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Sodium Hypochlorite and its Environmental Impacts; Time to Switch for Herbal Alternatives

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Abstract

Sanitizers are anti-microbial products in the form of spray, lotions, and creams. Sodium hypochlorite now plays an essential role in preserving hand cleanliness by denaturing microbial proteins by lysing the cell. These Sanitizers have also been used in medical, dental, and surgical treatments. If consumed, or through cutaneous or ocular exposure, sodium hypochlorite can be hazardous. When combined with acid it forms chlorine gas and when combined with basic solutions, chloramine is formed, both of which contribute to harmful consequences and it is an incredibly powerful oxidant. Furthermore, chlorination of drinking water with sodium hypochlorite oxidase organic pollutants, resulting in trihalomethanes, which are hazardous. It is critical for health care practitioners, particularly physicians, to understand the ways in which NaOCl can cause toxicity. The study of natural cures used to treat human sickness over millennia has laid the foundation for pharmaceutical development. The adaptation of alternative hand sanitizer formulations based on natural and herbal resources is one reasonable solution to address this toxicity problem. More extensive screens of indigenous plants with elevated flavonoids levels for antibacterial activities and the development of eco-friendly and efficient hand sanitizers should be conducted as contrast to artificial formulations.

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1. Introduction

Prevention of diseases associated with healthcare is achieved by appropriate sanitation procedures with emphasis for hand hygiene[1]. Among many types of chemicals, alcohol containing sanitizers is found to be effective in reducing health risk[2]. Sodium hypochlorite (NaOCl) is also a commonly used washing and sterilizing agent due to its oxidizing and chlorinating property (Figure 1).

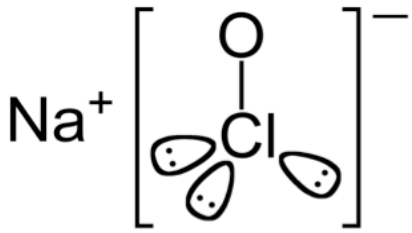


Figure 1. Structure of sodium hypochlorite.

It finds use in food, dairy, agriculture, paint, glass industries and also in dentistry due to its broad-spectrum antimicrobial activity, ability to solubilize in water, and stability in concentrated as well as dilute solutions[3]. In dentistry, sodium hypochlorite is the most commonly utilised irrigation solution. In paediatric dentistry, a 2.5% of NaOCl concentration is used[4]. Major concern of by-product of sodium hypochlorite is the formation of trihalomethanes and other carcinogenic halo-organic chemicals[5]. Another concern is it ignites and explodes when it meets organic materials like paper, wood, grease, and oil. Sodium hypochlorite with water generates highly reactive hypochlorous acid, which has antibacterial and antifungal effects. Superoxide radicals are produced by hypochlorous acid, causing oxidative damage and cell death[6] which by itself is a concern. Traditional disinfectants, such as sodium hypochlorite, are problematic because they are very corrosive and have an unpleasant taste and odour. The widespread usage of sodium hypochlorite as a root canal irrigating solution owes mostly to its pulpal disintegration and antibacterial action. A less concentrated solution, such as 1% sodium hypochlorite, is biologically acceptable. It has been observed that sodium hypochlorite shows a dynamic equilibrium[7].

It is hazardous at high doses and can harm both oral and peritoneal tissues. However, at low doses, its antibacterial action may be reduced. In addition, the NaOCl's substantiveness is minimal to nonexistent. Furthermore, NaOCl has a disagreeable odour and may cause corrosion of endodontic equipment and staining of clothing[8]. NaOCl increases capillary permeability in vascular system, most likely as a result of vessel injury and the production of histamine from affected tissue. When NaOCl is not administered appropriately as an endodontic irrigant, this feature causes fast swelling and frequently copious bleeding into the root canal[9].

Herbal compositions have gained popularity over raw plant materials and extracts due to dosage reduction, convenience, and ease of handling. These formulations are well-known over the world as therapeutic medicines for a variety of diseases that have a negative influence on one's quality of life. The majority of the population in underdeveloped nations relies on traditional medicines due to their affordability, traditional background knowledge on medicinal herbs, and the assumption that they are harmless[10]. Antiseptic, disinfecting, and antibacterial properties are found in traditional medicinal plants rich in polyphenols, alkaloids, and catechin chemicals. Plant extracts were employed as potent antimicrobial agents in the past[11]. Ever since, a wide range of herbal remedies have been accessible. *T riphala*, *tulsipatra*, neem, clove oil, pudina, ajwain, white oak bark, horsetail herb, plantain leaf, aloe vera, organic *Echinacea angustifolia root*, myrrh gum, organic lobelia herb and seed, organic peppermint leaf, wildcrafted goldenseal root, clove essential oil, peppermint essential *Coptis trifolia* derivatives were used as mouth rinses by Native Americans in America, North America, and Mesoamerica[12]. Oral rinses containing Ayurvedic medications are also used to minimise gingival irritation and bleeding. Triphala (TRP) can be used as a gargling agent in dental problems, according to the 20th slokha of Sushruta Samhita. TRP is an ancient ayurvedic medication produced from the fruits of three medicinal trees: *Emblica officinalis, Terminalia belerica* and Terminalia *chebula*. It possesses antibacterial and antiseptic qualities, as well as anti-inflammatory characteristics[13]. Aloe Vera has been claimed to be a powerful antibacterial agent due to its effectiveness in decreasing microbial contamination of dental unit water lines. When compared to hydrogen

peroxide and sodium hypochlorite, aloe vera has superior characteristics[14]. Hence a wide variety of plants and their active principles have been evaluated for antiseptic properties[15]. Despite the fact that sodium hypochlorite is a powerful disinfectant, there are certain toxicological implications to consider. The objective of this review is to analyse the toxicity of sodium hypochlorite and to explore a potential alternative to minimise toxicity.

2. Methodolody

A systematic search for sodium hypochlorite toxicity was conducted in the PubMed and google scholar electronic databases. The search terms used were sodium hypochlorite, toxicity, accidents and case reports. The following were the inclusion criteria evidence of an acute organ ingestion of sodium hypochlorite over a short period of time and genotoxic/cytotoxic effects of sodium hypochlorite. The articles dated from 2000 to 2022 were considered. Literature search of sodium hypochlorite is represented in Figure 2.

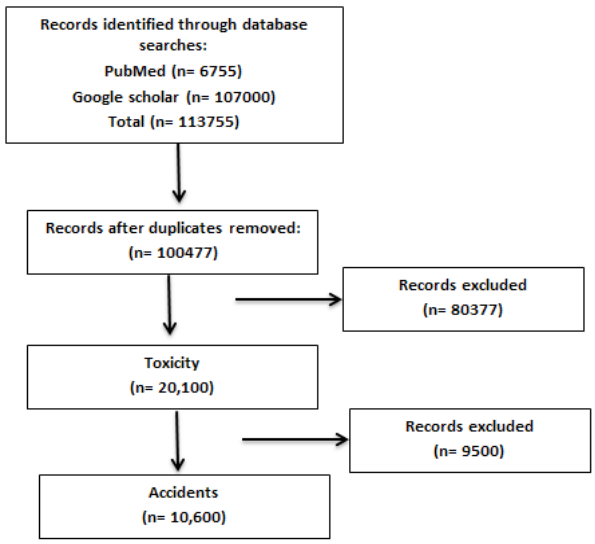


Figure 2. Literature search of sodium hypochlorite.

3. Exposure and Adverse Outcomes

Different ways of exposure to sodium hypochlorite include ingestion while drinking water and eating, inhalation, ocular and skin contact with bleached or disinfected items. Inhalation is also via directly or indirectly at workplace through environment or when it is an intermediate during chemical manufacture. When sodium hypochlorite bleach is combined with acid or alkaline chemicals the gaseous by-product are generally inhaled[16]. Ingestion of bleach leads a damaging impact to respiratory system which is due to bleach fumes ingested through aspiration after consumption[6]. Combining chlorine bleach or pool chlorine with other chemical components may lead to emission of chlorine or chloramine gas which may result in hypochlorite inhalational exposure. Both gases have toxicological effects such as aggravation of the upper respiratory tract, hoarseness, heart pain and stiffness, congestion, lacrimation, and migraine. Some of the most significant adverse effects include ischemia, pulmonary edema, tracheobronchitis, lung hypertension, and respiratory failure[17]. The tendency of sodium hypochlorite to change human dermal fibroblast development *in vitro* in accordance to concentration and exposure duration highlights that sodium hypochlorite is a very reactive chemical that may either hinder or accelerate cell division[18]. Nervous system complications are also a common occurrence. Upon intravenous injection, it produces a decrease in ventricular venous pressure and a decrease in return of venous blood. After discharging their contents into the surrounding structures, thin-walled venules collapse with their walls in close proximity[19].

3.1 Environmental Impacts

Chemicals generally occur in nature, and both humans and wildlife are exposed to them. Unfortunately, during the last three centuries, enormous expansions in industrialisation have increased both the type and amount of human exposures to both natural/synthetic chemicals.

Regular exposure to bleach and potentially similar irritating cleaning agents is linked to an elevated incidence of asthma and chronic bronchitis symptoms. Airborne chlorine and ammonia were detected during occupational household cleaning tasks. Indoor fluorescent lights and diffuse window daylight give enough photon energy to initiate photolysis of HOCl and Cl_2, resulting in the production of Cl and OH radicals and particles, both in the gaseous and particulate phases, which may have severe health consequences for indoor inhabitants. Cl_2 and $HOCl^-$ induced reactions and particle production

have the potential to be a health concern for those who work in the cleaning industry[20]. After surface sterilization with hypochlorite, chlorine-containing compounds and hypochlorite were retained in corrosion products, flaws, and cracks[21]. Sodium hypochlorite cleaning products react with organic debris in wastewater, forming halogenated organic compounds that adsorb on activated carbon and are harmful to aquatic life and persistent environmental pollutants[22]. Subsequently, for hatching in invertebrate eggs, to protect the eggs from invasion it was treated with sodium hypochlorite. However, as the concentration of sodium hypochlorite increased, hatching percentage of eggs reduced[23].

3.2 Genotoxicity and Cytotoxicity

Studies on sodium hypochlorite indicate that it can be a potent genotoxic and cytotoxic agent, even though

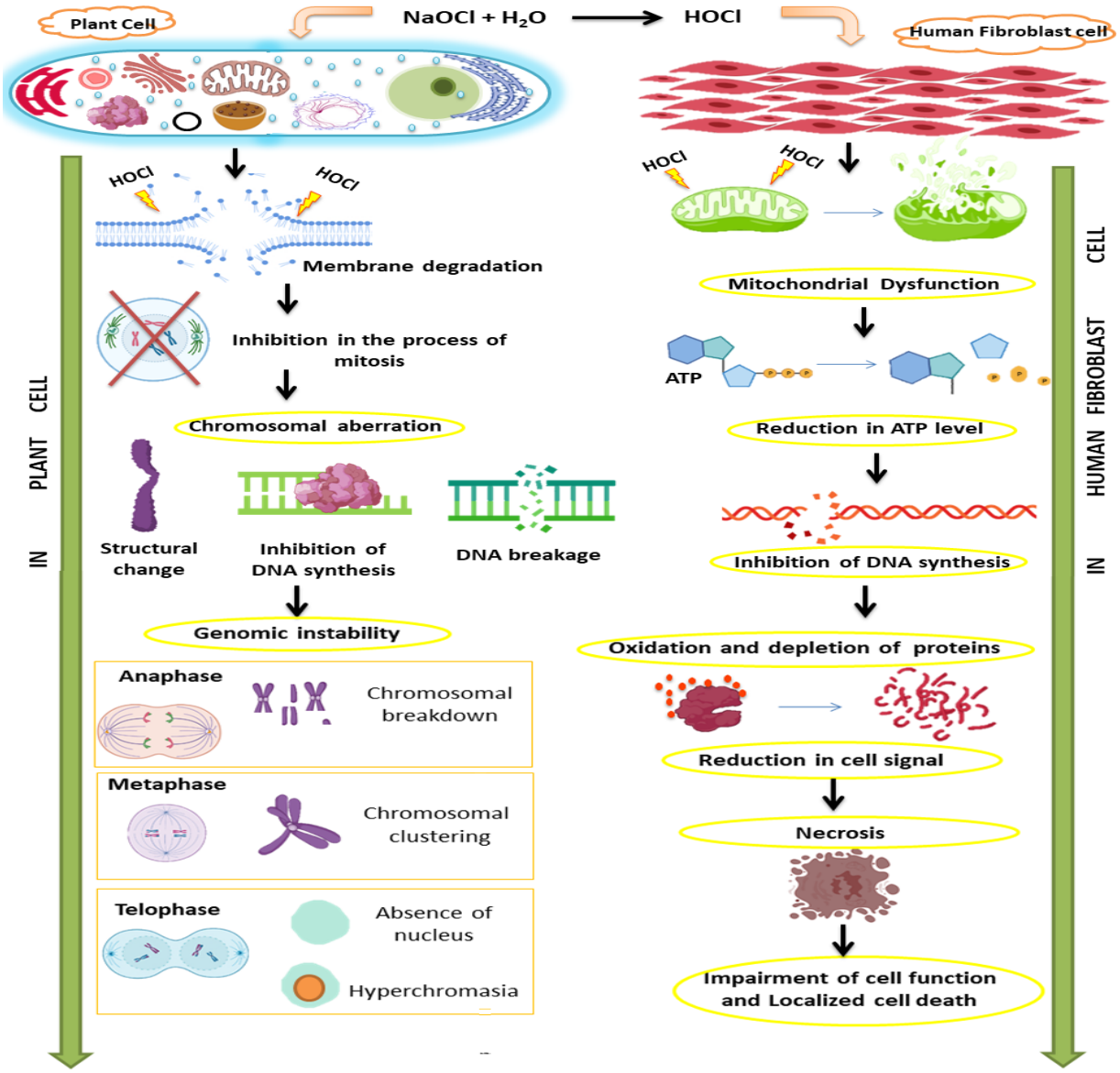


Figure 3. Mechanism of cytotoxicity/genotoxicity.

the evidence on its health effects is often contradictory. Researchers discovered that sodium hypochlorite significantly enhanced the incidence of chromosomal abnormalities in a dose-dependent manner in an *in vitro* examination. NaOCl concentration was also linked to chromosomal abnormalities in Progenitor cells, decaying cells, and multinucleated cells *in vitro*[24]. A further investigation in disinfection of distilled water with sodium hypochlorite, bleach, and peroxycetic acid at varying concentration and pH with untreated distilled water as a negative control proved that NaOCl treated samples at acid pH showed genotoxic activity. Since these chemicals are often found in drinking water for biological reasons, toxicological impact of such chemicals might be a threat to global health[25]. An investigation of the genotoxicity of different dental antiseptics found that sodium hypochlorite is not carcinogenic in rats or mice, however it did produce chromosomal aberration in Chinese hamster CHL cells[26]. Another assessment on the cytotoxic potential of sodium Hypochlorite using lentil as indicator suggested that NaOCl as a cytotoxic impact that causes chromosomal aberrations of various sorts. This demonstrates that as the amount of sodium hypochlorite is increased, it has a cytotoxic impact[27]. Histidine reversion-Ames test efficacy of sodium hypochlorite determined that sodium hypochlorite was liable for DNA modification in *Escherichia coli* which may result in multiple drug resistance[28]. Comparison study on cytotoxicity and genotoxicity effects in human fibroblast cell lines with various dental irrigation agents like chitosan, sodium hypochlorite and propolis as root canal irrigating solutions on revealed that the cytotoxic effects of sodium hypochlorite irrigation solution depend on dose and time of application. After 4 and 24 hours of exposure, NaOCl proved to be the most hazardous solution. Chitosan and propolis may be better irrigation solutions than NaOCl with minimal toxicity and minimal oxidative DNA Damage[29]. Similarly, another study was done to understand if certain endodontic treatment irrigates may cause genetic harm and/or cellular death *in vitro*. For 3 hours at 37°C, murine fibroblast cells were treated to increasing doses of ethylenediaminetetraacetic acid, sodium hypochlorite, MTADTM, and citric acid. Although NaOCl, EDTA, and citric acid were shown to be cytotoxic in a dose-dependent way, they did not cause genotoxicity harm[30]. When utilising lentil as an indicator to assess the cytotoxicity of sodium hypochlorite, the mitotic index showed that at higher concentration of sodium hypochlorite there is a decrease in mitotic index. These findings suggest that sodium hypochlorite causes genetic abnormalities[27]. Furthermore, the cytotoxic impact of various sodium hypochlorite concentrations was investigated using *P. sativum* apical root cells as a bioindicator. Root development was clearly reduced at higher doses of sodium hypochlorite. In addition, chromosomal abnormalities such as nuclear notch, lagging chromosomes, and chromosomal break were created in all doses tested. Furthermore, the detection of micronuclei at 2.0 and 1.6 mg suggests that sodium hypochlorite is a highly cytotoxic chemical[31]. Study on sodium hypochlorite effect on viral tissue reported that it is a highly efficient photolytic solvent and extremely cytotoxic. Hence sodium hypochlorite should be used judiciously and with caution in endodontic therapy[32]. Mechanism of cytotoxicity of sodium hypochlorite is presented as Figure 3.

3.3 Organotoxicity

Patients who use bleach frequently suffer from respiratory and esophageal toxicity. The harm might be caused by inhalation of bleach fumes, aspiration during intake, or vomiting. If the damage to the respiratory tract is extensive, it may lead to respiratory distress or acute respiratory distress syndrome. Acute consequences of NaOCl intake might range from minor discomfort of the respiratory mucous membranes to severe denudation of the mucosa, pulmonary edema, and even death. As examples of subepithelial fibrosis, mucous hyperplasia, increased inflammation, pulmonary fibrosis, and remodeling have been recorded in people who have recovered from NaOCl damage, the healing process may not restore normal structure and function[33]. In teeth, dentists frequently use hypochlorite to clean root canals since it is safe as long as the solution remains within the root canal. Extrusions into the periodical region can cause intense discomfort, massive and distributed swelling, and bleeding. In eyes, corneal injuries from ocular exposure are usual, with searing sensation and marginal disruption of the ocular surface, and they heal in 1 or 2 days. Severe eye discomfort might occur with higher concentration solutions[17]. In kidney, it causes local necrosis, discomfort,

and nerve damage; however sodium hypochlorite has never been linked to Acute Kidney Injury (AKI). A recent report described that the first case of an unintentional NaOCl injection into the infraorbital tissue during a dental treatment, caused AKI. It was hypothesized that oxidative species induced by NaOCl caused AKI as a result of proximal tubules injury, resulting in mild acute tubular necrosis[34].

4. Accidents and Poisoning

There seems to be apparently a massive void in regard to the aetiology and clinical aspects surrounding a NaOCl accident. According to the literature, when an accident happens, the operators seem to be at fault due to improper implementation of the approved irrigation strategy. According to a clinical study paper, a NaOCl accident is more likely to happen when NaOCl has direct access to a soft-tissue region, such as the buccal or infraorbital, rather than merely touching periodontal tissue[35]. Figure 4 represents types of accidents caused by sodium hypochlorite.

A case report of an occurrence in which 5.25% sodium hypochlorite solution was accidentally sprayed into the eye of a patient during endodontic therapy reported that the patient's eyes started tearing up excessively as he screamed of acute burning, it merely looked like both eyes had been injected and their conjunctivas were both erythematous[36]. Another case with black urine upon intravenous self-administration of a high dose of sodium hypochlorite indicated that human kidneys are prone to the effects of severe hemolysis caused by oxidative stress of sodium hypochlorite and severe hemolysis and tubular necrosis[37]. An investigation report on a 30-year-old male in good physical condition hospitalised in emergency room for contemplating suicide by injecting 20 mL sodium hypochlorite of concentration 5% into the right IV line. According to a study thrombosis has been triggered by acute endothelium destruction caused by sodium hypochlorite's strong oxidant capacity[38]. Another systematic review on sodium hypochlorite accidents mentioned a trio of signs/symptoms NaOCl extrusion include sudden pain, extensive hemorrhage, and nearly instantaneous swelling[39]. Accidental extruding of concentrated sodium hypochlorite into Periradicular tissues during root canal irrigation has been described as having significant clinical consequences. There was a quickly growing swelling and haematoma, as well as an extensive bruising and local oral mucosa necrosis[40]. The consequences of an unintentional insertion of sodium hypochlorite into the cheek during root canal irrigation of the right maxillary central incisor are reported. A 32-year-old lady came to a dental facility with shattered anterior superior teeth that needed to be restored. The pH of the sodium hypochlorite that had been utilised was determined to be 12.9. Due to that accidental insertion of

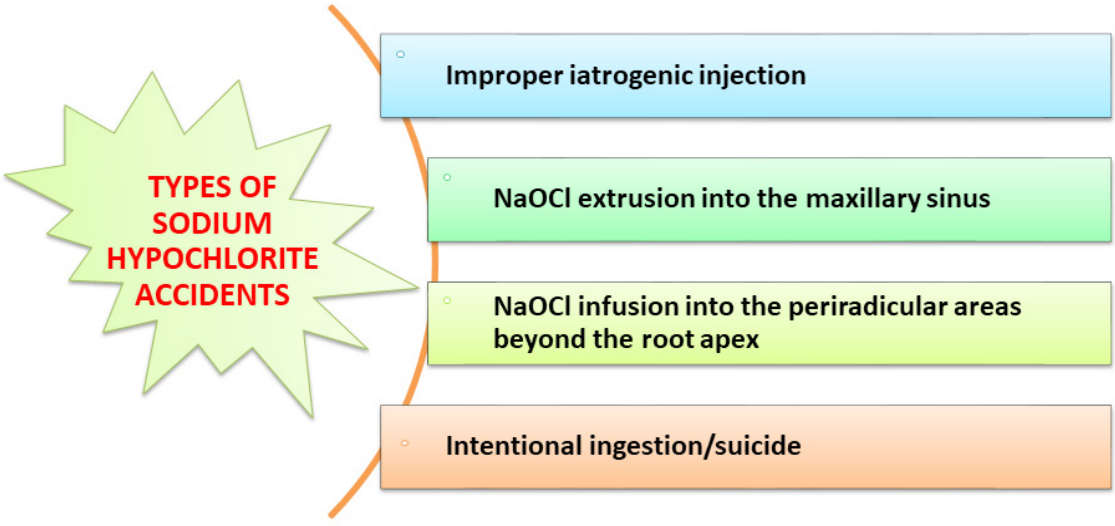


Figure 4. Types of Sodium hypochlorite accidents.

sodium hypochlorite, the tissue was partially obscured by necrotic squamous epithelium in which the dark outlines of the epithelial cells could be distinguished, but there was no nuclear staining on histopathological analysis of the material obtained after surgery. A collection of yeast-like organisms resembling monilia, as well as bacterium colonies, invaded the ulcerated surface. There was just a little inflammatory cell response. Haemorrhages and basophilic degradation of collagen were seen in the sub mucosa[41]. Another NaOCl accident involving a 4 years old child complained of a lesion in the upper left posterior area and significant discomfort, with rapid spontaneous oral swelling on the left side of the face reaching from the left infraorbital border to mandibular region. Because of NaOCl's cytotoxic nature, it induced vascular permeability in blood vessels, most likely as a result of capillary destruction as well as the release of chemical mediators such as histamine from affected tissue[42]. Furthermore, a case report on accidental administration of NaOCl instead of anaesthetic solution during root canal treatment showed that the patient had significant discomfort during the administration of the NaOCl solution. 2–5 minutes of intense agony, most likely due to internal necrosis and abdominal distension, as well as acute edema of the tissue in the region. Oedema and progression in ecchymosis have also occured, accompanied by tissue necrosis and paraesthesia[43].

5. Alternatives for Sodium Hypochlorite

Although NaOCl has a huge amount of potential, it is not chemically stable. Light, air, pH changes, and organic and inorganic pollutants all contribute to the intrinsic instability of NaOCl solutions. Various investigations in NaOCl because of its instabilities, lack of effectiveness, and short shelf life. Over the previous 90 years, several researchers have looked at the potential harmful consequences of sodium hypochlorite. As a result, many researches were conducted to find alternative disinfectants to replace sodium hypochlorite. In this instance, peracetic acid has recently proven to be a feasible solution suitable of adequately neutralising all kinds of microorganisms, boosting its usage both in the health sector and in the food business. The peroxide of acetic acid, peracetic acid or peroxyacetic acid, is a powerful oxidizing agent and disinfectant with a redox potential greater than chlorinated components or chloramines with lower toxicology[44]. Dichloroisocyanurate, which is also extensively used in water emergency treatment, has recently been approved by the US Environmental Protection Agency and the World Health Organization for routine drinking water treatment. As a result, it might provide advantages such as microbiological efficacy, compliance, acceptance, and cost[45]. A study comparing the effectiveness of a hydrogen peroxide powdered system and a 0.5% sodium hypochlorite in sanitising *Clostridium difficile*-contaminated surfaces found that hydrogen peroxide powdered sterilisation system is considerably more efficient than 0.5 percent sodium hypochlorite at exterminating *C. difficile* spores and could initiate a unique alternative[46]. Another research looked at the effectiveness of citric acid and NaOCl against *M. bovis* have suggested that 0.5% of citric acid solution or 1% of NaOCl solution are likely to be efficient disinfectants for *M. bovis*. However, upon organic abrasive particles 0.04 % of NaOCl solution or 0.25 % of citric acid are likely to be effective following organic abrasive particles. Hence citric acid could also be an effective alternative for sodium hypochlorite[44].

5.1 Herbal Alternatives

Sanitation potential with herbal components is an old concept, but it has recently emerged as a source of increased attention and relevance. The ever-increasing prevalence of antibiotic-resistant bacteria microorganisms and adverse impacts of man-made chemical components has promoted researchers to look for herbal alternatives. The major benefits of utilising herbal sanitation/disinfection include widespread accessibility, less expenditure, improved life span, and reduced microbial function in developing resistance. Further research found that BioPure MTAD is more effective in killing bacteria than sodium hypochlorite. *Emblica officinalis* (Gooseberry) and *Psidium guajava* (guava) are efficient against *Enterococcus faecalis* and can be used as a effective alternative for sodium hypochlorite to decrease root canal microorganisms and root canal defects[47]. *Curcuma longa*, *Azadirachta indica*, Triphala, and *Morinda citrifolia* are studied as an alternative for sodium hypochlorite. Although the effectiveness was reported to be lower to that of NaOCl. Mean zone of

Table 1. Antimicrobial Efficiency of Herbal extracts

Comparison	Herbal disinfectants	Study	Outcome	Efficiency	Reference
0.2% chlorhexidine	3% Neem	Reduction of *Streptococcus mutans*	3% neem has greater efficacy than other solutions	Reduction rate: 88%	[51]
	4.15 mg/mL Garlic			Reduction rate: 96%	
	40 mg/mL Green Tea			Reduction rate: 83%	
5% Sodium Hypochlorite	Triphala	*Mycoplasma bovis*	Showed statistically significant antibacterial activity similar to sodium hypochlorite	Minimal Inhibitory Concentration: 3.125 mg/mL	[49]
	Green Tea Polyphenols			Minimal Inhibitory Concentration: 3.125 mg/mL	
2.5% NaOCl	*Emblica officinalis*	E. faecalis	Against *E. faecalis*, *E. officinalis* has greater antibacterial action than sodium hypochlorite. *P. guajava* was also shown to have antibacterial properties.	Zone of inhibition:18.97±0.55	[52]
	Psidium guajava			Zone of inhibition:14.83 ±0.29	
0.04% sodium hypochlorite	0.5% citric acid	*Mycoplasma bovis*	0.04 % NaOCl or 0.25 % citric acid optimum for *Mycobacterium bovis* disinfection.	˜106 fold decrease in viability	[53]
5% NaOCl	Propolis	*Enterococcus faecalis*	Triphala, GTPs, and *Morinda citrifolia* all have antibacterial properties. *Morinda citrifolia* had the least bactericidal activity of the test agents. Triphala was more effective against *E. faecalis* biofilm.	Bacterial colony counts: 158.17 CFUs/µl	[54]
	Morinda citrifolia (Noni)			Bacterial colony counts: 56.67 CFUs/µl	
	Azadirachta indica (neem)			Bacterial colony counts: 15.92 CFUs/µl	
5.25% sodium hypochlorite	Propolis	*Enterococcus fecalis* biofilm	Propolis and triphala showed no statistically significant difference GTPs also exhibited significant antimicrobial activity.	MIC as determined by Zone:12.50 mm	[55]
	Morinda citrifolia			MIC as determined by Zone:11.75 mm	
	Azadirachta indica, triphala			MIC as determined by Zone:12.25 mm	
	Green tea polyphenols			MIC as determined by Zone:13.75 mm	

5% sodium hypochlorite	20% *Thymus vulgaris*	*Enterococcus faecalis*	All herbal irrigant do exhibit antibacterial activity against endodontic pathogens and can be used as a substitute for sodium hypochlorite	Zone of inhibition:12.50 mm	[56]
	12.5% *Salvadora persica*			Zone of inhibition:11.75 mm	
	10% *Acacia nilotica*			Zone of inhibition:12.25 mm	
	10% *Calendula arvensis*			Zone of inhibition:13.75 mm	
2.5% Sodium Hypochlorite	*Eucalyptus Galbie*	*Enterococcus Faecalis*	99% reduction	Reduction rate: 99.33%	[57]
	Myrtus Communis L. Extracts			Reduction rate: 99.33%	
	Chlorhexidine			Reduction rate: 99.96%	

inhibition in descending order was found as sodium hypochlorite > Propolis > *Azadirachta indica* > Triphala > *C. longa* = MC > ethanol. In the realm of endodontic treatment, these extracts offers a potential benefit over NaOCl, including simple availability, improved shelf life, low adverse impacts, and no documented microbial resistance[48]. Another comparison study on MTAD, Triphala, polyphenols from green tea and 5% sodium hypochlorite were tested for antibacterial effectiveness *against E. faecalis* Biofilm produced on dental substrate showed that the antibacterial activity of 5% sodium hypochlorite was highest over 3- and 6-week *E. faecalis* biofilm grown on the tooth substrate. Triphala and MTAD demonstrated for about 100% elimination in a 3 weeks biofilm[49]. Similarly, *Morinda citrifolia* and turmeric showed a considerable reduction in growth of *E. faecalis*[50]. Even though herbal formulations were not as effective as NaOCl, they are also showing considerable antimicrobial activity which is highly similar to sodium hypochlorite. Upon the numerous drawbacks of NaOCl as a root canal irrigant, using herbal approaches for a root canal irrigant might be considered (Table 1).

6. Conclusion

Sodium hypochlorite certainly induce cytotoxicity and tissue damage; however, it is usually due to accidental infusion much over the root apex of the teeth causing severe tissue injury. In certain persons, sodium hypochlorite can cause inflammatory responses. However, in order to defeat extremely resistant bacteria, it is necessary to utilise such powerful components as disinfection/sanitation agents. Researchers have been looking for herbal alternatives owing to the rapid development of antibiotic-resistant bacteria and the potential negative impacts of synthetic chemical components. Scientific evidence and ease of use support the use of herbal formulations instead of using sodium hypochlorite to minimize the cytotoxicity and environmental impacts.

7. Conflict of Interest

The authors declare that they have no conflict of interest.

8. Acknowledgement

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