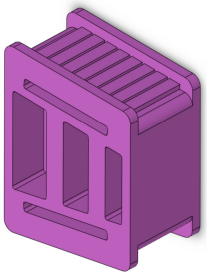
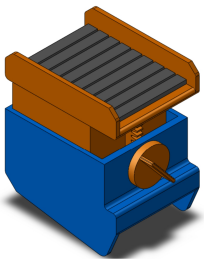
3.4.4 Development and Implementation Phase

A SolidWorks static simulation was performed to evaluate the structural safety of the redesigned dental mouth prop under realistic clinical loading conditions. The central support was assigned a fixed geometry, and a bite force of 416 N (Altayyar et al., 2023) was applied normal to the bite surface. The stress analysis showed contour values from 1.27×10^8 Pa to 2.72×10^8 Pa, indicating low- and high-stress regions. These stresses remained below the allowable limits of the selected materials. The Factor of Safety assessment also met the standard criteria, confirming that the redesigned geometry can withstand the expected bite loads without failure. Overall, the simulations confirm that the product meets the safety requirements, as shown in the supplementary file.

This phase provides improvement recommendations to save material costs and enhance the DMP product. Initially, silicone rubber was used at 6.25 USD/kg, while the proposed improvements involve PMMA at 2.94 USD/kg and TPE at 2.02 USD/kg. The material cost savings calculation shows a 20.6% reduction, indicating significant cost efficiency by switching materials. Table 9 presents the proposed product images and specifications for a clearer overview of the design and materials.

The redesigned DMP reduces PMMA rigidity issues through smoother contours and minimized soft-tissue contact, and safe force distribution is confirmed by simulations. Because PMMA and TPE cannot endure autoclaving, cold-chemical or UV-C sterilization is recommended. As the study is based on QFD, VE, and simulations, further work must include prototyping, clinical testing, and ergonomic and manufacturing improvements. To illustrate, Table 8 highlights the design differences.

Table 8 Comparison of Proposed Design and Finalized Technical Specifications

Aspect	Actual product	Proposed product
Material composition	• Single material: silicone rubber • Moderate elasticity; decreases after repeated sterilization	• Dual material: PMMA (central support) + TPE (bite surface) • PMMA provides structural rigidity; TPE enhances flexibility and comfort
Material property	• Flexural/tensile strength: 1–10 MPa • Toughness: 1–10 MJ/m^3	• PMMA (central support): flexural strength 92.44 MPa → much stronger support • TPE (bite surface): tensile strength 10–60 MPa; toughness 20–60 MJ/m^3 → more durable and comfortable
Key functional features	• Fixed width • No adjustability • No self-locking system	• Width-adjustable system (screw-jack mechanism) • Integrated self-locking for stability • The flexible TPE bite surface improves comfort • The PMMA frame increases strength and support
Material cost	• Silicone rubber: 6.25 USD/kg • Used as the baseline: 100% material cost	• PMMA: 2.94 USD/kg • TPE: 2.02 USD/kg • Combined material cost leads to 20.6% (primarily due to cheaper raw materials than silicone rubber)
Manufacturing complexity	• Simple single-material workflow • Multiple mold sizes are required to fit different patients	• Slightly higher complexity due to dual-material assembly • The adjustable design eliminates the need for multiple mold variants
Design		

4. Conclusions

Based on the QFD and VE analyses, this study successfully redesigned the to achieve better size compatibility, enhanced mechanical performance, and reduced material cost. QFD Phase I highlighted the need for a width-adjustable mechanism and identified Mechanical Strength and Material Elasticity as critical characteristics, which guided focused improvements in QFD Phase II. Value Engineering further supported the selection of polymethyl methacrylate (PMMA) for the central support offering superior rigidity, dimensional stability, and structural strength, then thermoplastic elastomer (TPE) for the bite surface due to its higher flexibility, resilience, and

patient comfort compared to silicone rubber. This material transition not only provides these engineering benefits but also yields a material cost reduction of 20.6%. Overall, the QFD and VE integration resulted in a more robust, comfortable, and cost-efficient DMP design that aligns with clinical needs while improving performance over the previous silicone-based product.

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