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3D-Assisted Personalized Mucoadhesive Patch for Targeted Delivery of Lidocaine Hydrochloride

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ABSTRACT

Background: Conventional local anesthetic dosage forms are often associated with adverse effects such as injection-related pain and prolonged numbness, which limit patient comfort and compliance. The development of personalized drug delivery systems represents a promising strategy to overcome these limitations.
Objectives: The aim of this study was to develop and evaluate a personalized mucoadhesive lidocaine hydrochloride patch using three-dimensional (3D) scanning and printing technologies for targeted oral delivery.
Methods: A three-dimensional oral cavity model was obtained using a 3D scanner, and the corresponding cast and mold were fabricated in a dental laboratory using 3D printing technology. Twenty-Twenty experimental mucoadhesive patch formulations containing lidocaine hydrochloride were prepared and evaluated for physicochemical and technological parameters, including pH, tensile strength, mass uniformity, thickness, swelling index, moisture content, adhesive properties, and surface morphology. In vitro drug release studies were performed using a Franz diffusion cell, with subsequent spectrophotometric analysis.
Results: Based on biopharmaceutical studies, a mucoadhesive lidocaine hydrochloride patch formulation was successfully developed. Among the investigated formulations, F19 was identified as optimal. Its composition consisted of lidocaine hydrochloride (0.5 g), sodium alginate (0.43 g), polyvinyl alcohol (0.4 g), polyethylene glycol 1500 (0.5 g), sorbitol (0.25 g), glycerol (0.7 g), ethyl cellulose (0.1 g), 96% ethanol (5.0 mL), and distilled water (8.0 mL). demonstrated optimal physicochemical and mechanical characteristics. In vitro release studies revealed that approximately 50% of lidocaine hydrochloride was released within the first 15 minutes, followed by sustained release over the subsequent 30 minutes, indicating suitability for local anesthetic application.
Conclusions: The study demonstrates that 3D technologies can be effectively used to create personalized molds for the preparation of mucoadhesive patches. The optimized formulation shows potential for targeted oral anesthesia and site-specific drug delivery.
Keywords: 3D Printing; lidocaine hydrochloride; mucoadhesive patch; oral drug delivery; personalized medicine.

BACKGROUND

Personalized treatment is one of the key challenges in modern medicine. Recent studies indicate that the global personalized medicine market is growing at an annual rate of 11.5% and is expected to reach USD 896.5 billion by 2028. In recent years, the pharmaceutical industry has shown increasing interest in three-dimensional (3D) technologies that enable the development of dosage forms tailored to individual patients' needs.[1] Local anesthesia is one of the most commonly used procedures in dental practice. However, approximately 30% of patients experience anxiety before dental treatment, often due to fear of anesthesia. Conventional approaches, including injections and topical anesthetic gels, are frequently associated with adverse effects such as difficulty swallowing, accidental numbness of surrounding tissues, and post-procedural discomfort.[2,3] The development of 3D technologies offers promising solutions to these challenges. Studies have shown that 3D-printed pharmaceutical products provide more accurate drug dosing, reduce side effects, and significantly improve patient satisfaction.

METHODS

This study aimed to develop, optimize, and evaluate a mucoadhesive lidocaine hydrochloride patch for targeted oral delivery via 3D-assisted mold fabrication. To achieve this aim, the following objectives were defined:

- To create a three-dimensional model of the oral cavity using 3D scanning;
- To print the prepared cast by using a 3D printer;
- To design a mold for the target area based on the printed oral cavity model/cast;
- To determine the formulation of a lidocaine hydrochloride-containing patch;
- To develop the manufacturing technology of the patch for a personalized oral target site;
- To evaluate the quality characteristics of the lidocaine hydrochloride patch;
- To determine the stability of the patch under standard storage conditions.
- The processes related to 3D scanning, cast fabrication, and mold design were carried out with the assistance of a dental laboratory using 3D technologies.
- The object of the study was lidocaine hydrochloride, and the excipients in the patch formulation are presented in Table 1 according to their functional roles.

The mucoadhesive patch was prepared by the solvent-casting method.[2-5] Its quality attributes were evaluated using methods described in the scientific literature.[2-10] Modern pharmacotechnological, physical-chemical, and biopharmaceutical methods were used in the research, including pH, tensile strength, average mass and weight variation, thickness and uniformity, swelling index, moisture content, adhesive strength, and surface morphology under

microscopy. All experiments were performed in triplicate, and the results are expressed as mean±standard deviation. The 3D scanning and printing process was used to generate an oral cavity model and fabricate a customized mold for patch preparation.

TABLE 1. Composition of the patch and purpose of excipients

Substance	Purpose
Lidocaine Hydrochloride	Active pharmaceutical ingredient (API)
Polyvinyl alcohol (PVA)	Mucoadhesive polymer
Hypromellose	Mucoadhesive polymer
Ethyl cellulose	Polymer
Hydroxyethyl cellulose	Polymer
Sodium alginate	Natural polymer
Gelatin	Natural polymer
PEG 1500 / Glycerol	Plasticizer
Sorbitol / Xylitol	Plasticizer / Sweetener
Ethyl alcohol, 96%	Solvent
Distilled water	Solvent

Abbreviations: PEG, polyethylene glycol

RESULTS

At the first stage of the study, twenty experimental anesthetic patch formulations were designed based on data from the scientific literature. The results are presented in Table 2. Based on data from the scientific literature, a manufacturing process for preparing the experimental patch formulations was developed. During patch preparation, the physicochemical and technological properties of the components, such as solubility, melting temperature (Tm), and swelling properties, were considered. Adhesive and backing layers were prepared separately, with the active pharmaceutical ingredient incorporated into the adhesive layer.

The preparation process included the following steps:

- The polymer or polymer blend included in each formulation was allowed to swell in distilled water.
- In a separate vessel, xylitol (or sorbitol) was melted at its melting temperature (95-97 °C), then PEG 1500 was added under continuous stirring as the temperature decreased to approximately 50 °C.
- The molten mixture was cooled to room temperature and then added to the swollen polymer under stirring.
- Glycerol was added to the resulting mass, which was subsequently transferred into a mold.
- A backing layer consisting of an ethanolic solution of ethyl cellulose was applied to the formed patch and allowed to stand until ethanol had completely evaporated.

TABLE 2. Investigational compositions of anesthetic patches

Ingredients	Formulations and composition (g)																			
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
Lidocaine Hydrochloride	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PEG-1500	4.0	2.0	2.0	1.0	4.0	4.0	4.0	2.0	1.0	0.5	0.6	1.0	1.0	1.0	0.7	0.56	0.56	0.56	0.5	0.5
Hypromellose	0.4	0.4	0.3	0.1	0.1	0.2	-	-	1.0	0.5	-	-	-	-	-	0.5	-	-	-	-
Glycerine	0.5	1.0	0.5	0.5	-	-	-	-	-	0.3	-	-	-	0.2	0.28	0.5	0.75	1.62	0.7	0.7
Xylitol	1.2	1.0	1.2	0.5	1.2	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-
Gelatin	-	-	-	-	-	-	0.5	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Sodium alginate	-	-	-	-	-	-	-	-	-	-	-	0.3	1.0	1.0	1.0	-	1.0	0.82	0.43	0.41
Sorbitol	-	-	-	-	-	-	-	-	-	-	0.5	1.5	0.5	0.5	0.3	0.26	0.25	0.25	0.25	0.25
PVA	-	-	-	-	-	-	-	-	-	-	-	0.2	1.0	1.0	1.0	-	1.0	0.83	0.4	0.4
Ethyl cellulose	-	-	-	-	-	-	-	-	-	-	-	-	0.16	0.16	0.16	0.16	0.2	0.16	0.1	0.1
Ethyl alcohol, 96%	-	-	-	-	-	-	-	-	-	-	-	-	8.0	8.0	8.0	8.0	8.0	10.0	5.0	10.0
Distilled water	-	-	-	5.0	3.0	5.0	-	-	8.0	5.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	8.0	8.0

Abbreviations: PEG, polyethylene glycol; PVA, polyvinyl alcohol

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Patches made under F1-F17 formulations do not have a uniform structure or sufficient adhesiveness. Among the prepared compositions, F18, F19, and F20 demonstrated optimal characteristics. Therefore, at the next stage of the study, their physicochemical and technological properties were evaluated, including pH, tensile strength, average mass uniformity, thickness and thickness uniformity, swelling index, moisture content, mucoadhesive properties, and surface uniformity assessed by microscopy. The results are presented in Table 3.

TABLE 3. Results for the determination of quality indicators of lidocaine hydrochloride patches

Quality Indicator	Requirements	F18	F19	F20
Description	Homogenous mass	Satisfy	Satisfy	Satisfy
pH	6.0-7.4	6.77	6.75	6.76
Tensile test (N)	Not specified	0.542	1.523	0.464
Average mass, g	Deviation within ±5-15% of the mean value	0.055±0.023	0.063±0.010	0.035±0.015
Thickness, mm	0.2-0.6 ± 10%	0.50±0.02	0.30±0.02	0.40±0.02
Swelling index	Lower values preferred	407.9%	185.7%	586.2%
Moisture, %	10-20%	28.9%	17.5%	30.0%
Thumb test	Adhesiveness	Good	Excellent	Good

Evaluation of physicochemical properties:

- The pH of the patches was determined using a digital pH meter in a medium simulating artificial saliva.
- The thickness of the patches was measured at multiple points using a digital caliper (vernier caliper), and the average value was calculated.
- The average mass and mass uniformity were determined by weighing individual patches.
- Tensile strength was measured using a Shimadzu testing instrument. The samples were fixed between two clamps. Moreover, force was applied until the patch broke. The maximum force required to break the patch was recorded.
- The swelling index was determined by measuring the weight increase of the patches over time after immersion in artificial saliva.
- Moisture content was determined by drying the patches in a drying oven at 70°C until a constant weight was achieved.
- Mucoadhesive properties were evaluated qualitatively using a thumb test.
- Surface morphology was examined using a digital microscope (Axio Observer, Carl Zeiss).
- In vitro drug release studies were performed using a Franz diffusion cell. A cellulose membrane (0.5 mm thickness) was used as the diffusion barrier. The patch was placed on the membrane, and the receptor compartment was filled with a buffer solution simulating artificial saliva (pH 6.7). The experiment was conducted at 37°C to mimic physiological conditions. Samples were collected at predetermined time intervals and analyzed spectrophotometrically to determine the amount of released lidocaine hydrochloride.
- Statistical analysis: All experiments were performed in triplicate, and the results are presented as mean ± standard deviation.

DISCUSSION

The development of mucoadhesive anesthetic patches requires optimizing both structural integrity and adhesive properties to ensure effective drug delivery and patient comfort. Buccal drug delivery systems have attracted considerable attention for their ability to provide a rapid onset of action and improved patient compliance compared with conventional dosage forms. Similar advantages of buccal drug delivery systems have been described in previous studies, which emphasize their potential for local and systemic drug administration through the oral mucosa.[3]

In the present study, formulations F1-F17 did not demonstrate uniform structure or satisfactory adhesiveness, indicating that the selected polymer ratios and composition were not optimal for stable patch formation. The structural characteristics of polymeric matrices are known to significantly influence the mechanical strength, swelling behavior, and adhesion properties of buccal dosage forms.[4] Therefore, optimization of formulation components is a critical step in the development of effective mucoadhesive drug delivery systems.

Among the investigated formulations, lidocaine hydrochloride patches F18, F19, and F20 demonstrated improved physicochemical and technological properties. The evaluation of parameters such as pH, tensile strength, thickness uniformity, swelling index, moisture content, and mucoadhesive properties confirmed their suitability for further investigation. Similar evaluation approaches have been applied in previous studies investigating buccal films containing lidocaine hydrochloride, where these parameters were shown to play an essential role in determining the performance and stability of the dosage form.[5]

The in vitro drug release study conducted using Franz diffusion cells revealed differences in the release profiles among the investigated formulations (Fig.1). The results indicated that formulation F19 exhibited the most favorable lidocaine hydrochloride release profile.

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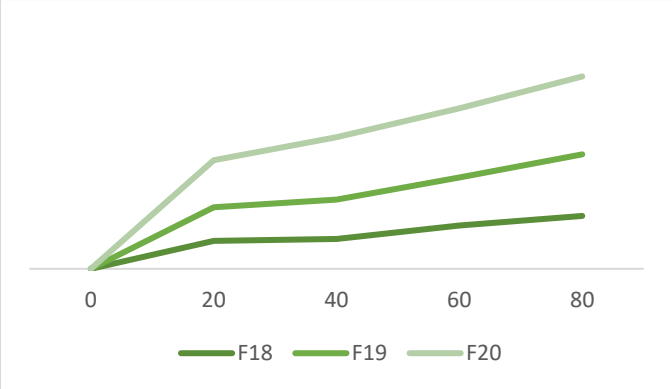
FIGURE 1. Release profile of lidocaine hydrochloride from F18, F19, and F20



formulations over time

This controlled release behavior may be attributed to the optimized composition of the polymeric matrix, which facilitates drug diffusion while maintaining structural integrity. Comparable results have been reported in previous studies on lidocaine-loaded buccal patches designed to reduce pain during dental procedures, where optimized formulations demonstrated improved drug release and enhanced patient compliance.[6] Furthermore, research on needle-free buccal anesthesia systems has highlighted the importance of formulation design in achieving efficient drug permeation through the oral mucosa.[7]

Based on these findings, formulation F19 was selected for further stability evaluation under normal storage conditions. Stability testing is a critical component of pharmaceutical product development, ensuring that the drug product maintains its physicochemical properties, efficacy, and safety throughout its shelf life.[8]

The data presented indicate that the patch prepared from formulation F19 exhibited an optimal drug-release profile. The lidocaine hydrochloride release profile observed in this study is suitable for its intended use. A rapid initial release helps achieve a fast onset of local anesthesia, which is important in dental applications. The slower release that follows may help maintain the anesthetic effect for a longer period. Therefore, this release behavior is appropriate for oral mucosal drug delivery. At the final stage of the research, the stability of the anesthetic patch during storage under normal conditions was evaluated (Tab.4).

TABLE 4. Stability determination results of F19 formulation (3 months)

Evaluation Parameters	25°C±20°C /60±5% RH
Description	Light brown
Adhesiveness	Satisfies
pH	6,75
Thickness, mm	0.30±0.02
Moisture content, %	23.4
Mass uniformity, g	0.06±0.015
Tensile strength, N	1,523
Swelling index, %	182.5

Overall, the results of this study suggest that the optimized lidocaine hydrochloride patch formulation, particularly F19, demonstrated the most balanced physicochemical and mechanical performance.

CONCLUSIONS

The present study involved the development of a potentially personalized anesthetic patch containing lidocaine hydrochloride intended for application to a specific site in the oral cavity. The corresponding physical cast and mold were fabricated with the assistance of a dental laboratory using 3D printing technology. The obtained mold was used to prepare mucoadhesive patches.

During biopharmaceutical investigations, 20 experimental formulations of the anesthetic patch were developed, along with the corresponding preparation technology. Following the evaluation of key quality attributes, including pH, tensile strength, average mass and weight variation, thickness and thickness uniformity, swelling index, moisture content, mucoadhesiveness, and surface uniformity assessed by microscopy, the optimal formulation was identified as F19. This formulation consisted of lidocaine hydrochloride (0.5 g), sodium alginate (0.43 g), polyvinyl alcohol (0.40 g), polyethylene glycol 1500 (0.5 g), sorbitol (0.25 g), glycerol (0.7 g), ethyl cellulose (0.1 g), 96% ethanol (5.0 mL), and distilled water (8.0 mL). The in vitro release study using Franz diffusion cells demonstrated that approximately 50% of lidocaine hydrochloride was released within the first 15 minutes, while the remaining amount was released over the subsequent 30 minutes, which is relevant to the intended use and duration of action. Furthermore, stability studies conducted under standard storage conditions confirmed that the developed personalized patch maintained optimal quality characteristics throughout the three-month observation period.

Based on the results of this study, the F19 anesthetic patch containing lidocaine hydrochloride demonstrates appropriate physicochemical and technological characteristics. The use of 3D technologies in this study was limited to the fabrication of a personalized mold, while the patch itself was prepared by solvent casting. The findings indicate the potential of this approach for site-specific oral drug delivery. However, further studies are required to fully validate the clinical benefits of personalization.

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REFERENCES

1. Zhu, X.; Li, H.; Huang, L.; Zhang, M.; Fan, W.; Cui, L. 3D printing promotes the development of drugs. Biomed. Pharmacother. 2020, 131, 110644.

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2. Norman J, Madurawe RD, Moore CM, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. Adv Drug Deliv Rev 2017; 108:39-50. doi: 10.1016/j. addr.2016.03.001, PMID 27001902.
3. N. G. R. Rao, B. Shravani, and S. Reddy, "Overview on Buccal Drug Delivery Systems." Journal of Pharmaceutical Sciences and Research. Vol.5(4), 2013, 80 – 88.
4. S.K. Maurya, V. Bali, K. Pathak, Bilayered transmucosal drug delivery system of pravastatin sodium: statistical optimization, in vitro, ex vivo, in vivo and stability assessment, Drug Deliv. 19 (1) (2012) 45–57.
5. Esra Demirtürk, et al. "Preparation of Lidocaine Hydrochloride Containing Chitosan-Based Buccal Films for Mucositis: In-Vitro Evaluation and Cytotoxicity Assay." Istanbul Journal of Pharmacy, vol. 54, no. 1, 30 Apr. 2024, pp. 20–31, https://doi.org/10.26650/istanbuljpharm.2024.1372602. Accessed 28 Jan. 2025.
6. Elham P, et al. "Optimization and Comparison of Unidirectional Lidocaine-Loaded Buccal Patch with the Articaine-Loaded Buccal Patch to Reduce Injection Pain and Increment of Patients' Compliance in Dental Procedures: A Double-Blind Randomized Controlled Trial." Heliyon, vol. 10, no. 16, 1 Aug. 2024, pp. e35533–e35533, https://doi.org/10.1016/j.heliyon.2024.e35533. Accessed 18 Oct. 2024.
7. Oliveira, Renê, et al. "Towards the Advance of a Novel Iontophoretic Patch for Needle-Free Buccal Anesthesia." Materials Science & Engineering. C, Biomimetic Materials, Sensors and Systems, vol. 122, 1 Mar. 2021, pp. 111778–111778, https://doi.org/10.1016/j.msec.2020.111778. Accessed 20 July 2024.
8. United States Pharmacopeia and National Formulary (USP 43-NF 38). Rockville, MD: United States Pharmacopeial Convention; 2020. Monograph: Lidocaine Hydrochloride.
9. Rahman Z, Barakh Ali SF, Ozkan T, Charoo NA, Reddy IK, Khan MA. Additive manufacturing with 3D printing: Progress from bench to bedside. AAPS J 2018; 20:101. doi: 10.1208/s12248-018-0225-6, PMID 30209693.
10. Senping Ch, Timothy S, Xiaoling Li. 3D Printing Pharmaceuticals: Current Status and Future Opportunities. Pharmaceutical Fronts; 6(02): e192-e194. DOI: 10.1055/s-0044-1782512. 2024.

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