

Research Article

Development and Applications of a Novel 'Three-in-One Smart Aqua-Time X-Ray Film Hanger' in Dental Radiographic Film Processing

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A B S T R A C T

Introduction: Intraoral periapical radiographs (IOPAs) are essential diagnostic tools in dentistry. The traditional method of producing X-rays involves intraoral film placement, followed by manual processing in a darkroom using a developer, water, fixer, and a final rinse before drying. Common errors like underdevelopment, overdevelopment, underfixing, and overfixing, often due to improper immersion or timing, result in sub-optimal image quality. To mitigate these issues, a 'Three-in-One Smart Aqua-Time X-Ray Film Hanger' was designed. This device aims to standardise the processing procedure, reducing variability and ensuring consistent, high-quality radiographs.

Materials and Methodology: The materials used in developing this device were an X-ray hanger, a magnetic float sensor, and a setup box, including the battery setup. This device employs a Wi-Fi controller timer for precise processing times and a magnetic float to ensure complete film immersion. The system has audible alerts (an alarm) that notify the user when the processing time is nearing completion. This ensures precise development and avoids over- or underdevelopment of the X-ray film. A total of 20 films (10 IOPA and 10 occlusal radiographs) were processed using the smart X-ray hanger.

Results: All 20 films were well-developed, producing quality radiographs. The smart hanger reduced processing errors and faulty radiographs by 100%. The major processing errors, namely, over-/ underdeveloping, over-/ underfixing and improper immersion, were completely averted by the smart X-ray hanger. All the films were evenly developed and fixed with no inconsistencies.

Conclusion: The Smart Aqua-Time X-Ray Film Hanger is a significant innovation in traditional film processing, serving as an indispensable tool for achieving precise and reliable immersion and timing measurements. Its consistent performance contributes to a standardised processing protocol, minimising variability and ensuring uniform results across all films. By utilising this device, dental professionals can significantly reduce X-ray film wastage and consistently produce high-quality radiographs, facilitating accurate diagnoses for all dental diseases.

Keywords: X-Ray Films, Dental X-Ray, Film Hangers, Processing Solutions, Optimal Quality, Faulty Radiographs

Introduction

Radiographs are an essential investigative tool used for identifying and assessing a variety of disorders affecting the oral cavity and maxillofacial tissues.¹ Intraoral radiographs play a vital role in routine dentistry.² Intraoral periapical radiographs (IOPAs) provide detailed images of individual teeth and surrounding bone, which makes them essential diagnostic tools in dentistry. These radiographs are essential for precise diagnosis and effective treatment planning. IOPA films, used to capture the radiographic image, are composed of a plastic base covered with an emulsion that is sensitive to visible light as well as X-rays. To obtain clear images, the film must be positioned lingually in the mandible and palatally in the maxilla.³ These radiographs are useful in cavity identification, evaluation of tooth development, monitoring treatment progress, and assessment of root and bone structures. Excellent contrast, density, sharpness, precise size and shape representation, and thorough diagnostic information are all characteristics of optimal radiographs. In addition, minimising distortion in IOPA images requires knowledge of angulation techniques such as paralleling and bisecting angle techniques. Traditional film processing techniques are still widely used in rural dental clinics and most dental colleges. This conventional method of processing images is an essential part of dental radiology education, even if digital radiography, such as radiovisiography (RVG), is becoming widespread. The conventional method involves placing the film intraorally, then manually processing it in a dark room with the developer, water, fixer, and one final rinse in water before drying.

Sub-optimal visual quality is a result of common errors such as underdevelopment, overdevelopment, underfixing, and overfixing, which occur due to improper immersion or timing. These errors increase the requirement for retakes and unnecessary exposure of patients to radiation and also affect diagnostic accuracy. To eliminate these issues, the 'Three-in-One Aqua-Time X-Ray Film Hanger' was designed. This device consists of a Wi-Fi-controlled timer and a magnetic float sensor to ensure precise processing times and complete immersion of the films, thereby minimising faulty radiographs. This device aims to standardise the processing procedure, which reduces variability and produces a high-quality radiograph. The aim of the current study is to develop a novel 'Three-in-One Smart Aqua-Time X-Ray Film Hanger' which can be used to standardise the manual radiographic film processing.

The objectives of the study are

1. To develop a film hanger with a built-in timer and Wi-Fi for standardised film processing
2. To evaluate the quality of intraoral periapical radiographic images taken for patients using the 'Three-in-One Smart Aqua-Time X-Ray Film Hanger'

Materials

The materials used in developing the 'Three-in-One Smart Aqua-Time X-Ray Film Hanger' are an X-ray film hanger, a magnetic float sensor, and a setup box, which includes a battery setup (Figure 1). A regular X-ray film hanger, which could hold up to 10 films (AFH10), was used. The X-ray film hanger was made from high-quality stainless steel. The hanger featured a robust design that securely held up to 10 X-ray films simultaneously, ensuring optimal film positioning during exposure, development, and drying. The magnetic float sensor, used to detect the level of liquid within any kind of container, was attached at the top just above the last film-holding clip. This sensor was made up of a permanent magnet, a reed switch, and a stem. The stem was a piece of plastic that directly connected the switch to the keycap. Metal or plastic stems could be used, depending on the situation. Within the stem of the float switch, the reed switch was hermetically sealed. In response to changes in fluid level, the water float moved up and down the stem length by covering a sealed magnet. The amount of fluid visible on a guide tube determined the steady movement of the permanent magnet in the float switch. In the guide tube, a reed contact was connected, and the float magnet approached it through the float's non-magnetic walls. A small-gauge, low-current-rated wire with PVC insulation was used to attach this hanger setting to the setup box. Secondly, certain important parameters that were maintained for the proper functioning of the innovative smart hanger were temperature, switching voltage, switching current, types of switches, switching cycles, types of wire used, and parts of the magnetic sensor. The detailed specifications of these parameters are given in Table 1.

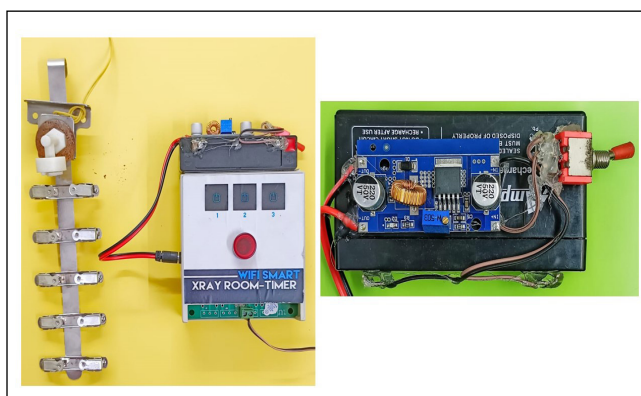


Figure 1. Three-in-One Smart Aqua-Time Hanger (Complete Setup) Along with Lead Acid Battery

Table 1. Specifications of Smart Aqua-Time X-Ray Film Hanger

Parameter	Configuration
Temperature rating	10~80°C
Accurate error	± 2 mm
Repeatability	± 1 mm (in the water)
Contact form A & B	A (normally open) B (normally closed) (single switch)
Contact rating	Max 10 W (50 W on demand)
Switching voltage	Max 100 V DC
Switching current	Max 0.5 A DC
Ideal operational rating	< 36 V DC and < 50 mA DC
Installation	Vertical
Life expectancy	Switching cycles, Minimum 0.5 x 10 ⁶
Wire length	2 m
Type of wire	Copper wire

Components of Setup Box

The setup box (Figure 2) included a toggle switch to indicate its on/ off state and was powered by 6-volt, 1.5 Ah (ampere-hour) lead-acid batteries. These batteries utilised electrochemical reactions to convert chemical energy into electrical energy. Modern lead-acid batteries for automotive applications typically consist of six cells, providing a total voltage of 12.6 volts (V) when fully charged. Each cell contained a positive electrode (cathode), which was primarily composed of lead dioxide, and a negative electrode (anode) made of spongy lead. An electrolyte solution of sulphuric acid in water surrounded both the electrodes. The advantages of lead-acid batteries included their low cost, high-power output, established high surge current technology, reliability, and excellent recyclability. With proper maintenance, they also offer a long lifespan. A compact 6 V lead-acid battery was sufficient for this device, providing high capacity for extended run times. These 6 V batteries were robust and could withstand repeated charge-discharge cycles more effectively. A buck converter was included to regulate the voltage from 6 to 5 V. A 3-watt infrared LED light was positioned in the centre of the setup box. This light was illuminated when the X-ray film hanger was immersed in the processing solutions, indicating complete submersion of all X-ray films. Since a red GBX-2 filter was advised as a safelight in darkrooms,

infrared illumination was selected. Three adjustable Wi-Fi controller touch switch timers were placed above the infrared light indicator. These three timer switches were provided to manage the processing times for the three different solutions used: developer, water, and fixer.

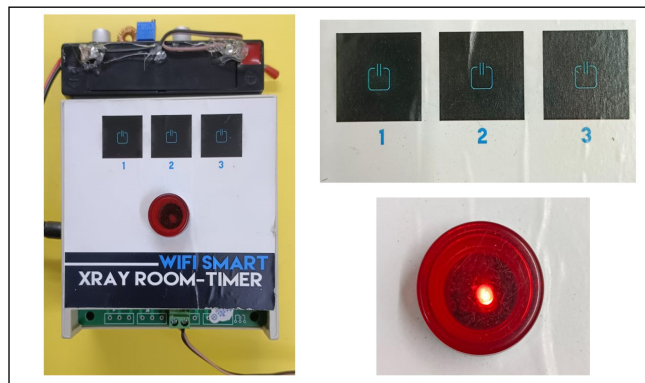


Figure 2. Setup Box with an Infrared LED Indicator Light and Three Wi-Fi-Controlled Touch Switch Timers

Methodology

- **Step 1: Solution replenishment:** Restocking the developer and fixer is the first stage in manual tank processing. It was ensured that the films on the top clips of the film hangers were covered by the developer and fixer by checking the solution levels.
- **Step 2: To avoid cross-contamination:** A different paddle was used for each solution, and the developer and the fixing solution were stirred to mix the chemicals and balance the temperature throughout the tanks. One paddle was marked for the developer and the other for the fixer.
- **Step 3: Film mounting:** The exposed film was taken out of its lightproof packet or cassette in the darkroom using only a safelight. The films were held only by their edges to prevent surface damage. One film at a time, the exposed film was clipped to a hanger.
- **Step 4: Film loading:** The X-ray films were carefully loaded onto the film hanger. As the films were placed into the hanger, proximity sensors detected their positioning.
- **Step 5: Immersion monitoring:** When the film hanger was placed into the developing solution, magnetic float sensors detected when the film was fully submerged in the processing chemicals. This activated the immersion indicator light, which turned “on” to indicate that the film was then being processed. The light remained on as long as the film was immersed.
- **Step 6: Timer operation:** Once the timer was activated, it began tracking the processing time. This could be set for various stages of processing, such as the time for developer, stop bath, and fixer stages. Also, the

timer used was Wi-Fi smart, by which timers can be set in the mobile phone, according to the power of the developer solution.

- **Step 7: Time alerts:** The system had audible alerts (an alarm) that notified the user when the processing time was nearing completion. This ensured precise development and fixation and avoided faulty radiographs.
- **Step 8: Completion and immersion light off:** Once the processing time was complete, the timer signalled the user to remove the film, and the immersion indicator light turned off. At this point, the film was moved to the next stage in the process, such as rinsing or drying. The device was used to process a total of 10 IOPA and 10 occlusal radiographs.

Results

This device effectively mitigates the common errors associated with manual processing, such as underdevelopment, overdevelopment, underfixation, and overfixation, thereby minimising the production of sub-optimal radiographs. The pre-set timers, along with the built-in alarm system, performed well in both the processing solutions, including water. The timing was repeatedly changed through Wi-Fi, and different devices were connected. The red indicator light flashed consistently on complete immersion of all the X-ray films, and the alarm alerts were audible. The outcome of the current study was to develop optimal X-ray films with no processing errors. The incidence of faulty radiographs was reduced by 100%. Two films had cross-contamination from the developer solution, which resulted in blackish streaks in one corner of the film. However, the major processing errors, namely, over-/ underdeveloping, over-/ underfixing and improper immersion, were completely averted by the smart X-ray hanger (Figure 3).

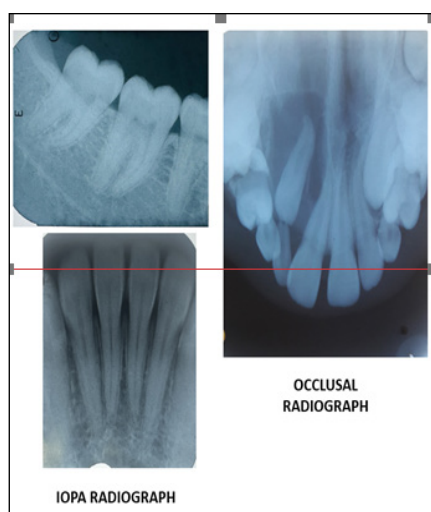


Figure 3. Radiographs Processed using the Three-in-One Smart Aqua-Time Hanger

Discussion

An optimal radiograph is defined by several essential attributes: visual features, geometric properties, anatomical precision of the radiographic image, and sufficient coverage of the anatomical area of interest. Visual features consist of density and contrast. Geometric properties encompass sharpness or detail, resolution or definition, magnification, and distortion, all of which enhance the clarity and precision of the image. Additionally, anatomical precision is achieved when the anatomical structures are depicted on the film in their natural relationships.⁴ Density refers to the extent of darkening of the film after exposure and development. The darker the region, the higher the density. Radiographs with insufficient density will seem overly bright, while those with excessive density will appear overly dark. It is challenging to discern details in a film that is either excessively dark or excessively light.⁵ The density of a radiograph, or its overall darkness, is influenced by a range of factors, which can be categorised into first- and second-degree influences. First-degree factors, which have a direct and substantial impact, include milliamperage, exposure time, operating kilovoltage peak (kVp), and the source-film distance. Second-degree factors, while still significant, exert a more indirect influence and encompass subject thickness, developing conditions, film processing, the type of film used, the presence and type of screens, grids, and filters, as well as the presence of fog. Previous studies done with intraoral radiographs have also mentioned errors associated with these factors, like cone cut, elongation, overlap, brown stains, light, dark, light exposed, foreshortening, reverse film, artefacts, dark spots, and light spots.⁶

The X-ray film needs to be subjected to the processing chemicals for designated periods (Table 2). To control the time of development and fixation, an interval timer is indispensable in the darkroom.⁷ Traditionally, the absence of integrated timing mechanisms or audible alerts often resulted in over- or underdeveloped/ fixed films, rendering them diagnostically unreliable. Our device addresses this critical issue with three independent timers. The timers are Wi-Fi-controlled and can be connected to mobile phones. This allows for effortless adjustments based on solution potency and replenishment schedules. Separate switches provide dedicated timing control for the developer, water rinse, and fixer solutions, ensuring meticulous management of each stage. The device eliminates the need for manual timekeeping, reducing human error and ensuring consistent results. The ability to remotely monitor and adjust processing times enhances workflow efficiency, minimising downtime in the darkroom. Customised processing profiles, tailored to specific film types and solution characteristics, can be stored and recalled, ensuring optimal and repeatable image quality. The ability to diagnose instantly and troubleshoot

allows for the quick detection and fixing of processing problems, thereby reducing film waste and maximising resource use. With the use of this wireless control, dentists can maintain ideal film processing standards, consistently delivering films of high quality.

Table 2. Temperature and Timer Interval of Developer Solution

Solution Temperature (°C)	Developing Time (min)	Rinsing Time (min)	Fixing Time (min)	Washing Time (min)
65	6.0	0.5	10–12	20
68	5.0	0.5	10	20
70	4.5	0.5	9–10	20
72	4.0	0.5	8–9	20
75	3.0	0.5	6–7	20
80	2.5	0.5	5–6	20

Apart from its Wi-Fi capability, the Smart Aqua-Time X-Ray Film Hanger comes with an audible alarm system. When the timer is started and the hanger is submerged in the processing solution, a clear 'beep' sound indicates the start of the development cycle. The audible signal gives an instant indication. The alarm naturally turns off when the hanger is taken out of the solution, providing an efficient workflow. The sound of the 'beep' is a clear indication, especially useful in the darkroom where visual monitoring is difficult. This auditory feedback allows the dental professional to focus on other tasks while the film is processing, knowing they will be alerted at the precise moment to remove the hanger. The alarm sound provides a consistent and reliable indicator, minimising the risk of accidentally leaving the film in the solution for too long, which could lead to overdevelopment or overfixing. Such real-time feedback on processing progress, provided through the mobile interface, allows for immediate adjustments, if necessary.

Magnetic float sensors operate according to the buoyancy principle. A significant amount of liquid in contact with the float causes it to submerge itself in the liquid and cease alarming; otherwise, it floats on top of the liquid surface and sounds an alarm. To determine whether there is water in a tank or vessel, the most popular kind of water level switch is the mechanical float switch. As the liquid level changes, the device's float rises and falls. An arm or lever on this kind of float switch rises and falls in response to the liquid level where it is mounted. More weight is placed on top of the container when there is more liquid inside, which

moves the lever and signals the timer and the immersion indicator light. As less weight is added to the top of the tank or pool when there is less liquid in it, the arm does not travel downward due to gravity but instead stays stationary because there is an equal amount of weight on both sides. The same concept has been applied to this X-ray hanger. Thus, the hanger facilitates total submergence of all clipped X-ray films in the solutions being processed. In the case of improperly submerged films, the red light does not work, showing a failure in the processing method. The magnetic float sensor with the indicator light is an essential device that can prevent improper immersion errors in film processing techniques.

Optimal performance in dental radiography in any dental setup requires a quality assurance programme, including frequent testing of key components. Periodic checking of processing chemicals and their replacement schedule is important to ensure optimal solution efficacy. Changes in the quality of radiographs might lead to wrong interpretations and treatment plans.⁸ Regardless of the technique used, processing errors such as stains, streaks, or improper use of fixative lead to the production of faulty radiographs.⁹ The usage of innovative devices like the smart X-ray hanger in routine radiography can ensure radiographic quality assurance by minimising errors. It can save time and decrease the workload in hospital environments. It can ease the work among radiologists and dental professionals by lessening the requirement to monitor films during development.

Conclusion

The Smart Aqua-Time X-Ray Film Hanger combines modern technology and serves as an innovative advancement in traditional film processing techniques. It greatly enhances immersion and timing measurement with accuracy. Processing errors such as overdevelopment, underdevelopment, underfixation, overfixation, and improper immersion are alleviated. Dental professionals utilising this gadget experience reduced wastage of X-ray films and consistent production of clear radiographs, resulting in continuous improvement of images and enhanced accuracy in diagnosis and treatment of patients. Its consistent performance helps to standardise the processing protocol and helps to achieve the same results across all films. Its regular control of timing and immersion improves the control over chemicals used in the process, thereby reducing the environmental effect created by traditional processing techniques. This device enhances the ease of performing the process, even for individuals lacking any prior exposure to manual film development. Additionally, the well-known ALARA (As Low As Reasonably Achievable) principles are also followed, as there is a decrease in patient exposure due to fewer faulty radiographs. With these

remarkable features, this device could help increase the clinical applications of radiographic imaging using lower doses of radiation for patients and medical staff.

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