Histopathologic Evaluation of Pulpal Response to Castor Oil versus Formocresol in Deciduous Teeth Pulpotomy

Wafaa Yahia Alghonemy [1,2], Shimaa M. Hadwa [3]

1 Department of Basic Medical and Dental Sciences, Faculty of Dentistry, Zarqa University, Zarqa, 13132, The Hashemite Kingdom of Jordan.

2 Department of Oral Biology, Faculty of Dentistry, Tanta University, Tanta, Egypt

3 Department of Pediatric Dentistry, Oral Health and Preventive Dentistry, Faculty of Dentistry, Tanta University, Egypt.

***Abstract*- Objectives:** The present investigation compared and assessed the pulpal responses to castor oil versus formacresol (FC) through pulpotomy medications in deciduous teeth. **Material and Methods:** The present study was done on thirty-one children aged between seven and nine years with bilateral deciduous teeth that need serial extraction attending the Clinic of Pediatric Dentistry Department, Faculty of Dentistry. Every child has one or two teeth bilaterally, fulfilling the clinical and radiographic criteria for the research. The teeth were separated into two groups randomly, each with thirty teeth, rendering to the utilized pulp capping materials—the group I had been treated with FC. In contrast, Group II had been treated with castor oil. Also, two sound (Negative control) teeth were used to standardize normal pulp structure and tissue organization. Ten teeth were removed from each group at intervals of two, four, and twelve weeks. Pulpotomy procedures were done in both groups. Teeth in each group were extracted and underwent processing for histological analysis and then statistical evaluation. **Results:** Castor oil showed statistically significantly higher results than FC regarding pulp inflammation, soft tissue organization, and dentin bridge formation. **Conclusions:** Castor oil is associated with decreased pulpal inflammation and more preservation of the odontoblastic layer with enhanced regenerative tendency than FC. **Clinical Significance:** Castor oil is a biocompatible substance compatible with deciduous pulp tissue. Moreover, it has a strong capacity for maintaining the health and functionality of the remaining pulp tissue.

Keywords: Castor oil, Formocresol, Pulpotomy, Primary teeth, Histological evaluation.

I. INTRODUCTION

In pediatric dentistry, the most typical problem is the conservation of the last vital area of the pulpal tissue, which is newly exposed when necessary to maintain the tooth's health [1]. Depending on the severity of the injury and the specifics of the pathologic state affecting the pulp tissues, there are currently a variety of techniques and studies for managing the pulp of primary teeth [2]. A pulpotomy is a conservative approach to removing the diseased coronal pulp while preserving the remaining uninfected tissue with inert material [3]. Bactericidal and safety for pulp and nearby structures are requirements for the ideal pulp capping substance. Also, it must encourage root pulp healing, not hinder the biological root resorption during shedding, not cause failure in conservative endodontic treatment, and not allow the spread of infection. It shouldn't have transferability of inflammatory processes to radicular pulp tissues [4].

Various pulpotomy materials were used for capping the radicular pulp, including FC and glutaraldehyde [5]. Also, mineral trioxide aggregate, ferric sulfate, and collagen material are utilized as pulpotomy materials [6]. Noteworthy, since Sweet [7] introduced FC in pulpotomy procedure in the deciduous teeth 70 years ago, it has gained widespread use. Moreover, it remains the greatest popular taught and favored pulp treatment for deciduous teeth [1], [8], [9]. However, fears have grown about FC usage in humans, primarily because of many estimated hazards, including immunologic, cytotoxic, mutagenic, biochemical, and carcinogenic modifications in the living [10]. As well as it is found to cause malformation in the enamel of permanent teeth [11].

In contrast, it was demonstrated that FC was absorbed into the blood from the treated teeth. Also, when the number of teeth treated with FC increased, the level of FC in the blood augmented. Moreover, tissue damage has happened in numerous internal organs, especially the kidney and liver [12]. Even with this, several studies have found that FC pulpotomy's clinical success declines over time, and the primary pulp's histological reaction is unpredictable, from persistent inflammation to necrosis [13]. As a result, the increased use of indigenous plant remedies in emerging nations evolved into a WHO 1970s policy [14]. The necessity for natural medications to substitute FC as a pulpotomy material becomes critical. Today's world is looking for alternatives to synthetic medications with natural products having therapeutic potential. The improved effectiveness of new plant-based medicines and the expanding popularity of natural items have fueled interest in medicinal plants [15].

Castor oil is a new material widely available worldwide, and it has drawn a lot of attention recently because of its widespread commercial availability [16]. Castor oil is formed from the Castor oil plant seeds (Ricinus communis) and has a distinctive flavor. It is colorless to extremely pale yellow [17]. Also, it has several advantages as vegetable oil, including low toxicity, high availability, antibacterial and antioxidant capabilities, ability to preserve glutathione, and inexpensive cost [18]– [20].

Accordingly, this in vivo research was conducted to compare and evaluate pulpal response to Castor oil with FC for pulpotomy in deciduous teeth.

II. MATERIALS AND METHODS

1. Ethical Consideration and Study Setting:
This research was carried out at the Pediatric Dentistry Department outpatient clinic, Faculty of Dentistry, and histological evaluation at the Oral Biology Department, Faculty of Dentistry.
This study received research ethics committee (REC) approval from the Faculty of Dentistry, Tanta University, Egypt, code (#R-PED-10-22-6) in compliance with the moral guidelines outlined in the Helsinki Declaration of 1964 and its subsequent revisions. Clinical treatment was started after fathers signed written informed consent.

2. ClinicalTrials.gov Identifier: NCT05723900

3. Sample Size Calculation and Randomization:
The Epi-Info statistical package developed by the World Health Organization and the Centers for Disease Control and Prevention, Atlanta, Georgia, USA, version 2002, computed the sample size and power analysis. The following criteria were used to calculate the sample size:
-95% confidence interval -80% of the study's power
The predictable favorite pulpal response was 95% in the best treatment groups compared to 65% in the least favorable treatment groups. Depending on the formerly specified criterion, the sample size was initiated at N=28 in every group. The researcher raised the sample size to 30 cases to account for inaccurate data.

4. Sample selection:
a. Patient Selection:
A sample of (62) primary teeth from thirty healthy cooperative children of both sexes was referred to the Pediatric Dentistry Department and aged (7-9). Two sound teeth lacking the pulpotomy procedure were extracted and exposed to histologic procedures to inspect the healthy pulp tissue and tissue organization (Negative control). On sixty deciduous teeth, the pulpotomy was done by split-mouth design.

b. Inclusion and Exclusion Criteria:
The inclusion standards included healthy, cooperative children with sound deciduous canines designated for orthodontic causes (interceptive therapy and serial extraction). Exclusion criteria included caries primary teeth, the presence of systemic pathology as well, and a past of allergic reactions to local anesthesia or capping materials.

c. Sample Grouping:
Regarding the dressing material type used, the deciduous teeth were distributed randomly into two groups by a technology that generated random numbers. Summarized in the flowchart fig. (1).

Group I (Control): (n=30): Treated with FC (Sultan Healthcare-Inc. Engle Wood-NJ.) after pulpotomy procedure.
Group II (Castor oil): (n= 30): Treated with castor oil (Imtenan health shop, Obour city, Egypt) after pulpotomy procedure.

5. Clinical procedure:
Single-visit pulpotomy was performed under strict aseptic conditions by a single operator. Before starting pulpotomy, the pre-operative evaluation was done using an intraoral digital PSP (photo-simulated phosphorus plate) sensor from Helsinki, Finland's Planmeca ProSensor HD. The deciduous teeth were anesthetized with 2% mepivacaine with 1:20:000 levonordefrin (Alexandria Co., Egypt) and isolated using a rubber dam (Midwest Dental, Texas, USA). Firstly, using a high-speed contra No. 330 sterile round carbide burst, caries were eliminated under copious water cooling and high suction. Access opening was gained, and the pulp chamber roof was removed. By sharp sterile spoon excavator, the coronal pulp was surgically removed, and cotton pellet blocked initial bleeding dampened in saline slightly pressed against the removed pulp stump, then over the pulp stump that had been amputated, and the capping agents were used according to the groups. In group I, the cotton pellet was dampened with Buckly's FC applied for five minutes; then, a profuse paste made by combining zinc oxide powder (Meta Biomed) with one drop of eugenol was applied to the pulp stumps. In group II, the cotton pellet was dampened with Castor oil. It was applied for five minutes on the pulp stump, followed by the dressing of the pulp stump with a fresh mix of zinc oxide powder and one drop of Castor oil (30 µl) until it reached the proper consistency (1:1 volume-to-volume ratio) to cover pulp stumps. Afterward, all treated teeth from both groups were filled with glass ionomer cement (Medfill Glass Ionomer Filling Cement, Promedica, Germany). Ten teeth from the two groups were extracted after two, four, and twelve weeks.

6. Histological evaluation Method:
After carefully washing all the extracted with normal saline, they were fixed in 10% formalin for about 48 hours and then decalcified in 20% EDTA at four °C for about (6-8) weeks. EDTA was changed daily until complete decalcification was confirmed by manual testing of the specimens. Following a thorough washing under running water, the specimens were dehydrated in increasing concentrations of alcohol and finally embedded in paraffin wax blocks. After that, serial 4µm slices were cut with the microtome machine, and the deparaffinized sections were exposed to hematoxylin and eosin (H&E) staining. Afterward, the stained sections were blindly evaluated using a light microscope (LM) supported by an internal camera (Leica ICC50 HD). The inspector was unfamiliar with the applied material because he received numbered slides without being aware of the group to which they belonged.
The photomicrographs of the specimens were evaluated using the standards established by Fuks et al.[21] that evaluate the degree of pulp inflammation (Table. 1) and the absence or presence of dentin ships and bridges (Table. 2). Furthermore, other criteria were evaluated according to Mahfouz and Wahba [22] that assess the degree of pulpal vascularity and blood vessels formation (Table. 3), the intensity of pulp fibrosis (Table. 4), the quality of odontoblastic layer (Table. 5), and the presence or absence of pulp stone (Table. 6).

Description	Score
No inflammation	0
Mild inflammation	1
Moderate inflammation	2
Severe inflammation	3
Necrosis	4
Abscess	5

Table (1): Degree/scoring of pulp inflammation

Description	Score
No dentin bridge	0
Presence of dentin bridge	1

Table (2): Presence/scoring of dentin bridge/ships

Table (3): Degree/scoring of pulpal vascularity

Description	Score
Mild vascularity	1
Moderate vascularity	2
Severe vascularity	3

Table (4): Degree/scoring of pulp fibrosis

Description	Score
No fibrosis	0
Mild fibrosis	1
Moderate fibrosis	2
Severe fibrosis	3

Table (5): Quality/scoring of odontoblastic layer

Description	Score
Organized layer (intact)	0
Non-organized layer (not intact)	1

Table (6): Presence/scoring of pulp stone

Description	Score
No pulp stone	0
Presence of pulp stone	1

7. Statistical analysis:

All data obtained in the current study were collected, computerized tabulated, and statistically analyzed at ($p \leq 0.05$) using SPPS (Statistical Package for the Social Sciences). Frequency and percentage were used to express quantitative data. The significance test Chi-square ($\chi 2$) was applied for the Comparison between different groups according to a categorical variable. The collected data were organized, tabulated, and statistically analyzed using the IBM SPSS version 19 (Statistical Package for Social Studies) created by IBM, Illinois, Chicago, USA. The range, mean, and standard deviations for numerical values were computed.

III. Results

Histopathological results:

A. Negative control teeth:

The two negative control teeth depicted the normal architecture of the pulp tissue. It appeared to consist of four zones: odontoblastic zone, cell-free zone, cell-rich zone, and center of the pulp consisting of collagen fibers and cells and a complex and rich vascular and neural network as shown in Figure (2).

B. Formacresol group:

Pulp inflammation was significantly noted in all teeth treated with FC. After two weeks, the teeth revealed moderate to severe inflammation. On the other hand, the teeth with severe pulp inflammation and necrosis increased at four weeks. Also, teeth with severe pulp inflammation, necrosis, and abscesses appeared at twelve-week intervals. Reparative dentin formation did not appear in all cases. Pulp vascularity was different from mild to moderate. After two weeks, 70% of teeth had mild vascularity, and 30% had moderate vascularity, but at four and twelve weeks, mild teeth were 50%, and 50% displayed moderate pulp vascularity. As well as collagen fiber formation was also noticed. The teeth showed severe and moderate pulp tissue fibrosis at 40% and 60% at two weeks. At four weeks, the teeth showed severe and moderate pulp tissue fibrosis by about 80% and 20%, respectively. Also, at twelve weeks intervals, teeth with severe pulp fibrosis were about 80%, and those with moderate were 20%. The odontoblastic layer was not intact through the pulpal surface of the dentin. About 70%, 80%, and 100% of cases showed disorganized odontoblasts at 2, 4, and 12 weeks respectively. Pulp stones were solitary after two weeks by about 20% and after four and about 40% and 50% after four and twelve weeks, respectively. All these results can be identified in Tables (7-12) and Figure (3).

C. Castor oil group:

Interestingly, in this group, almost normal pulp architecture was detected. Another finding in the Castor oil group was the existence of inflammatory reactions with different grades of severity. First, mild inflammatory cell infiltration was observed in 20%, 30%, and 10% of cases at two, four, and twelve-week intervals, respectively. There was no inflammation in 20% of cases at two weeks and no necrosis or abscess in all cases in all follow-up periods. Reparative dentin formation appeared only at the interval four and twelve weeks in 20% and 40% of cases in fragments of dentin ships. Usually, blood vessel development was evident, and the degree of pulp vascularity ranged from mild to severe. After two weeks, 30% were mild, 50% of teeth revealed moderate pulpal vascularity, while 20% showed severe. The findings were 10% mild, 50% moderate, and 40% severe at four-week intervals. The pulp fibrosis appeared as 80% mild and 20% moderate. The odontoblastic layer was almost intact through the pulpal surface of the dentin. Only 10%, 30%, and 50% of cases showed

disorganized odontoblasts at 2, 4, and 12 weeks, respectively. Pulp stones were not present at two weeks, but they appeared solitary in about 10% and 20% after four and twelve weeks, respectively. All these results can be recognized in Tables (7-12) and Figure (4).

Statistical results:

Table (7) demonstrates the distribution of the two experimental groups regarding the degree of pulp inflammation at different follow-up periods. When the Castor oil group was compared with the FC group regarding the pulp inflammation intensity, it appeared statistically non-significant at two-week intervals (p=0.245), significant statistically at four weeks (p= 0.023), and high statistical significance at twelve weeks (p=0.001). Similarly, the Comparison of four weeks versus 12 weeks in the FC group was statistically significant, and the Comparison of four weeks versus 12 weeks in the Castor oil group was statistically significant.

Table (8) reveals the distribution of the two experimental groups concerning the presence of dentine bridge at different follow-up periods. When the Castor oil group was compared with the FC group regarding the dentine bridge formation, it appeared statistically non-significant at 2, 4, and 12-week intervals at (p=1.000, 0.474, and 0.087), respectively. However, the Comparison of four weeks versus 12 weeks in the FC group was statistically non-significant, and the Comparison of four weeks versus 12 weeks in the Castor oil group was statistically significant.

Table (9) divulges the distribution of the experimental groups by the degree of pulpal vascularity at different follow-up periods. In Comparison of the castor oil group with the FC group regarding the degree of pulpal vascularity, it seemed statistically non-significant at two-week intervals (p=0.167). However, it exhibited statistical significance at four weeks (p= 0.046) and twelve weeks (p=0.011). In addition, the Comparison of four weeks versus 12 weeks in the FC group was statistically non-significant, and the Comparison of four weeks versus 12 weeks in the Castor oil group was statistically significant.

Table (10) reveals the distribution of the experimental groups regarding the degree of pulp fibrosis at different intervals. The Comparison of the Castor oil group with the FC group regarding the degree of pulpal fibrosis appeared statistically significant at two-week intervals (p=0.020). However, At the statistical level, it was insignificant at four weeks (p=0.070), and then at twelve weeks, it became statistically significant (p=0.033). In addition, the Comparison of four weeks versus 12 weeks in the FC group was statistically non-significant, and the Comparison of four weeks versus 12 weeks in the Castor oil group was statistically significant.

Table (12) depicts the distribution of the experimental groups concerning the presence of pulp stones at different follow-up periods. When the Castor oil group was compared with the FC group regarding the presence or absence of pulp stone, it appeared statistically non-significant at 2, 4, and 12-week intervals at (p=0.474, 0.303, and 0.350), respectively. Also, a comparison of four weeks versus 12 weeks in the FC or Castor oil groups was statistically non-significant.

IV. Discussion

The pulpotomy procedure is frequently used to treat deciduous teeth. It contributes to preserving the teeth integrity exaggerated by pulp inflammation coronally. Preserving the healthiness of the radicular pulp is the main purpose of pulpotomy and, eventually, the affected tooth [23]. To improve the success rate of pulpotomy procedures, it appears critical to identify novel and effective pulpotomy agents. As a result, various studies have assessed the radiographic and clinical success of different pulpotomy agents in deciduous teeth, including pain or swelling and the radiological signs of periapical lesions [24], [25]. Conversely, histological analysis is essential to assess the microscopic alteration of the pulp following the pulpotomy treatments [26]–[29].

Back to nature is a recent concept used in medical and dental fields. The application of extracts and essential oils from various plant classes is becoming increasingly prevalent. This prevalence stems from the antimicrobial and therapeutic properties, which have long been understood [30]. Thus, in the current research, we used Castor oil, a natural product, in the pulpotomy of deciduous teeth scheduled for serial extraction. Then, we compared the histological effects of Castor oil on pulp structure to that produced by FC after pulpotomy procedures.

Despite FC being debated a great deal, it continues to be the drug of choice for pulpotomies of deciduous teeth. It is regarded as the "Gold standard" against which every other medication for deciduous teeth pulpotomy is measured [21]. As far as we know, this is the first study comparing the histopathologic effects of castor oil against FC on the human vital pulp tissues of deciduous teeth. Hence, it needs to be regarded as preliminary.

The follow-up intervals for the current investigation are two, four, and twelve weeks to assess the inflammatory retorts of the two agents on the pulp structure, which may be sufficient for this issue. This contradicts the findings of Kakarla et al. [31], who histologically assessed the response of deciduous dental pulp tissue to pulpotec, pulpotomy agents, after one and two weeks. Furthermore, Sivadas et al. [32] evaluated the primary teeth in vitro reactions to ferric sulfate and diode laser at 4 and 6 weeks. In addition, According to Sivadas et al. [32] and Ratnakumari and Thomas [33], this study was a single-anonymized, in vivo investigation in which the oral pathologist was also blind to the histopathological results.

The initial inflammatory response is a common feature beneath different pulpotomy agents because it is considered a normal reaction of remaining pulp tissue to the exposure, pulp amputation procedure, probable bacterial contamination, material application, and condensation [34]. The inflammatory response is a critical phenomenon; once initiated, leukocytes are the first cells to be recruited to sites of injury against the irritants [35]. When the Castor oil group was compared with the FC group regarding the pulp inflammation intensity, it appeared significant statistically at four weeks (p= 0.023) and a high statistical significance at twelve weeks (p=0.001). Likewise, the Comparison of four weeks versus 12 weeks in the FC group was statistically significant, and the Comparison of four weeks versus 12 weeks in the Castor oil group was statistically significant. Furthermore, teeth with severe pulp inflammation, necrosis, and abscess appeared at twelve-week intervals. This was agreed by Ranly [36]and Omar et al. [37], who concluded that the treated group demonstrated moderate to severe vasodilation and a high inflammatory cell infiltrate and degenerative changes. Substantially, the reaction to FC can be

attributed to various causes, including trauma during pulp tissue removal or material cytotoxicity [38]. It was demonstrated that when formaldehyde in FC entered the pulp, it induced tissue fixation, and then, as it diffused apically, coagulation necrosis also occurred [39].

Moreover, the pulp liquefaction necrosis that followed this coagulation necrosis is believed to have been caused by the release of hydrolytic enzymes from dead neutrophils [40]. Furthermore, FC is well known for devitalizing the pulp and thus causing necrosis [41]. In addition, Gonna et al. [42] reported moderate to severe inflammation in teeth treated with FC after twelve weeks. Also, another histological study by El-Meligy et al. [43], Magnusson [44], and Toomarian et al. [45] supported similar results in the coronal part of the pulp. In addition, Srinivasan and Jayanthi [46] reported that FC had a more inflammatory effect and created an atrophy zone in the pulp's radicular section.

When the Castor oil group compared with the FC group regarding the dentin bridge formation, it appeared statistically non-significant at 2, 4, and 12-week intervals at (p=1.000, 0.474, and 0.087), respectively. This means that FC still showed minimal successful thin dentin layer formation features. These features are attributed to its bactericidal qualities, as determined by Cox et al. [47]. However, the Comparison of 4 weeks versus 12 weeks in the FC group was statistically non-significant, and the Comparison of 4 weeks versus 12 weeks in the Castor oil group was statistically significant. This was agreed upon by Haghgoo and Abbasi [48], who discovered that the FC demonstrated no dentinal bridge formation, as pulp calcifications were discovered at four-week intervals. Similarly, Gonna et al. [42] reported no dentine bridge formation after twelve weeks

of FC pulpotomy.

An increase in blood vessel formation or hyperemia in the pulp capping area usually indicates the pulpal vitality and biocompatibility of the capping materials [49]. The current research, a Comparison of the Castor oil group with the FC group regarding the degree of pulpal vascularity, seemed quantitatively significant at four weeks (p= 0.046) and 12 weeks (p=0.011). Nonetheless, the Comparison of 4 weeks versus 12 weeks in the FC group was statistically non-significant. The Comparison of 4 weeks versus 12 weeks in the Castor oil group was statistically significant.

The Comparison of the Castor oil group with the FC group regarding the degree of pulpal fibrosis appeared statistically significant at 2-week intervals (p=0.020). Statistically, it was insignificant at four weeks (p=0.070), then at 12 weeks, it became statistically significant (p=0.033). In addition, the Comparison of 4 weeks versus 12 weeks in the FC group was statistically non-significant, and the Comparison of 4 weeks versus 12 weeks in the Castor oil group was statistically significant. Mahfouz and Wahba [22] and Beltagy et al. [50] agreed and found that pulp fibrosis was detected at nearly all follow-up periods post-treatment with FC.

In a recent investigation by Mohamed et al. [51], Castor oil is excellent at influencing stem cells isolated from human deciduous teeth, migration, and proliferation. Also, it has a good effect on wound healing; thus, it is beneficial as a material for pulp capping. This substance's chemical component is a chain of fatty acids, the molecular apparatuses also present in human fatty tissue. As a result, castor oil cement is not viewed as a foreign object by the cells. Also, the investigation by Holm et al. [18] concluded that castor oil is efficient as a medium for a lens of rat transplantation, and it was considered a viable storage solution due to its ability to preserve glutathione and its antioxidant qualities. In addition, they attributed these returns to the presence of glutathione content within cells that aid in protein preservation and prevent cellular membrane damage.

The current study's histological findings confirmed that castor oil had promising outcomes when used as a vital medication for primary teeth pulpotomy, compared with FC, which persuaded pulp necrosis. Furthermore, castor oil caused pulp to experience minor inflammatory reactions, making pulp tissue repairable.

V. Conclusion

Based on this study's histopathologic results, it was concluded that castor oil is a biocompatible substance compatible with deciduous pulp tissue; it has a strong capacity for maintaining the health and functionality of the remaining pulp tissue. Also, it reduced pulp inflammation and preserved the odontoblastic layer better than FC. As a result, castor oil can be used as an acceptable pulpotomy medicament and as an alternative to FC.

Acknowledgments:

The authors thank the Deanship of Scientific Research, Zarqa University, Jordan, for supporting this research.

References:

[1] R. E. Primosch, T. A. Glomb, and R. G. Jerrell, "Primary tooth pulp therapy as taught in predoctoral pediatric dental programs in the United States," *Pediatr Dent*, vol. 19, pp. 118–122, 1997.

[2] M. Simancas Pallares, A. J. Díaz Caballero, and L. M. Luna, "Mineral trioxide aggregate in primary teeth pulpotomy—a systematic literature review," 2010.

[3] V. Smaïl-Faugeron, A. Glenny, F. Courson, P. Durieux, M. Muller-Bolla, and H. F. Chabouis, "Pulp treatment for extensive decay in primary teeth," *Cochrane Database of Systematic Reviews*, no. 5, 2018.

[4] D. Lee and G. Bogen, "Multifaceted use of ProRootTM MTA root canal repair material," *Pediatric Dent*, vol. 23, no. 4, pp. 326–330, 2001.

[5] P. J. Loos and S. S. Han, "An enzyme histochemical study of the effect of various concentrations of formocresol on connective tissues," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 31, no. 4, pp. 571–585, 1971.

[6] R. S. Schwartz, M. Mauger, D. J. Clement, and W. A. WALKER III, "Mineral trioxide aggregate: a new material for endodontics," *The Journal of the American Dental Association*, vol. 130, no. 7, pp. 967–975, 1999.

[7] C. A. Sweet, "Treatment for deciduous teeth with exposed pulps," *Mich St Dent J*, vol. 19, p. 13, 1937.

[8] G. Holan, E. Eidelman, and A. B. Fuks, "Long-term evaluation of pulpotomy in primary molars using mineral trioxide aggregate or formocresol," *Pediatr Dent*, vol. 27, no. 2, pp. 129–136, 2005.

[9] R. Vij, J. A. Coll, P. Shelton, and N. S. Farooq, "Caries control and other variables associated with the success of primary molar vital pulp therapy," *Pediatr Dent*, vol. 26, no. 3, pp. 214–220, 2004.

[10] P. L. Judd and D. J. Kenny, "Formocresol concerns. A review.," *J Can Dent Assoc*, vol. 53, no. 5, pp. 401–404, 1987.
[11] B. Ben Lewis and S. B. Chestner, "Formaldehyde in dentistry: a review of mutagenic and carcinogenic potential," *The Journal of the American Dental Association*, vol. 103, no. 3, pp. 429–434, 1981.
[12] H. W. Sun, R. J. Feigal, and H. H. Messer, "Cytotoxicity of glutaraldehyde and formaldehyde in relation to time of exposure and concentration," *Pediatr Dent*, vol. 12, no. 5, pp. 303–307, 1990.
[13] I. RöLLING and A. Thylstrup, "A 3-year clinical follow-up study of pulpotomized primary molars treated with the formocresol technique," *Eur J Oral Sci*, vol. 83, no. 2, pp. 47–53, 1975.
[14] A. Haq, P. I. Lobo, M. Al-Tufail, N. R. Rama, and S. T. Al-Sedairy, "Immunomodulatory effect of Nigella sativa proteins fractionated by ion exchange chromatography," *Int J Immunopharmacol*, vol. 21, no. 4, pp. 283–295, 1999.
[15] B. Sogut, İ. Çelik, and Y. Tuluce, "The effects of diet supplemented with the black Cumin (Nigella sativa L.) upon immune potential and antioxidant marker enzymes and lipid peroxidation in broiler chicks," *Journal of Animal and Veterinary Advances*, vol. 7, no. 10, 2008.
[16] M. B. Mensah, J. A. M. Awudza, and P. O'Brien, "Castor oil: A suitable green source of capping agent for nanoparticle syntheses and facile surface functionalization," *R Soc Open Sci*, vol. 5, no. 8, p. 180824, 2018.
[17] A. Thomas, B. Matthäus, and H. Fiebig, "Fats and fatty oils," *Ullmann's encyclopedia of industrial chemistry*, pp. 1–84, 2000.
[18] T. Holm, M. R. Brøgger-Jensen, L. Johnson, and L. Kessel, "Glutathione preservation during storage of rat lenses in optisol-GS and castor oil," *PLoS One*, vol. 8, no. 11, p. e79620, 2013.
[19] M. C. Valera *et al.*, "Effectiveness of castor oil extract on Escherichia coli and its endotoxins in root canals.," *Gen Dent*, vol. 60, no. 4, pp. e204-9, 2012.
[20] H. Yeganeh and P. Hojati-Talemi, "Preparation and properties of novel biodegradable polyurethane networks based on castor oil and poly (ethylene glycol)," *Polym Degrad Stab*, vol. 92, no. 3, pp. 480–489, 2007.
[21] A. B. Fuks, E. Eidelman, P. Cleaton-Jones, and Y. Michaeli, "Pulp response to ferric sulfate, diluted formocresol and IRM in pulpotomized primary baboon teeth.," *ASDC J Dent Child*, vol. 64, no. 4, pp. 254–259, 1997.
[22] S. M. Mahfouz and O. M. Wahba, "Comparative Evaluation of Pulpal Response to Tri-antibiotic Paste and Allium Sativum with Formacresol as Pulpotomy Medication in Primary Teeth: An in vivo Study," *Egypt Dent J*, vol. 65, no. 4-October (Orthodontics, Pediatric & Preventive Dentistry), pp. 3131–3142, 2019.
[23] A. B. Fuks, "Current concepts in vital primary pulp therapy," *Eur J Paediatr Dent*, vol. 3, pp. 115–120, 2002.
[24] D. Markovic, V. Zivojinovic, and M. Vucetic, "Evaluation of three pulpotomy medicaments in primary teeth," *Eur J Paediatr Dent*, vol. 6, no. 3, p. 133, 2005.
[25] A. B. Fuks and E. Eidelman, "Pulp therapy in the primary dentition.," *Curr Opin Dent*, vol. 1, no. 5, pp. 556–563, 1991.
[26] R. Menezes, C. M. Bramante, A. Letra, V. G. G. Carvalho, and R. B. Garcia, "Histologic evaluation of pulpotomies in dog using two types of mineral trioxide aggregate and regular and white Portland cements as wound dressings," *Oral surgery, oral medicine, oral pathology, oral radiology, and endodontology*, vol. 98, no. 3, pp. 376–379, 2004.
[27] D. S. de Albuquerque, L. F. Gominho, and R. A. dos Santos, "Histologic evaluation of pulpotomy performed with ethyl-cyanoacrylate and calcium hydroxide," *Braz Oral Res*, vol. 20, pp. 226–230, 2006.
[28] O. El-Meligy, M. Abdalla, S. El-Baraway, M. El-Tekya, and J. Dean, "Histological evaluation of electrosurgery and formocresol pulpotomy techniques in primary teeth in dogs," *Journal of Clinical Pediatric Dentistry*, vol. 26, no. 1, pp. 81–85, 2002.
[29] L. Toomarian, R. Fekrazad, D. Sharifi, M. Baghaei, H. Rahimi, and B. Eslami, "Histopathological evaluation of pulpotomy with Er, Cr: YSGG laser vs formocresol," *Lasers Med Sci*, vol. 23, pp. 443–450, 2008.
[30] B. L. Hart, "The evolution of herbal medicine: behavioural perspectives," *Anim Behav*, vol. 70, no. 5, pp. 975–989, 2005.
[31] P. Kakarla, J. S. S. Avula, G. M. Mellela, S. Bandi, and S. Anche, "Dental pulp response to collagen and pulpotec cement as pulpotomy agents in primary dentition: A histological study," *Journal of Conservative Dentistry*, vol. 16, no. 5, p. 434, 2013.
[32] S. Sivadas, A. Rao, S. Natarajan, R. Shenoy, and S. B. Srikrishna, "Pulpal response to ferric sulfate and diode laser when used as pulpotomy agent: an in vivo study," *J Clin Diagn Res*, vol. 11, no. 6, p. ZC87, 2017.
[33] N. Ratnakumari and B. Thomas, "A Histopathological comparison of pulpal response to Chitra-CPC and formocresol used as pulpotomy agents in primary teeth: a clinical trial," *Int J Clin Pediatr Dent*, vol. 5, no. 1, p. 6, 2012.
[34] S. Seltzer, I. B. Bender, and I. J. Kaufman, "Histologic changes in dental pulps of dogs and monkeys following application of pressure, drugs, and microorganisms on prepared cavities," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 14, no. 3, pp. 327–346, 1961.
[35] R. P. Schleimer, H. S. Freeland, S. P. Peters, K. E. Brown, and Cp. Derse, "An assessment of the effects of glucocorticoids on degranulation, chemotaxis, binding to vascular endothelium and formation of leukotriene B4 by purified human neutrophils.," *Journal of Pharmacology and Experimental Therapeutics*, vol. 250, no. 2, pp. 598–605, 1989.
[36] D. M. Ranly, "Pulpotomy therapy in primary teeth: new modalities for old rationales," *Pediatr Dent*, vol. 16, p. 403, 1994.
[37] O. M. Omar, N. M. Khattab, and D. S. Khater, "Nigella sativa oil as a pulp medicament for pulpotomized teeth: A histopathological evaluation," *Journal of Clinical Pediatric Dentistry*, vol. 36, no. 4, pp. 335–341, 2012.
[38] E. T. SB, E. D. Norhan A, and A. Zobah, "Comparative evaluation of jojoba oil versus formocresol pulpotomy in primary molars-in vitro study [histopathological and immunohistochemical]," 2009.
[39] R. M. Block, R. D. Lewis, J. Hirsch, J. Coffey, and K. Langeland, "Systemic distribution of [14C]-labeled paraformaldehyde incorporated within formocresol following pulpotomies in dogs," *J Endod*, vol. 9, no. 5, pp. 176–189, 1983.

[40] P. Cleaton-Jones, M. Duggal, R. Parak, S. William, and S. Setze, "Ferric sulphate and formocresol pulpotomies in baboon primary molars: histological responses," *Eur J Paediatr Dent*, vol. 3, pp. 121–125, 2002.
[41] S. L. Robbins, R. S. Cotran, V. Kumar, A. K. Abbas, N. Fausto, and J. C. Aster, "Robbins and Cotran pathologic basis of disease," in *Robbins and Cotran pathologic basis of disease*, 2010, p. 1450.
[42] S. Gonna, E. Deraz, N. Ghoname, A. Kabbash, and A. Yagi, "Acemannan and formocresol pulpotomies in primary teeth: a comparative histopathological study," *J Gastroenterol Hepatol Res*, vol. 6, no. 4, pp. 2386–2391, 2017.
[43] O. El-Meligy, M. Abdalla, S. El-Baraway, M. El-Tekya, and J. Dean, "Histological evaluation of electrosurgery and formocresol pulpotomy techniques in primary teeth in dogs," *Journal of Clinical Pediatric Dentistry*, vol. 26, no. 1, pp. 81–85, 2002.
[44] B. O. Magnusson, "Therapeutic pulpotomies in primary molars with the formocresol technique: A clinical and histological follow-up," *Acta Odontol Scand*, vol. 36, no. 3, pp. 157–165, 1978.
[45] L. Toomarian, R. Fekrazad, D. Sharifi, M. Baghaei, H. Rahimi, and B. Eslami, "Histopathological evaluation of pulpotomy with Er, Cr: YSGG laser vs formocresol," *Lasers Med Sci*, vol. 23, pp. 443–450, 2008.
[46] D. Srinivasan and M. Jayanthi, "Comparative evaluation of formocresol and mineral trioxide aggregate as pulpotomy agents in deciduous teeth," *Indian Journal of Dental Research*, vol. 22, no. 3, p. 385, 2011.
[47] C. F. Cox, C. L. Keall, H. J. Keall, E. Ostro, and G. Bergenholtz, "Biocompatibility of surface-sealed dental materials against exposed pulps," *J Prosthet Dent*, vol. 57, no. 1, pp. 1–8, 1987.
[48] R. Haghgoo and F. Abbasi, "A histopathological comparison of pulpotomy with sodium hypochlorite and formocresol," 2012.
[49] F. Moazzami, Y. Ghahramani, A. M. Tamaddon, A. D. Nazhavani, and A. Adl, "A histological comparison of a new pulp capping material and mineral trioxide aggregate in rat molars," *Iran Endod J*, vol. 9, no. 1, p. 50, 2014.
[50] T. M. Beltagy, N. A.-H. Ghoname, and D. A. Teiama, "Histopathological Pulp Response to Platelet-Rich Plasma Pulpotomy in Primary teeth," *Egypt Dent J*, vol. 64, no. 3-July (Orthodontics, Pediatric & Preventive Dentistry), pp. 1961–1972, 2018.
[51] E. N. Mohamed, O. S. El-Shall, M. H. Mostafa, and N. E. B. Ahmed, "Effect of Propolis and Castor Oil Cement as Pulpotomy Materials on the Properties and Osteogenic Differentiation of Stem Cells Isolated from Human Exfoliated Deciduous Teeth (SHED)," *Al-Azhar Dental Journal for Girls*, vol. 9, no. 2, pp. 331–339, 2022.

AUTHORS

First Author – **Wafaa Yahia Alghonemy**,
1- Department of Basic Medical and Dental Sciences, Faculty of Dentistry, Zarqa University, Zarqa, 13132, The Hashemite Kingdom of Jordan. 2- Department of Oral Biology, Faculty of Dentistry, Tanta University, Tanta, Egypt.
Second Author – **Shimaa M. Hadwa**, Department of Pediatric Dentistry, Oral Health and Preventive Dentistry, Faculty of Dentistry, Tanta University, Egypt

Correspondence Author –**Wafaa Yahia Alghonemy.**
ORCID: https://orcid.org/0000-0002-0452-2565.
. **Postal address:** PO Box 2000, Zarqa, 13110 Jordan.

Table (7): Distribution of the experimental groups by degree of pulp inflammation at different periods of follow-up:

Degree of pulp inflammation	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					**0.245**
None	0	0.0	2	20.0	
Mild	0	0.0	2	20.0	
Moderate	6	60.0	4	40.0	
Severe	4	40.0	2	20.0	
At four weeks					**0.023***
Mild	0	0.0	3	30.0	
Moderate	2	20.0	5	50.0	
Severe	4	40.0	2	20.0	
Necrosis	4	40.0	0	0.0	
Z	2.828		1.732		
p	0.005*		0.083		
At 12 weeks					**0.001***
Mild	0	0.0	1	10.0	
Moderate	0	0.0	5	50.0	
Severe	2	20.0	4	40.0	
Necrosis	5	50.0	0	0.0	
Abscess	3	30.0	0	0.0	
Z	2.919		2.333		
p	**04*00.**		**0.020***		

*Significant

Table (8): Distribution of the experimental groups by presence of Dentine Bridge at different periods of follow-up:

Dentine bridge	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					**1.000**
Absent	10	100.0	10	100.0	
Present	0	0.0	0	0.0	
At four weeks					**0.474**
Absent	10	100.0	8	80	
Present	0	0.0	2	20	
Z	0.000		1.414		
p	1.000		0.157		
At 12 weeks					**0.087**
Absent	10	100.0	6	60.0	
Present	0	0.0	4	40.0	
Z	0.000		.0002		
p	**1.000**		**46*0.0**		

*Significant

Table (9): Distribution of the experimental groups by degree of pulpal vascularity at different periods of follow-up:

Pulpal vascularity	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					0.167
Mild	7	70.0	3	30.0	
Moderate	3	30.0	5	50.0	
Severe	0	0.0	2	20.0	
At four weeks					0.046*
Mild	5	50.0	1	10.0	
Moderate	5	50.0	5	50.0	
Severe	0	0.0	4	40.0	
Z	1.414		2.000		
p	0.157		0.046*		
At 12 weeks					0.011*
Mild	5	50.0	0	0.0	
Moderate	5	50.0	6	60.0	
Severe	0	0.0	4	40.0	
Z	1.414		2.236		
p	**0.157**		**0.025***		

*Significant

Table (10): Distribution of the experimental groups by degree of pulp fibrosis at different periods of follow-up:

Degree of pulp fibrosis	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					0.001*
Mild	0	0.0	8	80.0	
Moderate	6	60.0	2	20.0	
sever	4	40.0	0	0.0	
At four weeks					0.001*
Mild	0	0.0	3	30.0	
Moderate	2	20.0	7	70.0	
sever	8	80.0	0	0.0	
Z	2.000		2.236		
p	0.046*		0.025*		
At 12 weeks					0.001*
Mild	0	0.0	6	60.0	
Moderate	3	30.0	4	40.0	
sever	7	70.0	0	0.0	
Z	1.732		1.414		
p	0.083		0.157		

Comparison of four weeks versus 12 weeks in the Formacresol group: Z= 1.000, p= 0.317
Comparison of four weeks versus 12 weeks in the Castor oil group: Z= 1.732, p= 0.083
*Significant

Table (11): Distribution of the experimental groups by quality of odontoblastic layer different periods of follow-up:

Quality of odontoblastic layer	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					**0.020***
Organized	3	30.0	9	90.0	
Non-organized	7	70.0	1	10.0	
At four weeks					**0.070**
Organized	2	20.0	7	70.0	
Non-organized	8	80.0	3	30.0	
Z	1.000		1.414		
p	0.317		0.157		
At 12 weeks					**0.033***
Organized	0	0.0	5	50.0	
Non-organized	10	100.0	5	50.0	
Z	1.732		2.000		
p	**0.083**		***0460.**		

*Significant

Table (12): Distribution of the experimental groups by presence of pulp stone at different periods of follow-up:

Presence of pulp stone	Formacresol		Castor oil		p
	n	%	n	%	
At two weeks					**0.474**
Absent	8	80.0	10	100.0	
Present	2	20.0	0	0.0	
At four weeks					**0.303**
Absent	6	60	9	90.0	
Present	4	40.0	1	10.0	
Z	1.414		1.000		
p	0.157		0.317		
At 12 weeks					**0.350**
Absent	5	50.0	8	80.0	
Present	5	50.0	2	20.0	
Z	1.732		1.414		
p	**0.083**		**0.157**		

*Significant

Figures

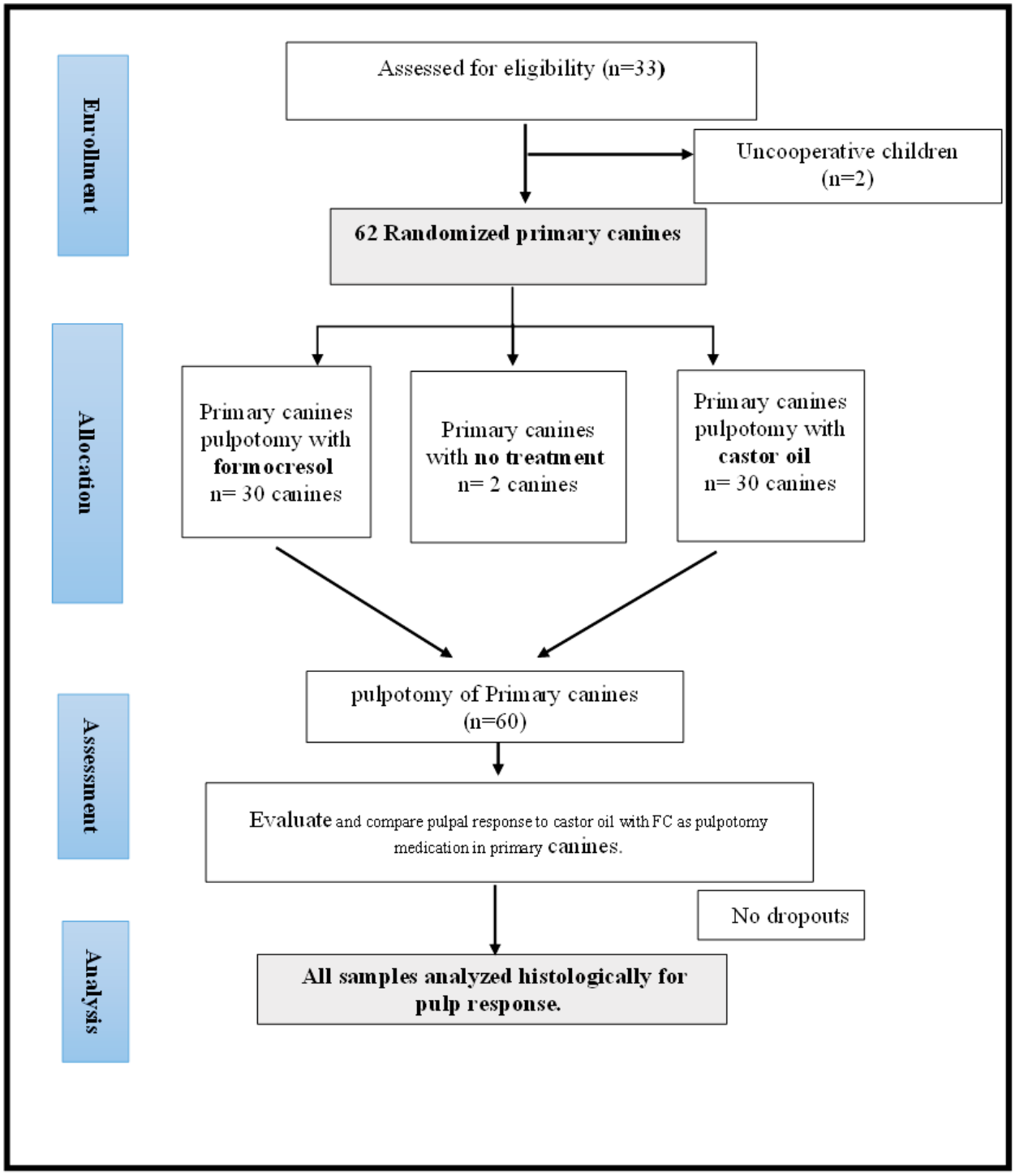

Fig. (1): Flowchart explaining the child patient's randomization and the variables assessed throughout the clinical study.

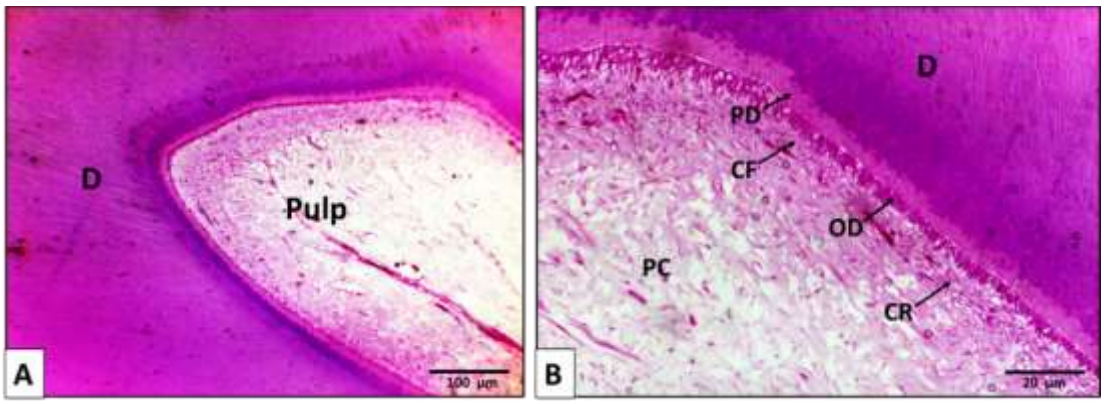

Fig. (2): (**A&B**) light microscopic image of a sound tooth with normal pulp tissue depicted normal pulp architecture, intact odontoblastic layer, and delicate connective tissue consisting of pulp cells, collagen fibers, and blood vessels. (D) Dentin, (OD) Odontoblasts, (PD) predentin, (PC) pulp core, (CF) cell-free zone, (CR) cell-rich zone (H&E stain. Orig. mag. AX100, BX400).

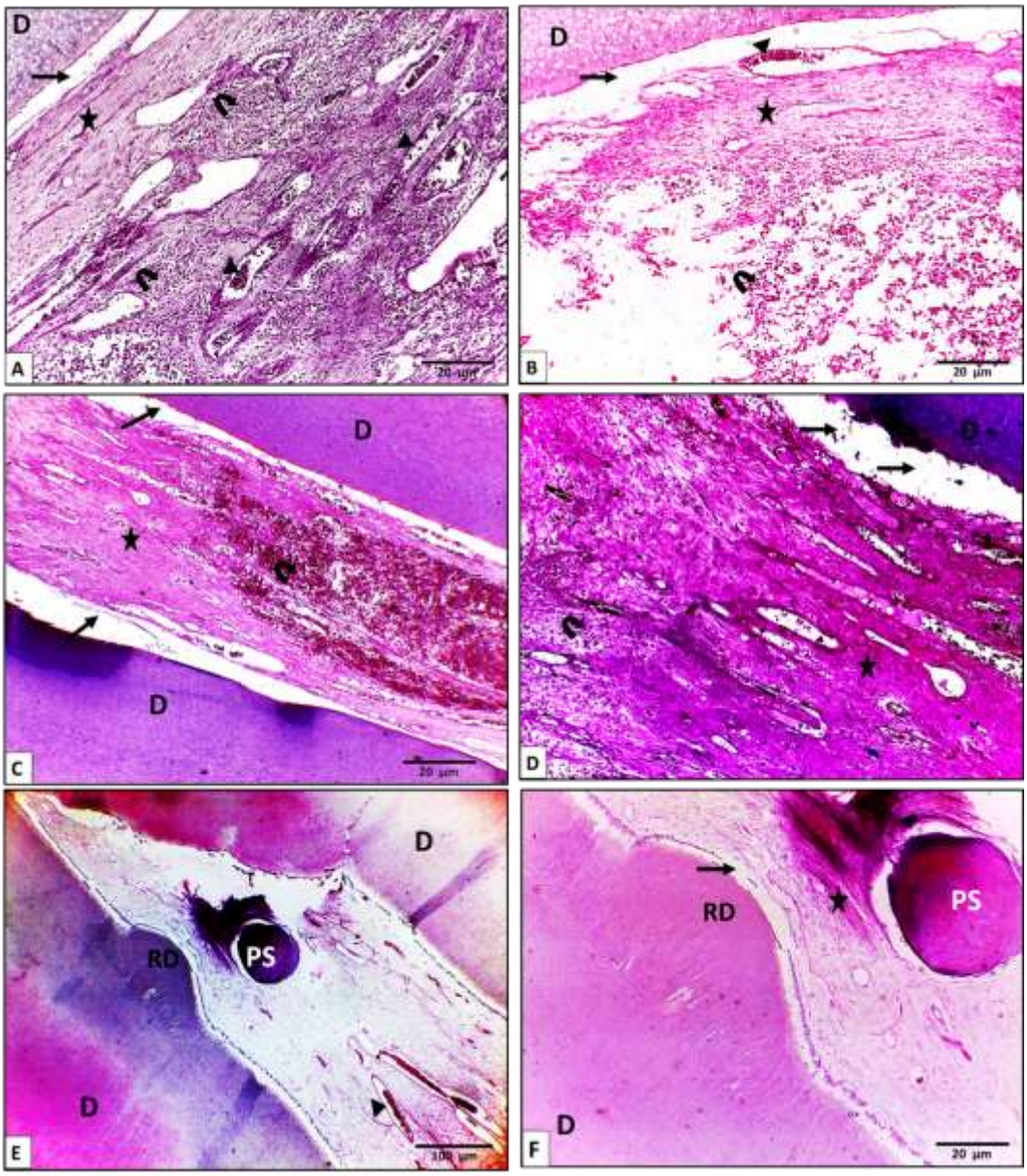

Fig. (3): (**A-F**) light microscopic image of teeth cases treated with FC (**FC group**) at the three intervals (two (A), four (B&C), twelve (D&E&F) weeks) in which pulp tissue depicted pulpal inflammation (curved arrow) that appears sever at A, B, and C. pulp fibrosis (star) that exists nearly at all images. Pulpal vascularity (arrowheads) that exists in all images with thrombi formation at C. Loss of odontoblasts with areas of pulp necrosis (straight arrow) that exists in nearly all images and appears large and severe at D. A small area of reparative dentin (RD) formation bridging the pulp at E and F. Small solitary pulp stone (PS) at E and F. Dentin (D) (H&E stain. Orig. mag. A-DX400, EX100, FX400).

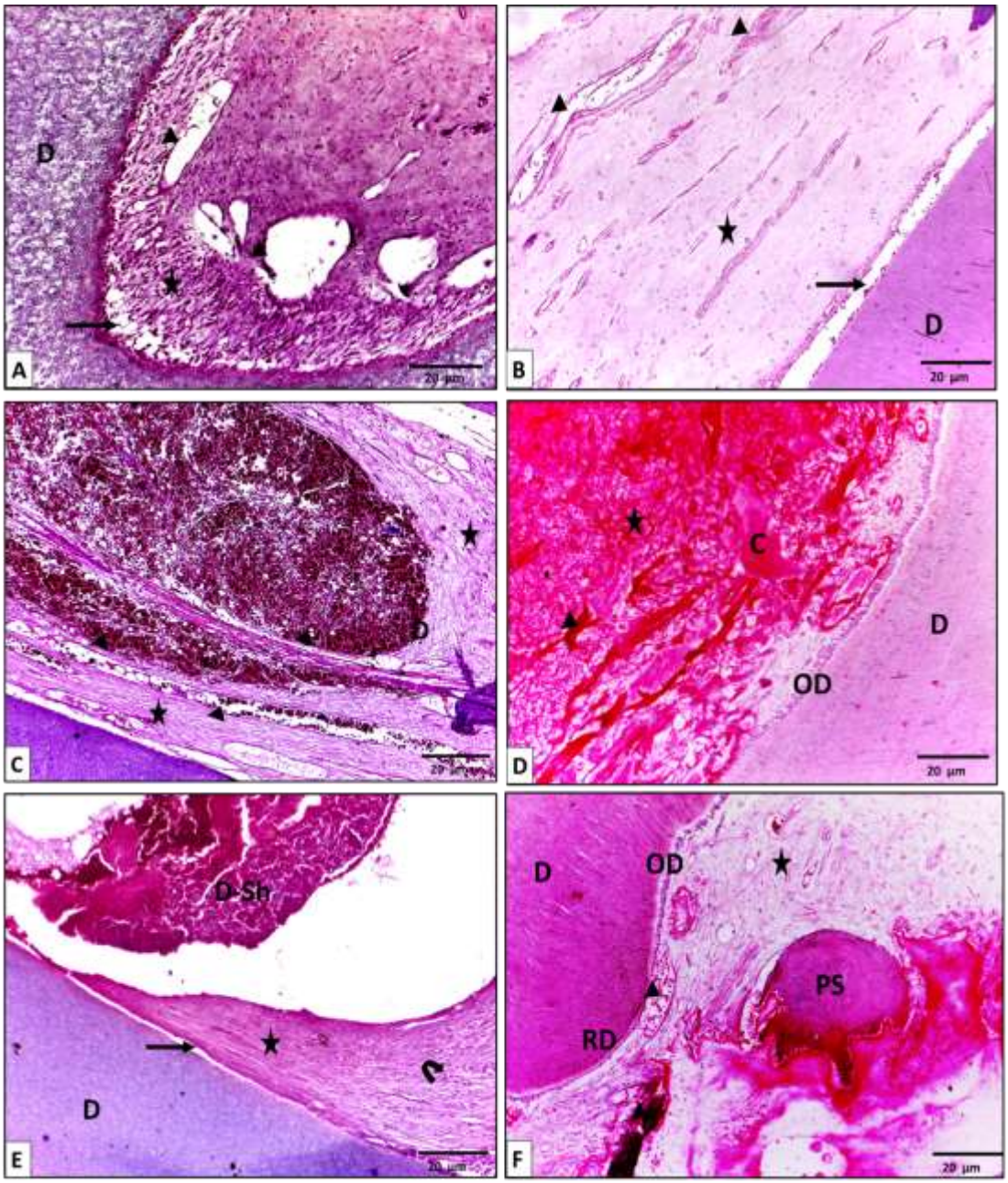

Fig. (4): (**A-F**) light microscopic image of teeth treated with castor oil (**castor oil group**) at the three intervals (two (A), four (B&C), twelve (D&E&F) weeks) in which pulp tissue depicted almost normal pulp architecture at (A). Pulp fibrosis (star) in all images appears with a large amount that entirely obstructs the exposure site. Pulpal inflammation (curved arrow) at (E). Pulpal vascularity (arrowheads) in almost all the images appears to occupy a large area at (C) with the formation of blood thrombi. Loss odontoblasts (straight arrow) at small areas of A, B, and E. large area of the pulp shows dentin ships (D-Sh) formation at E. Large solitary pulp stone (PS) appears as well as reparative dentin (RD) formation bridging the pulp at F, intact odontoblastic layer (OD) appears at A, D, and F. dentin (D). (H&E stain. Orig. mag. A-FX400).

Graphical Abstract