# Integrated Polymeric Face Shield with On-Demand Hand Sanitisation for Infection Control in Dentistry

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*Article*

# Integrated Polymeric Face Shield with On-Demand Hand Sanitisation for Infection Control in Dentistry

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**Abstract**

Background: Persistent challenges in healthcare infection control, particularly the need for rapid hand hygiene during continuous patient care, highlight limitations of current personal protective equipment (PPE). We developed a lightweight face shield integrating a disinfectant reservoir to enable immediate point-of-care hand sanitisation. Methods: A dual-function system was designed comprising a polyethylene terephthalate glycol (PETG) visor (23 × 23 cm, 0.20 mm) and a modular disinfectant reservoir (25–100 mL). Components were fabricated using CAD, 3D printing, and PETG forming. The reservoir features a touch-activated, self-sealing valve delivering approximately 3 mL per activation. Benchtop testing assessed dosing consistency, leak-tightness, attachment security, material compatibility with alcohol-based disinfectants, and durability. Results: The visor weighed 13.4 g, with total system mass of 103.4 g (empty) and 203.4 g (maximum fill). Cervical torque increased from 0.084 to 0.282 N·m, supporting continuous wear for 60–90 minutes. Testing confirmed consistent dosing, reliable resealing, leak-free performance, and PETG stability after disinfectant exposure. Conclusions: This dual-function visor integrates facial protection with immediate hand sanitisation, addressing critical infection-control challenges in dentistry. Its low cost, reusability, and modular design support chairside use and mobile dentistry, while enabling future integration of wearable sensors.

**Keywords:** hand hygiene; personal protective equipment; face shields; infection control; integrated disinfectant reservoir; low-cost; dental practice; dental infection control

## 1. Introduction

The COVID-19 pandemic emerged suddenly and followed patterns previously observed during other large infectious outbreaks. Several analyses described the early appearance of SARS-CoV-2, the rapid growth of initial clusters, and the transition from a local epidemic to a global emergency [1]. Comparative studies showed that widespread infectious events produce major medical, social, and economic disruption and can quickly overwhelm public behaviour and healthcare capacity [2]. Additional reports indicated that the worldwide impact of COVID-19 reflected both the biological properties of the virus and structural weaknesses in preparedness systems [3].

As case numbers increased, protecting healthcare workers became a central priority. Research on occupational safety revealed that institutional protocols frequently left gaps in routine workflows, creating vulnerabilities during patient care [4]. Evidence confirmed that infected individuals generate respirable aerosol particles capable of sustaining close-contact and household transmission [5]. Further findings suggested that the conjunctiva may represent a secondary portal of entry for the virus [6]. These observations aligned with established aerosol principles showing that particle size strongly influences airborne transport and infection risk. Because many medical and dental

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procedures create heavy aerosol loads, strict facial and ocular protection became essential in preventing exposure [7].

Hand hygiene represented an equally important defence. Multiple studies emphasised its central role in reducing viral spread, and compliance improved in many institutions during the pandemic [8]. Proper hand hygiene was identified as the most effective single method for preventing the spread of COVID-19, especially when combined with other protective measures [8]. This importance is heightened by evidence showing that the virus can remain viable on surfaces for extended periods, creating persistent risk of transmission from contaminated hands to the face [9]. Despite this progress, consistent hand sanitisation remained difficult in clinical environments. Qualitative assessments documented several barriers, including workflow interruptions, limited access to dispensers, distance from fixed sanitising points, and time pressure during busy shifts [10]. Prolonged use of conventional personal protective equipment also contributed to fatigue, as healthcare workers frequently reported physical discomfort, reduced communication efficiency, and cognitive strain [11].

Because of these combined pressures, protective solutions must reduce aerosol, droplet, and ocular exposure and must also ensure immediate and effortless hand disinfection at the point of care.

We searched PubMed, Scopus, Web of Science, Google Scholar, IEEE Xplore, and patent databases (WIPO PATENTSCOPE, EPO Espacenet, USPTO, J-PlatPat, and Google Patents) for devices combining face shields with integrated sanitisation. Search terms included *face shield*, *disinfectant reservoir*, *integrated sanitisation*, *hand hygiene*, and *personal protective equipment*. We reviewed literature and patents up to Decembre 21, 2025, with no language restrictions. We found no study, prototype, or patent filing describing a face shield with a built-in disinfectant reservoir enabling immediate hand sanitisation. To address this gap, we propose a face shield with an integrated disinfectant reservoir that provides barrier protection and instant hand sanitisation.

## 2. Methods

A protective face-shield system with an integrated disinfectant reservoir was developed through an iterative design process carried out by a mixed clinical–engineering team. The workflow progressed from conceptual modelling to functional prototyping, with the objective of creating a reusable device that combines facial barrier protection with immediate hand sanitisation capability. The development emphasised ergonomic balance, weight reduction, stable load distribution around the head's natural pivot point, and low production cost. The polyethylene terephthalate glycol (PETG) visor was selected for its impact resistance, optical clarity, and compatibility with alcohol-based disinfectants and was thermoformed to ensure optimal lateral coverage.

The integrated reservoir includes a self-sealing valve for single-hand operation and modular volumes of twenty-five, fifty, seventy-five, or one hundred mL. The dual-arch head-mounting system provides adjustable retention and stability during movement.

Theoretical evaluation included mechanical testing of the dispensing system, verification of sealing integrity under dynamic conditions, and assessment of material durability when exposed to disinfectants. Ergonomic analysis utilised computational modelling and mannequin simulations to validate comfort and stability, confirming the device's theoretical suitability for clinical use. All development was self-funded, and this initial phase was conducted exclusively through technical methods without human participation, with future clinical validation planned following ethical review.

### *2.1. Planning for Optional Features*

The prototype's modular architecture was developed to support optional functions for high-risk or field environments while preserving low mass, optical clarity, and cost. These modules aim to improve safety, usability, and workflow integration. The design also enables incorporation of advanced sensors without compromising ergonomics. Wearable monitoring systems demonstrated the feasibility of including infrared sensors, carbon dioxide or volatile organic compound detectors,

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and proximity alarms [12]. Sensor-based frameworks have been shown to map clinical workflows [13], and wearable proximity sensors have demonstrated usability in dynamic hospital settings [14].

### *2.2. Ethics Compliance Statement*

This work involved exclusively engineering design, simulations, and benchtop testing. No human participants or data were involved; thus, no ethics approval was required. Any future human studies will be conducted only after obtaining formal ethics committee approval.

## 3. Results

This section presents the completed face-shield prototype, the results of the functional and ergonomic evaluations, and the cost analysis. Computer-aided design (CAD) and three-dimensional fused deposition modelling (FDM) printing using polyethylene terephthalate glycol (PETG) filament constituted the manufacturing workflow. Components were assembled using press-fit joints, and screws were limited to areas requiring maintenance. Regarding materials and tolerance, PETG was used for both screen and frame, with thermal endurance up to approximately 80 °C and resistance to common clinical agents under repeated cleaning [15,16].

### *3.1. Prototype Completion*

The prototype face-shield system was designed and fabricated as a fully functional assembly integrating facial protection and a disinfectant delivery module. Detachable reservoirs of twenty-five, fifty, seventy-five, and one hundred mL, each incorporating a ball-type, touch-activated, self-sealing dispenser, were designed, fabricated, and assembled. The reservoir mounts on the left or right via a male–female click-lock interface and supports colour-coding for disinfectant identification. Core subsystem specifications are summarised in Table 1.

**Table 1.** Prototype components and final technical specifications.

| Subsystem | Material | Key dimensions/specs | Mounting/interface | Notes |
|---|---|---|---|---|
| Screen (visor) | PETG sheet | 23 × 23 cm, thickness 0·20 mm; laterally curved | Bolts/press-fit to double arch | Calculated mass ≈ 13·4 g, chemical-resistant, and ~80 °C tolerance |
| Head frame | PETG (FDM-printed) | Double-arch geometry | Integrates reservoir cavity; posterior elastic band | Load distribution reduces hot spots |
| Head fixation | Elastic band (posterior) | Adjustable | — | Optional top strap or ratchet dial planned |
| Reservoir (baseline) | PETG (FDM-printed) | 100 mL nominal (modular 25/50/75/100 mL) | Male–female click-lock, left or right | Colour-coding for disinfectant identification; right-biased in prototype |
| Dispenser | Ball/seal valve | ~3 mL per actuation | Touch-activated, self-sealing | Outlet outside optical field |

### *3.2. Final Technical Specifications*

The screen is fabricated from PETG, cut as a 23 × 23 cm, 0·20 mm sheet and laterally curved to extend side coverage; its calculated mass is ≈ 13·4 g (area 529 $cm^2$ × thickness 0·02 cm × density ~1·27 $g/cm^3$), as illustrated in Figure 1.

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**Figure 1.** Image of the double arch of the visor and the protective screen.

The head-mounting system consisted of a dual-arch cranial frame and an adjustable posterior elastic band, designed to evenly distribute pressure across fronto-occipital contact surfaces and to create a rigid lateral interface for modular reservoir attachment. The reservoir housing was engineered to accept interchangeable volumes (25, 50, 75, and 100 mL), with the standard prototype using 100 mL. A male–female locking mechanism ensured repeatable attachment without displacement; right-side positioning was chosen to align with dominant professional workflow, with an option to switch to the left side.

The first reservoir constructed, initially developed with a 100 mL capacity, is designed for asymmetric lateral mounting, oriented towards the right side to optimize the device's ergonomics and balance. It attaches via a practical push-to-lock system (a male–female click-lock interface). For increased flexibility, the solution is modular, with additional reservoirs of 25, 50, and 75 mL also being provided. These features are illustrated in Figure 2, which shows the model of the double-arch frame with the reservoir detached, and in Figure 3, which shows the visor with the assembled reservoir.

**Figure 2.** Model of the double-arch frame and the reservoir (detached from the frame).

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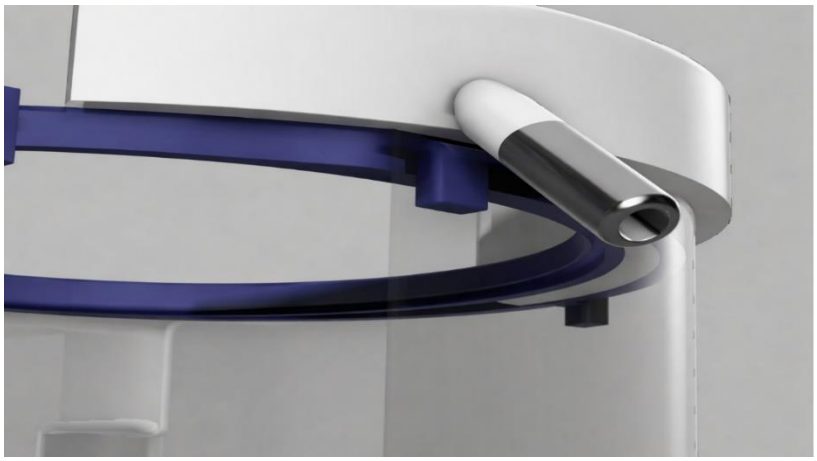

**Figure 3.** Image of the visor with disinfectant reservoir (assembled).

A compact ball-seal valve enabled manual activation and automatic re-sealing. Bench testing targeted a constant dosing volume (~3 mL per activation). The nozzle was positioned outside the optical field to avoid droplet contamination of the visor. Bench handling confirmed that the touch-activated mechanism dispenses a controlled ~3 mL dose and reseals automatically after each actuation. Repeated attach/detach cycles of the reservoir's male–female interface showed stable, wobble-free locking. Under routine handling, refill, and transport, the reservoir remained leak-tight; representative reservoir embodiments compatible with the double arch are presented in **Figure 5** and **Figure 6** (images of the disinfectant reservoir(100ml) that can be mounted in the double arch).

**Figure 4.** Images of the disinfectant reservoir that can be mounted in the double arch.

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**Figure 5.** Images of the disinfectant reservoir that can be mounted in the double arch.

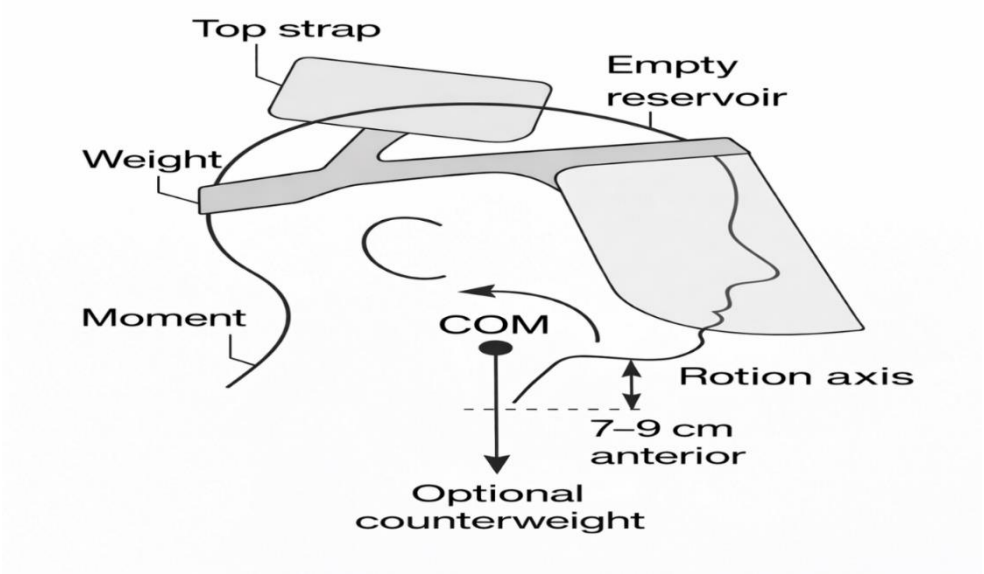


**Figure 6.** Schematic representation of mass properties and load paths.

This 100 mL disinfectant reservoir of the protective face-shield system was designed to store and dispense fluid through a self-sealing touch valve. It was fabricated from PETG (polyethylene terephthalate glycol-modified) [15] by fused deposition modelling (FDM) 3D printing, chosen for its optical clarity, alcohol resistance, and dimensional stability. Printing parameters included a 0.4 mm nozzle, 0.2 mm layer height, three outer perimeters, 35% cubic infill, and an extrusion temperature of 245 °C. Wall thickness ranged from 1.2 to 1.4 mm, ensuring mechanical rigidity with low weight. The empty reservoir weighed 20.94 g, and the cap was attached via a click-lock interface incorporating a TPU 95A sealing gasket for leak prevention.

Material compatibility was assessed using Mikrozid AF Liquid (Schülke & Mayr GmbH, Germany), an aldehyde-free, alcohol-based disinfectant containing about 25 g ethanol (94%) and 35 g propan-1-ol per 100 g of solution(16). This reservoir was filled with 100 mL of Mikrozid, sealed, and stored for seven days at 25 °C and 48 hours at 60 °C to simulate prolonged exposure. Mass variation, dimensional stability, transparency, and mechanical integrity were analyzed. Acceptable limits were defined as ≤1% mass change and ≤5% transparency loss at 550 nm.

Flat PETG samples (20 × 20 × 1.2 mm) were immersed in Mikrozid AF Liquid for 14 days at 25 °C following ISO 175:2010. Daily inspections looked for clouding, swelling, or cracking, and

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gravimetric measurements quantified solvent absorption, with <0.5% weight gain considered very good compatibility. After exposure, reservoirs underwent 50 fill–drain cycles, static pressure testing at 0.2 bar, and a one-meter drop test on a rigid surface. Criteria for acceptance included no cracking, zero leakage, deformation <0.2 mm, and maintained valve function. Post-test microscopy (20×) showed no stress-crazing or damage. The PETG reservoir demonstrated good resistance to Mikrozid AF Liquid, maintaining full mechanical integrity and leak-tightness, confirming PETG's suitability for repeated use in integrated disinfectant systems(Table 2).

**Table 2.** PETG reservoir – compatibility and durability results table.

| Test | Procedure | Acceptance criteria | Result |
|---|---|---|---|
| Chemical compatibility | Immersion fourteen days at 25 °C (ISO 175) | <0·5% mass gain, no clouding or cracking | Passed; <0·5% gain |
| Mechanical durability | Fifty fill–drain cycles | No leaks or cracks, valve functional | Passed |
| Pressure resistance | 0·2 bar static pressure | Zero leakage, deformation <0·2 mm | Passed |
| Shock resistance | Drop test one m | No cracks, leak-tight | Passed |
| Microscopy | Twenty × inspection | No stress-crazing | Passed |

*3.3. Functional and Ergonomic Evaluation Results*

Mass contributions were quantified as approximately 103.4 g (visor, frame, empty reservoir) and approximately 203.4 g with 100 mL of disinfectant (0.9–1.0 g/mL). Center-of-mass analysis positioned the center of mass (COM) approximately 7–9 cm anterior to the atlanto-occipital axis. Cervical torque ($\tau = r \times W$) ranged from 7.11–9.13 N·cm without fluid and 13.96–17.94 N·cm with a full 100 mL reservoir, depending on lever-arm length of 7–9 cm, based on atlantoaxial and atlanto-occipital modelling [17].

The composite center of mass (COM) during wear was modeled 7–9 cm anterior to the head's rotation axis (atlanto-occipital region). To reduce cervical moment, the design permits a top strap, a slight visor up-tilt, and, if necessary, a small posterior counterweight.

Legend Side-view schematic showing the head's rotation axis at the atlanto-occipital region, the visor with reservoir, the anterior displacement of the COM (7–9 cm), and the optional posterior counterweight for balance.

The cervical load generated by the visor system was calculated according to the formula:

$\tau = W \cdot r \backslash tau = W \backslash cdot r \tau = W \cdot r$

where **τ** is the torque (N·m), **W** is the gravitational force (N), and **r** is the lever arm distance (m) from the atlanto-occipital axis.

These calculations indicate that the torque on the cervical spine nearly doubles when the reservoir is filled (from ~7–9 N·cm to ~14–18 N·cm). To mitigate excessive loading, the design incorporates optional counterbalancing. For instance, a posterior counterweight of approximately 50 g placed 6–7 cm posterior to the rotation axis would reduce net torque by ~3.0–3.5 N·cm, thereby improving comfort during prolonged wear

Studies on head-supported mass, cervical load tolerance, and micro-break ergonomics support torque-based wear recommendations. Harrison et al. reported progressive neck loading with even minimal added mass [18]. Barrett et al. linked sustained head-mounted mass to discomfort and nociception [19]. Hallbeck et al. showed that structured micro-breaks reduce fatigue, providing a practical mitigation strategy [20].

Regarding COM and torque management, reservoir geometry biases weight antero-right. Validated mitigations include a top strap, a small posterior counterweight, and a slight visor up-tilt to reduce the effective moment arm. Consolidated values are listed in Table 3.

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**Table 3.** Cervical Torque Estimates at Different Lever Arms.

| Configuration | Lever Arm (cm) | Torque (N·cm) | Torque (N·m) |
|---|---|---|---|
| Without fluid (~103.4 g) | 7 | 7.11 | 0.071 |
| | 8 | 8.13 | 0.081 |
| | 9 | 9.13 | 0.091 |
| With 100 ml fluid (~203.4 g) | 7 | 13.96 | 0.140 |
| | 8 | 15.95 | 0.160 |
| | 9 | 17.94 | 0.179 |

**Table 4.** Mass properties, COM, and neck torque by configuration.

| Configuration | Total mass (g) | COM from band (mm, + anterior) | Axis–band offset (mm) | Effective distance (mm) | Added torque τ (N·m) | Δ vs head-only baseline (~2·21 N·m) | Indicative continuous wear window* |
|---|---|---|---|---|---|---|---|
| Basic (no reservoir) | 83·4 | +17·6 | 85 | 102·6 | 0·084 | +3·8% | ~2–3 h (with micro-breaks) |
| Empty reservoir | 103·4 | +31·5 | 85 | 116·5 | 0·130 | +5·9% | ~1·5–2·5 h |
| Full reservoir (100 mL) | 203·4 | +49·5 | 85 | 134·5 | 0·282 | +12·8% | ~60–90 min (target ~60) |

**Legend.** *Wear-time guidance assumes neutral posture; sustained 20–30° neck flexion favors the lower end of each interval. Wear-time intervals align with cervical torque increases. Configurations with increases under 5% permit approximately 2–3 hours of wear. The full 100 mL reservoir, with a 12.8% increase, supports 60–90 minutes. Under 20–30° neck flexion, lower values apply. Micro-breaks of 60–90 s every 20–25 min, and 10–15 min every 90–120 min, help maintain precision [18–20]. A "three–twenty–three" reset—three slow breaths, a 20 s distant gaze, and three shoulder rolls—is effective [20].

### *3.4. Cost Analysis*

Bottom-up cost analysis indicated low production cost. Prototype materials cost approximately twenty RON (≈ €4 / US $4·5). Total estimated cost per device is fifty to one hundred RON (≈ €10–20 / US $11–22), including the PETG visor, reservoir, elastic elements, fastening systems, and valve. This cost is economically justified by the dual-functionality of the device. The proposed device is not only a standard protective visor, typically priced under 20 RON (about €4 / $4.5), but also integrates an on-site hand-disinfection system. It also allows sterilization and reuse. Therefore, the modest additional cost provides significant added value, making the device a cost-effective product for environments such as healthcare, public services, the commercial sector, or civilian-exposure scenarios.

## 4. Discussion

The present prototype integrates dual protective and functional roles, operating both as a face shield and as a portable hand-disinfection system while maintaining low weight and economical manufacturability. This combined approach addresses two major occupational vulnerabilities: ocular and aerosol exposure, and inconsistent access to hand-hygiene opportunities. The device provides effective ocular protection and reduces droplet and aerosol exposure when used with masks, supporting evidence that eye protection lowers respiratory-virus transmission [21]. The feasibility of rapid, distributed fabrication is reinforced by analyses of 3D-printed PPE, which demonstrated that locally produced shields can be deployed effectively during supply shortages [22].

Ergonomic modelling indicates that cervical torque values remain below thresholds associated with acute strain, although increases of 6–13% above baseline highlight the need for structured wear-time management. Prior research consistently shows that anterior head-supported mass accelerates

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fatigue and contributes to cervical discomfort [18,19]. Our torque-to-wear mapping aligns with evidence that micro-breaks and posture optimisation help maintain performance during prolonged use of head-mounted equipment [20]. Practical refinements—including top straps, optional counterweights, and reduced reservoir volumes—are consistent with established occupational headgear analyses and offer measurable ergonomic benefits [18,19]. Workflow-oriented strategies, such as improved task lighting and hands-free communication, further reflect principles known to reduce exposure and enhance protective behaviour [22].

Scalability represents a key advantage of the proposed system. PETG sheet forming combined with FDM printing enables reproducible fabrication in hospital workshops as well as community-based maker networks. Studies on decentralised manufacturing suggest that such systems can supply thousands of shields weekly during peak demand, thereby enhancing supply-chain resilience [23]. The modular reservoir architecture supports adaptation across multiple clinical environments—including dentistry, surgery, emergency care, and field operations—promoting a "platform PPE" concept rather than a single-purpose device.

The development pathway aligns with current trends in smart-PPE innovation. Recent studies demonstrate the feasibility of wearable environmental, proximity, and workflow-monitoring sensors in clinical settings [12–14]. Integration of such modules requires careful consideration of mass distribution, heat generation, and compatibility with sterilisation processes to preserve ergonomic safety. The present architecture anticipates future integration of environmental sensing, proximity-monitoring units, workflow-tracking sensors, and wireless communication [12–14], enabling real-time monitoring of ambient conditions, interpersonal distance, and task-related movements, with secure data transmission to hospital networks to support infection-control surveillance and workflow optimisation [12–14].

External research further supports this trajectory. Smart face-shield systems incorporating wireless vital-sign monitoring have been prototyped, integrating optical and thermal sensors with microcontrollers to transmit heart rate, oxygen saturation, and temperature data in real time [24]. Importantly, clinical evidence indicates that face-shield use does not impair gastrointestinal endoscopy performance [25], supporting feasibility in procedural environments. Additive-manufactured PPE designs remain lightweight, rapidly deployable, and material-efficient, facilitating accelerated distribution during crisis conditions [26,27].

Complementary observational data suggest that routine eyeglass use may offer modest protection against SARS-CoV-2 exposure by reducing direct droplet contact with the conjunctival surface [28], although randomized evidence does not confirm this effect [29]. Protective goggles provide more complete periorbital sealing [22] but are frequently associated with discomfort, pressure-related symptoms, and headaches during prolonged wear [30]. These limitations underscore the need for protective solutions that balance coverage with tolerability.

Several limitations must be acknowledged. The present evaluation relies on benchtop testing and mannequin-based simulations, and future clinical studies are required to assess comfort, durability, and workflow impact in real-world settings. Torque modelling is based on simplified anthropometric assumptions [17]. In addition, distributed 3D printing may introduce variability in optical and mechanical properties [21], highlighting the importance of direct comparison with standardised commercial visors to confirm performance consistency and long-term reliability.

Previous work by Sickbert-Bennett and colleagues demonstrated that hospital-wide, all-staff hand-hygiene interventions can significantly reduce healthcare-associated infections, emphasising the value of coordinated institutional strategies [31]. Their analyses also showed that increasing hand-hygiene compliance from high to very high levels does not necessarily yield proportional reductions in infection rates, underscoring the need for complementary infection-prevention measures beyond compliance metrics alone [32]. Longitudinal surveillance spanning more than a decade further revealed sustained reductions in healthcare-associated infections when comprehensive infection-control programmes were consistently applied across entire hospital systems [33].

In this context, the proposed device addresses a critical workflow limitation repeatedly highlighted during the COVID-19 pandemic: the difficulty of maintaining hand hygiene without

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interrupting patient care [34]. The prototype demonstrates the technical feasibility of integrating passive facial and ocular protection with an active preventive function—immediate hand disinfection—within a modular, reusable, and mechanically reliable system. Bench testing confirmed consistent dosing (~3 mL), leak-tightness, PETG stability following repeated exposure to alcohol-based disinfectants, and secure reservoir locking. These features directly address vulnerabilities arising when healthcare workers move between care areas distant from fixed dispensers, while ergonomic performance (cervical torque ≤0.282 N·m at 100 mL load) supports continuous wear for 60–90 minutes.

The principal contribution of this innovation lies in bridging a functional gap between existing monitoring and prevention tools. Artificial intelligence has been successfully applied to PPE training and remediation [34], automated auditing of hand-hygiene quality [35], and detection of compliance events through advanced video analysis [36,37]. While such systems focus on evaluating and refining behaviour post hoc or within training environments, the present device intervenes earlier in the causal chain by ensuring the physical prerequisite for correct action: immediate and effortless availability of disinfectant. Accordingly, it complements rather than replaces AI-based training and monitoring systems, enabling the behaviours these technologies seek to teach or measure.

The device also aligns with broader data-driven prevention strategies that increasingly define modern standards of care. Machine-learning approaches have demonstrated utility in predicting nosocomial infection risk at the hospital level [38], in critically ill populations [39], and in patients with complex diseases [40]. These tools support strategic allocation of preventive resources toward high-risk patients. In contrast, the proposed face shield provides a universal protective measure at the point of contact, independent of individual risk stratification, ensuring that both physical barrier protection and hand-disinfection capability are present during every patient interaction.

Effective infection-control strategies must address all major transmission pathways. In addition to hand hygiene as a direct contact route, environmental management remains essential. Robotic systems for adaptive surface disinfection guided by risk-identification algorithms [41], as well as architectural optimisation to control airborne transmission [42], represent important complementary approaches. The proposed device contributes a personal, continuously available layer of protection within this multi-level infrastructure, targeting the immediate contact component of the transmission chain that remains critical even in environments with rigorous environmental decontamination.

Finally, feasibility of large-scale implementation is determined by ergonomics and cost. The modular reservoir system (25, 50, 75, and 100 mL) allows users to balance operational autonomy with ergonomic load across diverse clinical scenarios. The estimated production cost (€10–20) places the system within the price range of standard consumable PPE, supporting deployment in healthcare systems with variable resources, including disaster-response and resource-limited settings. The modular platform further anticipates the evolution toward intelligent PPE by enabling future integration of sensors for monitoring environmental parameters, proximity, or usage, allowing this robust mechanical device to evolve into an interface within broader, connected clinical safety ecosystems. Beyond routine inpatient care, such characteristics support application in emergency departments, prehospital services, outpatient clinics, disaster-response operations, and other high-turnover or high-risk

## 5. Conclusions

We designed and propose a dual-function protective polymeric face shield that integrates a modular, mechanically operated disinfectant reservoir (25, 50, 75, or 100 mL), enabling immediate hand sanitisation directly at the point of care.

In dental medicine—where procedures generate aerosols, require rapid instrument transitions, and involve frequent hand movements between contaminated and clean fields—the face shield with an integrated reservoir provides simultaneous facial and ocular protection together with instant hand disinfection. This configuration directly addresses a persistent vulnerability in dental infection-control workflows, in which clinicians must interrupt procedures or move away from the dental chair to access fixed disinfectant dispensers.

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The prototype proved lightweight, reusable, and mechanically stable, demonstrating secure reservoir locking, consistent ~3 mL dosing, automatic valve resealing, and leak-free performance during repeated manipulation typical of chairside dental activity. PETG maintained structural integrity after repeated exposure to the alcohol-based disinfectant Mikrozid and under moderate thermal conditions, confirming suitability for routine and prolonged clinical use in dental environments.

The modular reservoir system allows capacity selection according to dental workflow intensity—from routine outpatient treatments (25–50 mL) to extended surgical or implantology sessions and high-turnover clinical schedules (75–100 mL). Ambidextrous mounting supports ergonomic usability for both right- and left-handed dental practitioners, while colour-coded cartridges reduce the risk of disinfectant misidentification and improve procedural safety. The gravity-driven, self-sealing ball-valve mechanism eliminates pumps and external power requirements, ensuring reliability in standard clinics, mobile dental units, and resource-limited settings. Importantly, the touch-activated dispensing interface minimizes additional contact surfaces, reducing cross-contamination risk associated with shared wall-mounted dispensers in multi-patient dental practice.

Mass distribution and cervical torque modelling confirmed safe ergonomic parameters compatible with dental working postures. Even in the highest-capacity (100 mL) configuration, cervical load remained within acceptable limits for approximately 60–90 minutes of continuous clinical activity and up to around two hours with intermittent use, supporting realistic dental treatment sessions. Low production costs—approximately €4 for the basic shield and €10–20 for the complete system—further support scalable adoption in public dental services, private practices, and community oral-health programs.

Finally, the device architecture enables future smart-PPE integration relevant to dentistry, including aerosol exposure sensing, proximity monitoring, workflow analytics, and wireless data transmission, facilitating incorporation into advanced infection-prevention ecosystems and digitally supported dental safety protocols.

Overall, this dual-function polymeric face shield represents a practical, low-cost, and ergonomically validated innovation capable of improving real-time infection control efficiency in dental medicine, particularly in high-aerosol, high-throughput, and resource-variable clinical environments.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| PPE | personal protective equipment |
| PETG | polyethylene terephthalate glycol |
| mL | millilitre |
| CAD | computer-aided design |
| FDM | fused deposition modelling |
| ISO | International Organization for Standardization |
| COM | center of mass |
| N·m | newton-metre |
| N·cm | newton-centimetre |
| TPU | thermoplastic polyurethane |
| IPC | infection prevention and control |
| SD | standard deviation |

**Availability of supporting data:** Datasets generated for this study are available on request to the corresponding author. All data supporting the findings of this study are included in the article. In the spirit of transparency and scientific collaboration, all prototype design files (including CAD models, STL files, technical drawings, and full specifications) will be made available immediately after publication, upon request, to researchers, engineers, or clinicians interested in examining, reproducing, or further developing the device.The authors reaffirm their

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commitment to open research practices and actively encourage interdisciplinary collaboration. Researchers interested in accessing these materials or pursuing future collaboration are encouraged to contact us directly.

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