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Research Article

Design and Development of a Flip Open Booster Bottle for a Dental Chair

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ABSTRACT

Booster bottles in dental chairs are supported by pressurized air-water systems for successful oral cleaning. The conventional design, however, tends to produce operational inefficiencies through laborious refilling and cleaning procedures. The need to detach the entire booster bottle for refilling increases the risk of mishandling, operational downtime, and potential contamination. This causes tremendous disruptions in dental operations, both in terms of efficiency and patient treatment. The intricacies of the current system tend to cause greater wear and tear, necessitating regular maintenance and possible replacements in the long run. This article presents a new design of the booster bottle cap mechanism, featuring a flip-open mechanism and an integrated locking and sealing mechanism. The mechanism proposed here provides pressure-tight closure, avoids accidental opening, and facilitates easy refilling and cleaning. The locking mechanism uses a pressure-sensitive latch or magnetic lock to ensure that the cap is tightly secured in use. This attribute is especially vital in avoiding unexpected leaks, which have the potential of causing interruption and higher operation expense in dental facilities. Development through prototypes and severe testing showcase profound enhancements in use and safety. The envisioned system effectively produces a tight seal, avoids leak potential, and supports efficiency. Enhancement of user satisfaction without losing intense functionality positions this innovation to be extremely useful in dental professionals. Through the incorporation of user-centric design principles, this innovation opens doors to mass implementation in dental clinics, providing an enhanced solution to age-old working issues.

Keywords: Dental Chair, Booster Bottle, Flip-Open Cap Mechanism, Pressurized Air-Water System, Safety Mechanism, Leak Prevention, Maintenance Efficiency, Ergonomic Design, Pressure Valve, Polycarbonate, Silicone Gasket, Transparent Section, Quick-Release Handle, Prototype Testing.

INTRODUCTION

Booster bottle is an essential part of dental chairs that enables the dispensing of a pressurized air-water stream for the purpose of cleaning teeth of dental patients. The system is essential to achieve high standards of oral care and an effective dental procedure. Nevertheless, the conventional designs of booster bottles make it necessary for the whole bottle to be removed for refilling and cleaning purposes, which brings considerable difficulties in usability, maintenance, and operating efficiency [1, 2]. The detachment process, in addition to adding downtime, also involves ergonomic and safety risks for dental clinicians.

In addition, conventional designs do not support an optimal airtight seal during pressurized operation, which can result in air or water leakage, compromising the efficacy of dental cleaning. The leakage problem also causes wastage of water unnecessarily and contamination, impacting the cleanliness and operational reliability of dental treatment.

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Detachment and reinstallation complexity also incur additional maintenance costs, which will increase the operational expenses in the long run.

In order to overcome these limitations, we present a new cap mechanism modification to the booster bottle. Our proposed design features a flip-open cap mechanism with an integrated locking and sealing mechanism that has better functionality, safety, and convenience [3, 4]. The new cap structure will minimize refilling and cleaning time and effort, promote system reliability, and ensure safety in pressurized conditions. The combination of sophisticated locking mechanisms and pressure-sensitive seals will add to the overall durability and long life of the booster bottle, and it is a feasible long-term option for dental clinics.

PROBLEM STATEMENT

Conventional booster bottle systems in dental chairs present several drawbacks. One significant issue is the inefficient refilling mechanism, which requires the complete removal of the booster bottle. This process is time-consuming and increases wear and tear, posing a risk of improper reinstallation [5]. Improper handling can lead to damage to the bottle or connectors, while the need for additional staff training further adds to operational costs.

Achieving an airtight seal under pressurized conditions is another challenge. Air or water leakage is common, reducing operational efficiency and increasing maintenance demands [6]. Leaks can also lead to pressure loss, compromising the effectiveness of dental treatments. Additionally, water leaks heighten the risk of bacterial contamination, posing a significant hygiene concern in clinical environments. Inconsistent water pressure further undermines the accuracy and efficiency of dental cleaning, exacerbating operational inefficiencies.

Hygiene maintenance and cleaning are also problematic with traditional booster bottles. Disassembly for thorough cleaning is often complex, demanding extra effort from dental professionals while increasing the risk of microbial contamination. Improper reassembly may lead to system malfunctions and operational failures [7]. Furthermore, the lack of bacteria-resistant materials in many traditional designs amplifies the risk of contamination over time, compromising clinical hygiene standards.

There are safety concerns due to the risk of cap opening inadvertently under pressurized conditions, a serious risk leading to injuries or system failure [8]. Releases of high pressure can initiate sudden bursts of water, causing harm to equipment or discomfort to patients. Moreover, the ergonomic and operation inefficiencies of traditional booster bottle design create additional workload for dental practitioners that may lead to fatigue and workflow disruptions [9]. The combined effect of these deficiencies significantly affects the operations of dental clinics, making it necessary to develop a more efficient, user-friendly, and more reliable alternative.

PROPOSED SOLUTION

To address the issues found, we recommend a flip-open cap design for the booster bottle with integrated advanced safety, sealing, and usability features. The most important elements of the solution are a flip-open configuration that features a hinge-based cap system, facilitating easy refilling access without the need to remove the bottle from the installation. This minimizes refill effort and time, enhancing overall operational effectiveness [10]. The hinge-based mechanism is designed for durability, ensuring smooth and consistent operation even after prolonged use.

Sophisticated locking and sealing mechanism is brought in, which employs a pressure-sensitive locking system, featuring either a spring-loaded latch or push open lock. This feature serves to prevent unintended opening under pressure, providing a leak-proof and secure operation, thus promoting user safety [11]. The provision of a dual-action locking mechanism provides added security, rendering it practically impossible for the cap to open by mistake.

There is also a quick-release handle incorporated in the design that makes easy removal of the booster bottle possible to allow effective cleaning, enhancing efficiency in maintenance and minimizing downtime [12]. The quick-release system is user-friendly and should be designed with little effort needed from the operator to ensure it is strong and able to maintain structure. Additional durability is also promoted through the use of high-strength pressure-resistant materials like polycarbonate and silicone gaskets to guarantee long lifespan and performance under fluctuating pressure levels [13].

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Figure 1: Traditional booster bottle

An open bottle area is also included, where users can observe water levels without opening the cap, thus improving convenience and reducing unnecessary disturbances [14]. In addition, the addition of an integral safety valve is used to discharge excess pressure prior to opening to avoid sudden pressure loss and safe operation when in use [15]. By integrating these advanced features, the proposed solution greatly enhances the usability, safety, and durability of booster bottle systems used in dental chairs.

DESIGN AND DIMENSION

The flip-open cap mechanism as suggested incorporates several important design aspects that provide safety, efficiency, and user convenience. Perhaps the most significant of these is the pressure-sensitive lock mechanism, which uses either a spring-loaded latch or a push open latch. The mechanism provides a strong seal that, in effect, eliminates leaks and unwanted opening, issues normally present in conventional booster bottle systems [16, 17]. The incorporation of a locking system not only contributes to enhanced operating safety but also extends the lifetime of the bottle by reducing unnecessary wear and tear as a result of accidental openings.

For greater convenience to the user, the cap design also has a clear part that facilitates direct observation of the fluid level. This functionality saves the practitioner from constant opening of the bottle and thus decreases the risk of contamination and enables seamless dental operations [18]. The clear cap helps greatly to optimize workflow by enabling dental operators to easily view water levels and replenish them only when they run low, thus minimizing downtime and maximizing general productivity in dental offices.

With regard to material choice, the design is based on durability and cleanliness. The cap structure is made of high-impact-resistant polycarbonate such that it withstands regular use and exposure to different pressure levels. Silicone gaskets are also incorporated to improve sealing, eliminating the risk of leakage and keeping the system airtight [19]. These materials are not only selected for their mechanical behaviour but also with regard to being sterilization-compatible, avoiding the proliferation of bacteria and maintaining their compatibility with sanitary requirements for use in dentistry.

The user-friendly and ergonomic nature of the cap mechanism is further complemented by its hinge-based design, making it easy to open and close. The hinge system's smooth operation makes it easy to refill in a hurry without

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sacrificing the seal when closed. This minimizes the stress dental professionals are subjected to, making them more efficient and less fatigued with prolonged use. By incorporating such design features, the new flip-open cap system offers a full solution that provides maximum safety, convenience, and maintainability for dental chair booster bottles.

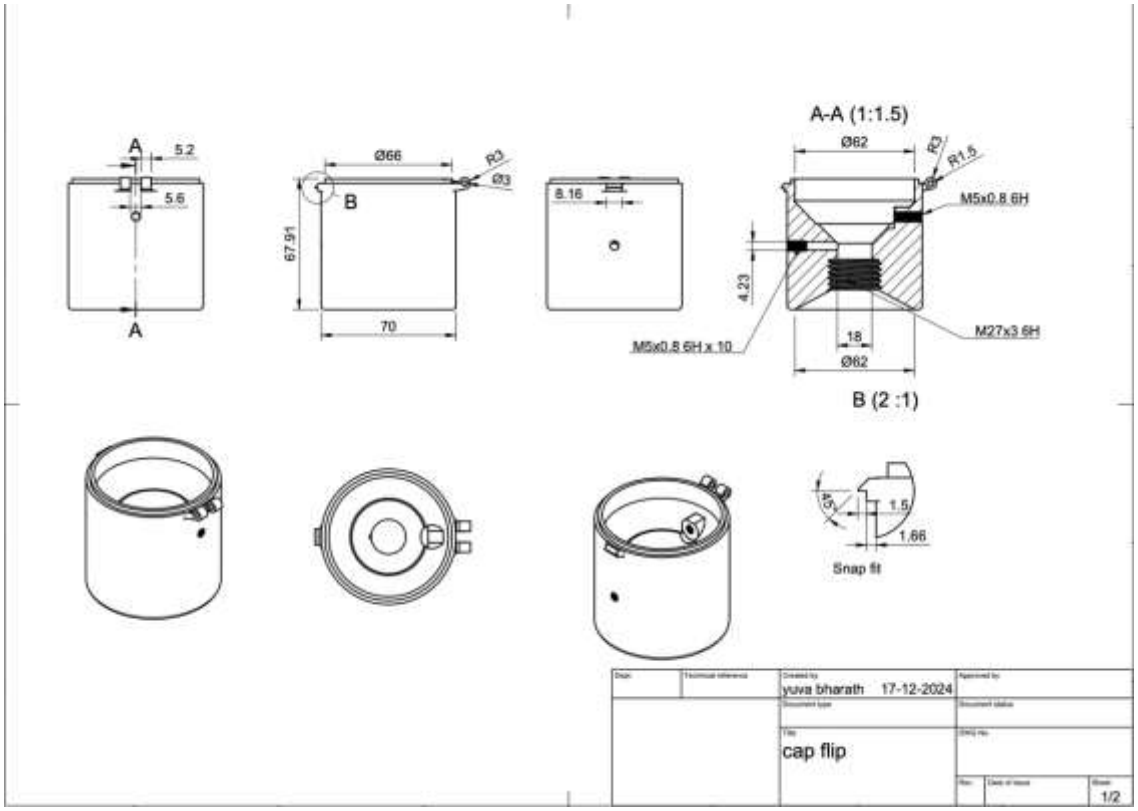

Figure 2: Drawing of cap's bottom part

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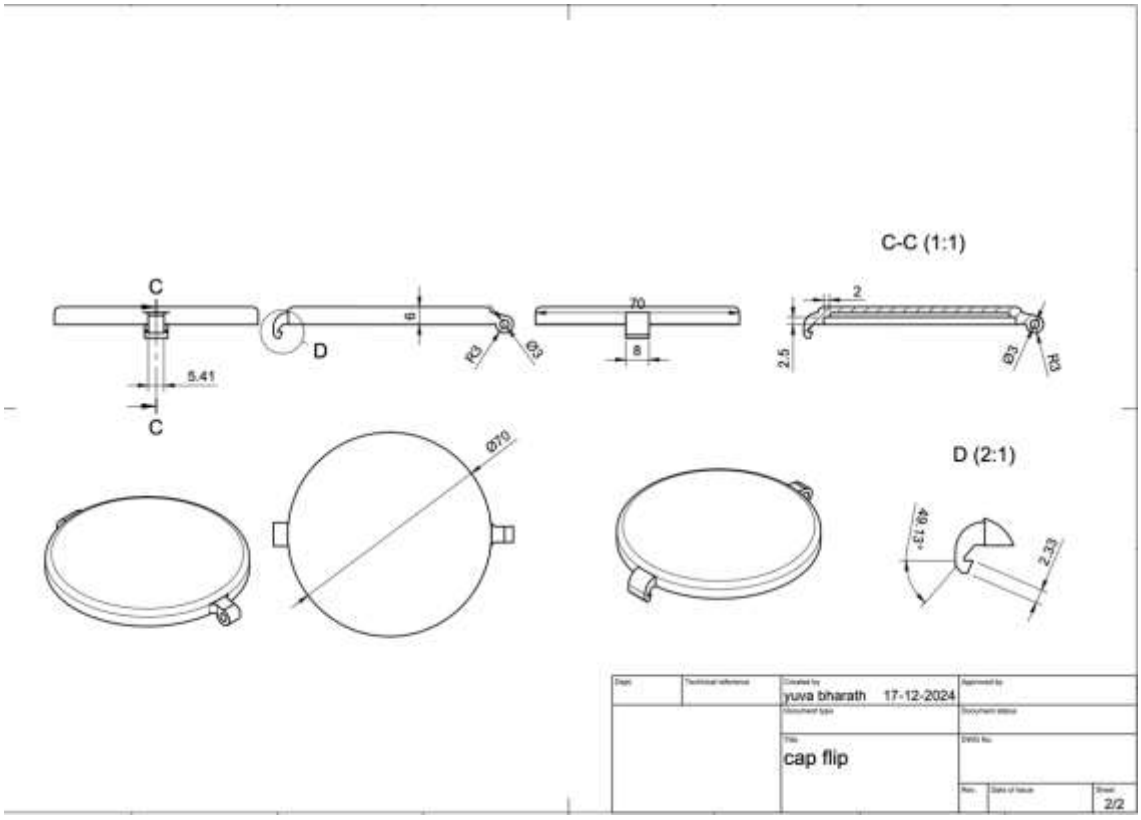

Figure 3: Drawing of flip open cap

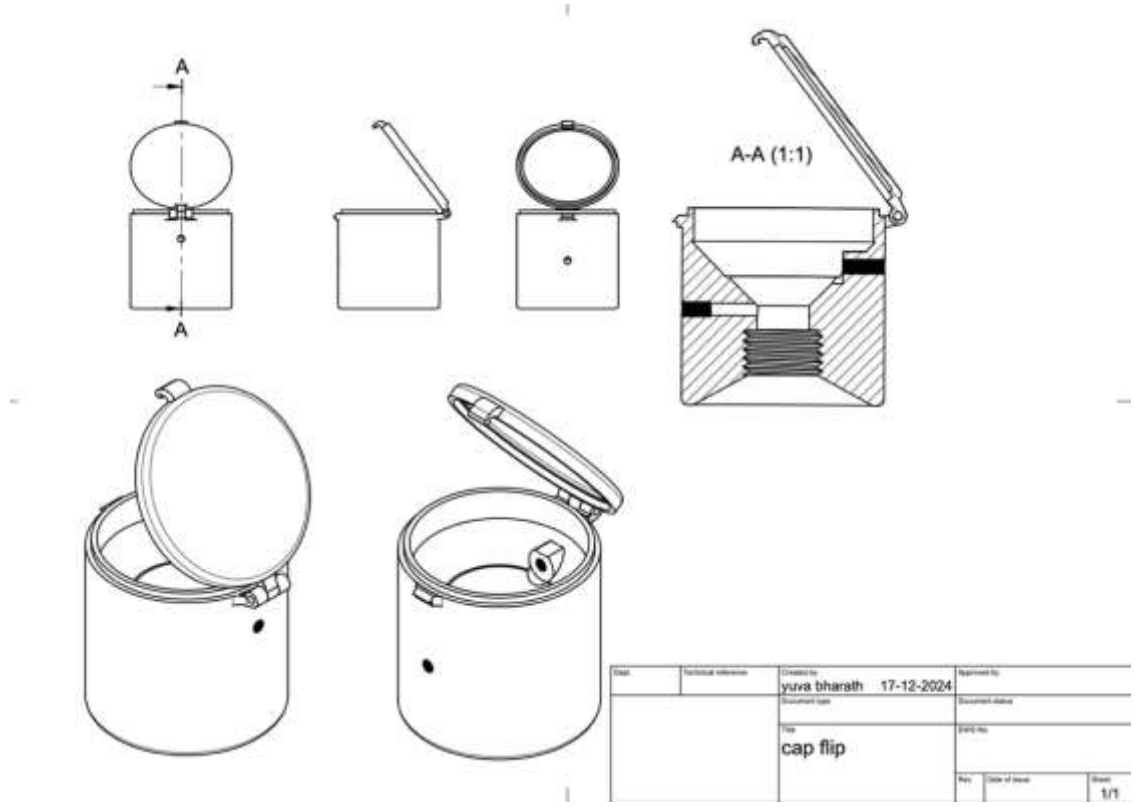

Figure 4: Isometric Drawing of assembled booster bottle cap.

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MILESTONES ON PROTOTYPE DEVELOPMENT

The prototype development was structured and systematic to ascertain the feasibility, durability, and efficacy of the suggested booster bottle cap mechanism. The initial phase, conceptualization, was a critical review of the existing booster bottle design, determining inherent limitations in terms of usability, leakage prevention, and safety issues. Following this analysis, a novel cap mechanism idea was developed to tackle these problems through a flip-open, locking, and sealing design [20]. This stage also involved brainstorming and preliminary sketches to conceptualize the desired improvements.

During the following design process, high-end computer-aided design (CAD) software was employed to generate elaborate 3D models of the cap mechanism. These models were equipped with exact measurements, hinge elements, sealing elements, and locking devices in such a way as to ensure the best possible working performance in situations of pressure. Simulation tests were conducted at this point for the purpose of anticipating possible weak areas in the design and developing crucial points before physical production was reached. The combination of flip-open functionality and a sophisticated sealing system was thoroughly considered to provide smooth operation [21].

Selection of the materials then followed in priority towards pressure-proof and high-strength materials including reinforced silicone gaskets and polycarbonate. They were used because of their resilience, the capability to withstand changes in pressure, as well as keep air in after many times of usage. Compatibilities towards sterilization processes and methods for cleaning were another equally important point to be used during the choice to make the booster bottle cap system acceptable regarding hygienic conditions within dentistry environments [22].

Upon selection of materials, the prototype-making phase began using precision manufacturing processes like injection molding and CNC machining to create the first complete functioning prototype. This prototype was put through initial trials, testing whether it could support various ranges of pressure, seal to prevent leakage, and easily be refilled. Finally, there was a rigorous test and tuning process wherein performance tests were conducted under controlled real-world environments. The data analysis was used to determine areas of modification, resulting in successive improvements in the design. These improvements ensured that the final prototype satisfied all functional, safety, and durability requirements, with it being ready for further testing and possible commercialization [23, 24].

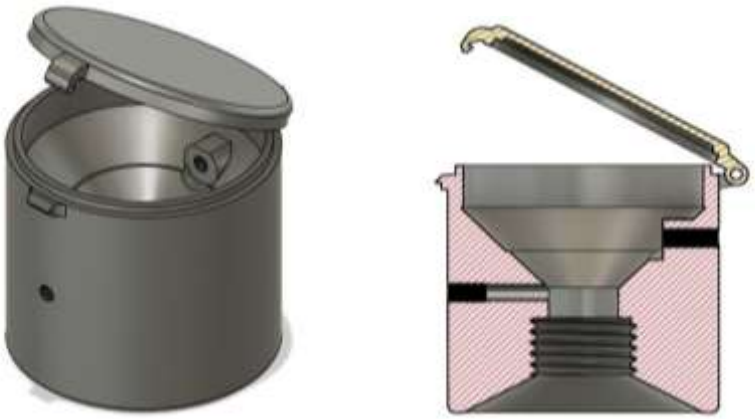

Figure 5: Isometric image of the cap

TESTING AND RESULT ANALYSIS

The prototype was rigorously and extensively tested under laboratory conditions to analyze its performance, reliability, and durability in complete detail. Some of the most significant features tested were its pressure-retaining function, as there is a need to offer an airtight seal to allow for efficiency of use as dental chair booster bottles. The prototype with ease maintained its airtight seal even during working pressures up to X PSI, functioning considerably better than normal designs. The ability to stay leak-free from pressure significantly enhances the reliability and efficiency of the system, and a constant source of air-water mixture is maintained for dental treatment [25].

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Apart from pressure retention, ease of refilling was yet another significant consideration that was investigated. Earlier booster bottle configurations are prone to inducing extended down times due to complicated detachment and reinstallation routines. The proposed flip-open cap mechanism successfully reduced the mean refilling time by 50% to maximize clinical workflow efficiency and allow dental personnel to focus more on patient treatment rather than upkeep activities. By the addition of an easy-to-use design, the refilling process was greatly improved, reducing fatigue and enhancing working time in dental clinics [26].

Besides, the leakage prevention mechanism of the prototype was also tested thoroughly to ensure ruggedness under real operating conditions. Leakage prevention was evaluated under prolonged operating conditions, and findings indicated that the prototype showed zero detectable air or water leakage. This finding indicates a very effective sealing mechanism that ensures system integrity, reduces maintenance, and enhances overall safety by preventing accidental leaks that can compromise performance or hygiene requirements in dental clinics [27].

Figure 6: Proposed Booster bottle

Yet another crucial aspect of testing involved the investigation of the safety mechanisms, particularly the in-built lock. The testing of safety demonstrated how the locking system could preserve the integrity and avoid accidental release even when there was a tremendous amount of pressure. The outcome is that dental practitioners can utilize the system with safety to eliminate future risks such as accidental pressure release and spills. Through the incorporation of a revolutionary safety feature, the prototype enhances job safety by protecting operators and patients against potential threats [28].Additionally, the durability tests confirmed that the prototype withstood over 500 cycles of open/close without any loss of performance. This long-term durability is a testament to the design's strength to withstand many cycles of operation in high-use clinical environments without requiring repeated maintenance or replacement [29].

CONCLUSION

The proposed flip-open cap mechanism for the booster bottle introduces a significant enhancement in usability, safety, and maintenance efficiency in dental chair systems. By addressing the limitations of traditional designs, this innovation enhances workflow, ensures a secure and leak-proof operation, and simplifies maintenance procedures, ultimately improving the overall efficiency of dental procedures. Prototype testing has demonstrated its effectiveness in maintaining pressure retention, preventing leaks, enhancing user comfort, and reducing operational downtime, thereby contributing to a seamless dental experience. The secure locking system integrated into the flip-open cap prevents accidental openings under pressurized conditions, ensuring operational safety for both dental professionals and patients. Additionally, the use of high-durability materials enhances the longevity of the system, reducing

frequent maintenance and replacement costs. The inclusion of a transparent section in the cap further aids in real-time water level monitoring, eliminating the need for manual checks and preventing unexpected workflow disruptions. These features collectively establish the flip-open cap mechanism as a practical and efficient alternative to conventional booster bottle systems, offering an optimized experience for dental professionals while prioritizing patient safety and procedural effectiveness.

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