



SATHYABAMA INSTITUTE OF SCIENCE & TECHNOLOGY

(Deemed to be University)

Jeppiar Nagar, Chennai



EFFECT OF BIODENTINE, EVERSTICK POST AND SMART DENTIN REPLACEMENT ON FRACTURE RESISTANCE OF SIMULATED IMMATURE HUMAN MAXILLARY CENTRAL INCISOR TEETH WITH BIODENTINE APICAL PLUG - AN IN VITRO STUDY

By
Dr. R. BRINDHA JAIN

Dissertation submitted to
Sathyabama Institute of Science & Technology
(Deemed to be University) Chennai, Tamil Nadu.

In partial fulfillment of the requirements for the degree of

Master of Dental Surgery
in the speciality of

CONSERVATIVE DENTISTRY AND ENDODONTICS

under the guidance of

Prof. Dr. R. KURINJI AMALAVATHY, M.D.S

Head of the Department

Department of Conservative Dentistry and Endodontics

Sathyabama Dental College and Hospital

Jeppiar Nagar, Chennai-600119, Tamil Nadu.

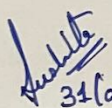
2019 – 2022

CERTIFICATE BY THE GUIDE

This is to certify that this dissertation titled **EFFECT OF BIODENTINE, EVERSTICK POST AND SMART DENTIN REPLACEMENT ON FRACTURE RESISTANCE OF SIMULATED IMMATURE HUMAN MAXILLARY CENTRAL INCISOR TEETH WITH BIODENTINE APICAL PLUG - AN IN VITRO STUDY** is the bonafide record of work done by **Dr. R. BRINDHA JAIN**, under our guidance during her postgraduate study between 2019-2022.

A Dissertation submitted to the **Sathyabama Institute of Science & Technology (Deemed to be University)** Chennai, Tamil Nadu, in partial fulfillment of the requirements for the degree of **Master of Dental Surgery** in the speciality of **Conservative Dentistry and Endodontics**.

CO-GUIDE


31/03/2022

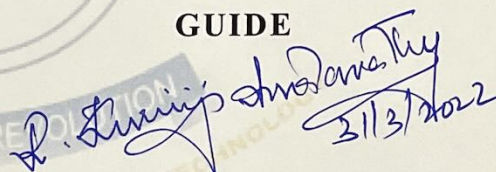
Dr. SUSHMITA SHIVANNA M.D.S

Reader

Department of Conservative Dentistry
and Endodontics

Sathyabama Dental College &
Hospital, Chennai.

GUIDE


31/3/2022

Dr. R. KURINJI AMALAVATHY, M.D.S

Professor and Head of the Department

Department of Conservative Dentistry
and Endodontics

Sathyabama Dental College &
Hospital, Chennai.

Date: 31/3/2022

Place: Chennai

**ENDORSEMENT BY THE HEAD OF THE
INSTITUTION AND HEAD OF THE DEPARTMENT**

This is to certify that the dissertation titled **EFFECT OF BIODENTINE, EVERSTICK POST AND SMART DENTIN REPLACEMENT ON FRACTURE RESISTANCE OF SIMULATED IMMATURE HUMAN MAXILLARY CENTRAL INCISOR TEETH WITH BIODENTINE APICAL PLUG - AN IN VITRO STUDY** is the bonafide record of work done by **Dr. R. BRINDHA JAIN**, under the guidance of **Dr. R. KURINJI AMALAVATHY, M.D.S** Professor and Head, Department of Conservative Dentistry and Endodontics, Sathyabama Dental College & Hospital, Chennai, Tamil Nadu.

Head of the Department

Dr. Kurinji Amalavathy
31/3/2022

Dr. R. KURINJI AMALAVATHY M.D.S

Professor and Head of the Department

Department of Conservative Dentistry and
Endodontics
Sathyabama Dental College &
Hospital, Chennai.

DEAN

Dr. Thayumanavan.B
31/3/22

Dr. Thayumanavan.B M.D.S

Dean

Sathyabama Dental College &
Hospital, Chennai.

Date: 31/3/2022.

Place: Chennai

DECLARATION BY THE CANDIDATE

I hereby declare that **Sathyabama Institute of Science & Technology**, Chennai, shall have the rights to preserve, use and disseminate this dissertation titled **EFFECT OF BIODENTINE, EVERSTICK POST AND SMART DENTIN REPLACEMENT ON FRACTURE RESISTANCE OF SIMULATED IMMATURE HUMAN MAXILLARY CENTRAL INCISOR TEETH WITH BIODENTINE APICAL PLUG - AN IN VITRO STUDY** as print or electronic format for academic/ research purposes.



Bindha J
Signature of the candidate

Date: 31/3/2022.

Place: Chennai



SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600119.



EC/NEW/INST/2020/1397

6th October 2021

Ref: 183/IRB-IBSEC/SIST Dated 30th September 2021

Dr. A. Wilson Aruni, PhD, FAMPV
Pro Vice chancellor,
Chair Person, Institutional
Biosafety & Ethical Committee
(IBEC), SIST

Dr. B. Thayumanavan, MDS
Dean, Sathyabama Dental College
Secretary & Convener
Institutional Review Board &
Institutional Biosafety & Ethical
Committee (IBEC), SIST

To,

Dr. Brindha Jain
Post Graduate
Department of Conservative Dentistry & Endodontics
Sathyabama Dental College & Hospital
Chennai -119

This is to inform you that the Institutional Bio-Safety & Ethical Committee has approved your study proposal entitled "**Effect of Biodentine, Everstick post and Smart Dentin Replacement on fracture resistance of simulated immature human maxillary central incisor teeth with Biodentine apical plug – An Invitro study**", based on the presentation of the proposal made and recommendations of the Institutional Bio-Safety & Ethical Committee meeting held on 30th September 2021.

The validity of the Ethical clearance is for one year and you are expected to submit six-month progress and the final report of the study to IBHSEC/IRB

Dr. Thayumanavan
Secretary & Convener
IBEC, SIST

Dr. A. Wilson Aruni
Deputy Chair Person
IBEC, SIST

DECLARATION OF PLAGIARISM CHECK

From,

Dr. R. BRINDHA JAIN,

III-year Post Graduate Student,

Department of Conservative Dentistry and Endodontics,

Sathyabama Dental College and Hospital,

Chennai - 600119.

To,

The Head of the Department,

Department of Conservative Dentistry and Endodontics,

Sathyabama Dental College and Hospital,

Chennai.

SUB: Declaration of plagiarism check of my dissertation titled “Effect of Biodentine, Everstick post and Smart Dentin Replacement on fracture resistance of simulated immature human maxillary central incisor teeth with Biodentine apical plug – An in vitro study” to be submitted to the “Sathyabama Institute of Science and Technology”- 2022.

I hereby declare that I have checked my dissertation for plagiarism using Grammarly Software (reference no: 50492668) - plagiarism checker software on 21-03-2022. The unique content was 81%, and the plagiarized content was 19%. The plagiarized content corresponds to definitions and terminologies that have to be quoted and are duly cited. Screenshots of the plagiarism report of individual sections has been attached in Appendix C

Yours sincerely,
Dr. R. BRINDHA JAIN

PLAGIARISM REPORT

Introduction	4%
Review of Literature	9%
Materials and Methods	1%
Results and Discussion	2%
Summary	3%
Conclusion	0%

ACKNOWLEDGEMENT

“At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us”.

- Albert Schweitzer

*I bow in gratitude to the **Almighty god**, who has sustained me through these best and toughest years of my life and also for providing me with immense strength and willpower to complete this work. I am very thankful to the Almighty for giving me courage and patience for keeping my ship sailing and not failing me in my journey.*

*Words can never be enough to express how grateful I am to those incredible people in my life who have made this dissertation possible. First and foremost, I take this opportunity to sincerely thank my respected Professor, **Dr. R. Kurinji Amalavathy**, M.D.S, Professor and Head of the Department of Conservative Dentistry & Endodontics, for her guidance. I thank her from the bottom of my heart for her time, patience and unyielding faith in me. I could not have imagined having a better advisor and mentor for my study.*

Without her, this thesis would not have been completed. Her observations and comments helped me to establish the overall direction of my research and to move forward with the investigations. I thank her for her tireless pursuit, immense support, encouragement and keen surveillance for the minute details throughout this dissertation.

*It is with great honour and pride that I convey my deep sense of gratitude to my respected teacher and my Co-guide, **Dr. Sushmita Shivanna**, M.D.S, Reader, Department of Conservative Dentistry & Endodontics, for her valuable guidance, suggestions, constant support, encouragement to strive for perfection and whole hearted willingness in sharing her vast experience throughout my postgraduate course.*

*I extend my deepest gratitude to my teacher **Dr. Hasini V.R**, M.D.S, Senior lecturer, Department of Conservative Dentistry & Endodontics for her continuous help and guidance from the very beginning. She has always extended her ever helping hand during difficult times, and has always supported me for the fulfillment of my research work.*

*I would also like to thank **Dr. Jayalakshmi, M.D.S,** Department of Conservative Dentistry & Endodontics, White Lab, Saveetha Dental College and Hospital, Chennai, for her guidance for the analytical portion of my study.*

*I would like to express my thanks to **Dr. Thayumanavan. B,** M.D.S, Dean, Sathyabama Dental College and Hospital, for giving me the freedom to utilize college facilities.*

*I would also like to express my sincere and heartfelt gratitude to **Dr. Megavarnan. R** for his valuable suggestions and guidance.*

*My sincere and respectful thanks to **Dr. Murali Sivakumar,** M.D.S Reader, Department of Conservative Dentistry & Endodontics and **Dr. Sathyanarayanan,** M.D.S, Reader, Department of Conservative Dentistry & Endodontics, Sathyabama Dental College and Hospital, Chennai, for their constant support and guidance. My sincere thanks to **Dr. Purushotham. M, Dr. Arun D.R, Dr. Mirnalini.S, Dr. Hari Krishna Reddy.K, Dr. Hrudi Sundar Sahoo, and Dr. Aravinthan. S** for their guidance throughout the course.*

*I thank **Dr. Vennila Anand** for helping me with the statistical analysis for my study.*

*It gives me immense pleasure to thank my batchmates and also my friends, **Dr. Kalpana.R and Dr. Deepika.R**, who have been with me throughout my postgraduate life, guiding and encouraging me during both the happy and hard moments. They have made this journey an easier and memorable one.*

*I would also acknowledge my seniors **Dr. Akshaya. N, Dr. Aravinthan. S, Dr. Dhanireddy.V Padmaja**, for their incredible help and advice throughout my course of study. I thank my juniors, **Dr. Adisree, Dr. Jayakrishnan, Dr. Angel Mariyam John, Dr. Anjana Mathew, Dr. Pavithra. P.S, Dr. Neela Shiva Tarun**, for their valuable support.*

*Last but not least, I would like to express my love and gratitude to my parents, **Mr. Rajaian. C& Mrs. Brigit Renjini.I**, my husband, **Mr. Jeba Robinson. A**, my brother, **Jerin Ahino. R** and my parents-in-law, **Mr.Alex Vincent Raj and Mrs. Vimala**, for encouraging me to follow my dreams*

with their everlasting support and love. I thank them for their faith in me and for allowing me to be as ambitious as I wanted even when my desires went beyond boundaries.

CONTENTS

S.NO	TITLE	PAGE NO.
1.	INTRODUCTION	1
2.	AIM AND OBJECTIVES	7
3.	REVIEW OF LITERATURE	9
4.	MATERIALS AND METHODS	59
5.	STATISTICAL ANALYSIS	80
6.	RESULTS	81
7.	DISCUSSION	87
8.	SUMMARY	97
9.	CONCLUSION	99
10.	BIBLIOGRAPHY	100
11.	APPENDIX	116

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
1.	Normality distribution	81
2.	Test of Homogeneity of variance	81
3.	Mean load to fracture and standard deviation of all groups	83
4.	Multiple comparisons using post-hoc Tukey test	83
5.	Overall frequency for mode of fracture	85
6.	Cross-tabulation between Group and Type of fracture using Chi-square test	85

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1	Armamentarium	61
2	Extracted teeth samples	65
3	Samples stored in 0. 1% thymol solution	66
4	Stereomicroscope (LEICA M205A)	66
5A & B	Stereomicroscopic Evaluation	66
6	Digital radiographic examination in Bucco- Lingual direction	67
7	Digital radiographic examination in Mesio- Distal direction	67
8	Included samples after exclusion criteria	68
9a	Standardization of crown length	68
9b	Standardization of root length	68
9c	Diamond disc used to section the crown and root length	68
10	Access cavity preparation	70
11a	Preparation with Peeso reamers	70
11b	Peeso reamers passed 1mm beyond apex	70
11c	Simulation of teeth using Number 3 Implant drill	70
12	Digital radiograph in mesio – distal direction	70
13	Digital radiograph confirming Biodentine apical plugs	70
14a	Amalgamator	72

14b	Biodentine	72
15	Condensation using Buchanan Pluggers	72
16	Digital radiograph – Biodentine group	73
17a	Placement of SDR material	74
17b	Light curing done for 20 seconds	74
18	Digital radiograph – SDR group	74
19a	Individually formed fiber post	75
19b	Application of stick resin	75
19c	Light curing done	75
19d	Digital radiograph - Everstick post group	75
20a	Teeth wrapped with aluminium foil	76
20b	Cylindrical moulds with acrylic resin – aluminium foil removal	76
20c	Insertion of light body impression material	77
20d	Tooth repositioned in socket	77
21	Instron E3000 UTM Electropuls	78
22	Custom made jig	78
23	130 ⁰ angle to the long axis of tooth	78
24	Mode of fracture	86

LIST OF GRAPHS

GRAPH NO	TITLE	PAGE NO
1.	Mean of maximum load to fracture among groups	84

LIST OF BOXES

BOX NO	TITLE	PAGE NO
1	Group assignment – Randomization method	70
2	Mode of fracture	78

INTRODUCTION

Traumatic dental injuries are a common cause of tooth damage and loss in the young and adolescent age group. Injuries to permanent teeth often result from falls, road traffic accidents, violent acts, and participation in various sports.⁽¹⁾ Previous studies have shown that the maxillary anterior teeth are the most frequently involved in dental impact injuries.^(2–5) When these injuries occur in the young and adolescent age group, it may lead to loss of pulp vitality and cessation of root development, resulting in an open apex and short roots with thin and weak root canal walls. These features of immature teeth further complicate root canal instrumentation and achieving a proper apical stop.⁽⁶⁾ In clinical practice, the management of teeth with incomplete closure of the apex poses both endodontic and restorative challenges.

Different techniques are available in treatment of immature pulpless teeth, including Apexification and Regenerative endodontic treatment. According to the American Association of Endodontists, Apexification is defined as a method to induce a calcified barrier in a root with an open apex.⁽⁷⁾ Conventionally, multi-visit calcium hydroxide apexification was the treatment of choice for immature pulpless teeth.^(8,9) However, with an extended treatment period and prolonged exposure to calcium hydroxide, the incidence of 28–77% cervical fracture depending on the stage of root development has

been reported by Cvek et al.⁽¹⁰⁾ Although it was commonly believed that prolonged use of calcium hydroxide-based combinations weaken the root structure⁽¹¹⁾, the cause of fracture may be more related to the thin and fragile walls of these teeth, particularly at the cervical third which is left vulnerable throughout the period of treatment.⁽¹²⁾

The single-visit apexification techniques differ from the multi-visit techniques only in that they help establish an apical stop enabling the root canal to be filled immediately. An attempt is not made for inducing a natural apical stop; instead, an artificial stop is created.⁽⁸⁾ The 'apical barrier technique' that creates artificial apical stops, also known as 'apical plugs,' with the help of bioactive materials such as MTA, reduced number of visits, shortened treatment times, producing favourable healing.⁽⁸⁾ Apical plugs help to create an artificial barrier & may also reinforce the weak dentin walls in the apical region.⁽⁸⁾

In recent times, regenerative endodontic procedures have received great attention as these biologically based procedures replace damaged pulp tissue with viable tissue, which restores the normal function of the pulp - dentin structure allowing for continued root development with significant gain in root length and dentinal wall width under ideal circumstances. Hence, recommendations have been made that REP's must be the first

treatment of choice for immature pulpless teeth.⁽¹³⁾ But the literature review offers mixed evidence on their success and survival rates are comparable to that of the apical barrier technique.^(14–16) Although these procedures offer promising outcomes with the potential to strengthen the tooth, evidences from clinical studies and systematic review show that the root maturation is variable, and the successful outcomes of increased root thickness is limited to the apical and mid root area with very little to no improvement in the pericervical region.^(17–19) In addition, many patient-related factors such as unpredictability of outcome, long follow-up periods, associated adverse effects, and limited insurance cover make these procedures less popular choice than apical barrier technique.⁽¹⁷⁾

Cervical root fracture continues to remains a problem even after a successful apexification procedure.⁽¹⁰⁾ After apical barrier placement, reinforcement of the immature teeth is an important step to eliminate cervical root fracture as these teeth are more susceptible to external and masticatory forces.⁽²⁰⁾

Many restorative procedures have been attempted to reinforce immature permanent teeth following placement of apical barrier. The remaining segment of the canal space may be restored with bonded resin in shorter roots.⁽²⁰⁾ In longer roots, a layer of gutta-percha or resilon with sealer may be used to obturate the coronal

two-thirds of the root canal space prior to restoring the access cavity with bonded resin.^(21,22) Placement of bonded resin below the cemento-enamel junction may also increase the fracture resistance of the tooth.

Several studies have illustrated the reinforcing effect of various materials like fiber post, resilon, reforpost, composite resin, fiber-reinforced composite resins, bioceramics, etc.^(22–25) But in most tested samples, the failure occurred in the cervical third of the tooth.

Smart Dentin Replacement (SDR) (Dentsply De Trey, Konstanz, Germany) is a bulk-fill flowable base, fluoride-containing, and visibly light-cured radiopaque composite resin material. It has polymerization stress-relieving properties leading to minimizing shrinkage which rectifies the problem of gap formation. Moreover, it can be applied in 4mm increments and has a self-levelling feature that allows proper adaptation.⁽²⁶⁾

The restorative technique known as anatomical post is proposed for the rehabilitation of anterior teeth with extensively compromised root canals to contribute in aspects of both masticatory function and in esthetics.⁽²⁷⁾ Everstick posts (EverStick post™ GC Corporation, Tokyo, Japan) are truly anatomical, custom-made, and individually shaped posts. It adapts to the morphology of

the canal to maximize the adhesive surface and strength in the most critical part of the tooth. It also preserves the tooth because canal preparation is not needed to the same degree as with traditional prefabricated posts. The polymer matrix of an individually formed post consists of a combination of unpolymerized linear and cross-linked phases known as the semi-interpenetrating polymer network (semi- IPN). Unpolymerized fibers are soft and can be easily shaped to fit any root canal. It possess greater bond strength while reducing the risk of microleakage.^(28,29)

Mineral trioxide aggregate (MTA) as a root-end barrier material has been widely recommended for the successful management of a tooth with an open apex.⁽³⁰⁾ A new calcium silicate-based material, Biodentine (Septodont, Saint-Maur-des-fosses, France), has been introduced. Biodentine is a silicate-based bioactive cement introduced with dentine-like mechanical properties and designed as a “dentin replacement” material. This material was formulated to improve several drawbacks associated with earlier calcium silicate cements while enhancing its physical and mechanical properties in clinical applications without negative characteristics.⁽³¹⁾ Biodentine has high compressive strength, reduced setting time (9–12 minutes), less solubility, and better handling characteristics when compared to MTA.⁽³²⁾

To the best of our knowledge, there are no studies comparing ability of Everstick post, Smart Dentin Replacement material, and Biodentine in reinforcing immature teeth with Biodentine apical plug. Therefore, the present study aimed to evaluate and compare the fracture resistance of simulated immature human maxillary central incisor teeth reinforced with Biodentine, Everstick post, and Smart Dentin Replacement material.

AIM AND OBJECTIVES

AIM:

The aim of the present study was to evaluate and compare the fracture resistance of simulated immature human maxillary central incisor teeth with Biodentine apical plug restored with Biodentine, Everstick post, and Smart Dentin Replacement.

OBJECTIVE:

The objective of this study were

- ❖ To measure the fracture resistance of simulated immature human maxillary central incisor teeth restored with Biodentine, Everstick post, and Smart Dentin Replacement after Biodentine apical plugs using Instron Universal Testing Machine.
- ❖ To determine fracture mode using a Stereomicroscope and employing the modified classification system by Santos – Filho et al. ⁽³³⁾

HYPOTHESIS:

1. The null hypothesis tested was that there would be no statistically significant difference in fracture resistance of simulated immature human maxillary central incisor teeth with Biodentine apical plug restored with Biodentine, Everstick post, and Smart Dentin Replacement.

2. The alternative hypothesis was that there would be a statistically significant difference in fracture resistance of simulated immature human maxillary central incisor teeth with Biodentine apical plug restored with Biodentine, Everstick post, and Smart Dentin Replacement.

REVIEW OF LITERATURE

Yasin et al., in 2021⁽³⁴⁾, evaluated the effect of root filling with white mineral trioxide aggregate (WMTA) (Angelus, Brazil) and Biodentine (Septodont, France) on fracture resistance of simulated immature teeth over different time periods. Sixty single-rooted premolars were randomly divided into three groups; (n = 20) – two experimental and one control groups. The control group was further subdivided into positive and negative controls (n =10). Root canals were prepared using ProTaper Universal rotary files (Dentsply Maillefer, Switzerland) upto size F3 and further prepared with Peeso reamers sizes 1-6 (Mani, Japan) to simulate immature apices. Following preparation, canals were completely filled with either MTA or Biodentine depending on the group and the ends were sealed with cavit-G (3M Espe, Germany). Fracture-resistance test was carried out using an Instron universal testing machine after two weeks and three months (n=30 each) with a 1 mm/min crosshead speed until a fracture occurred. The fracture location and pattern for each specimen were also assessed. It was observed that the MTA group had the highest fracture resistance after 2 weeks, while there were no significant differences among groups at 3 months ($P > 0.05$). There was no significant difference in fracture location between the groups at two weeks, but after three months, the difference was significant with the middle root fracture being more frequent (63.3%). The reason for this finding was explained by the

high alkalinity of hydrated WMTA and BD which induced a caustic denaturing and degradation effect on the organic components of interfacial dentin.

Santos et al. in 2021⁽³⁵⁾ assessed the fracture resistance of weakened and non-weakened teeth reinforced using Rebilda bundled glass fiber–reinforced composite posts (GT) (VOCO, Germany), Rebilda conventional glass fiber posts (RP) (VOCO, Germany), or both systems combined (GT+RP). Eighty bovine incisors were prepared and divided randomly into eight groups: (a) nWnR: without simulating weakness and without intraradicular reinforcement; (b) WnR: simulating weakness, but without intraradicular reinforcement; (c) nWGT: without simulating weakness, but with GT; (d) WGT: simulating weakness, and with GT; (e) nWRP: without simulating weakness, but with RP; (f) WRP: simulating weakness, and with RP; (g) nWGTRP: without simulating weakness, but with GT+RP; (h) WGTRP: simulating weakness, and with GT+RP. Fracture resistance was determined by subjecting specimens to a compressive load until fracture. Mechanical behaviour & stress distribution was assessed using finite element analysis. Results showed that fracture resistance of nWGTRP group was better than WGTRP, but not statistically significant ($P > 0.05$). However, significant difference was observed between these and the other groups except nWRP ($p < 0.05$). Evaluation of stress distribution inside the canal wall revealed good

mechanical behavior for nWGTRP and nWRP groups. Fractures were mostly observed in the cervical and middle thirds, denoting increased tensile stress in these areas, regardless of the model and suggestive of a higher risk of failure in the cervical area. It was concluded that Rebilda conventional fiber post (RP), combined with the Rebilda bundled glass fiber–reinforced composite post (GT), improved fracture resistance of immature teeth and stress distribution.

Frater et al. in 2020⁽³⁶⁾ assessed fracture-behaviour, survival and marginal microgaps in simulated immature teeth after apexification with MTA when restored with different fiber reinforced composites materials. One hundred and eighty bovine-incisors were randomly divided into six groups (n=30). Canals were prepared to simulate immature apices and apexification was done with MTA. According to the groups, reinforcement with FRC's was performed as follows: Group 1: Bioblock technique with short fiber-reinforced composite (SFRC) (everX Posterior, Belgium); Group 2: Bioblock technique with flowable SFRC (everX Posterior, Belgium); Group 3: Individually-made FRC post (everX Posterior, Belgium); Group 4: Conventional FRC post; Group 5: dual-cure core build-up composite; Group 6: control. After restoration, 5 teeth from each group were sectioned, stained and viewed under stereo microscope to calculate the percentage of microgaps within the root canal. Fatigue survival was measured using a cyclic-loading testing

machine (n=150). Survival rates of all experimental groups were significantly lower than the control group. Group 2 did not differ significantly from the control group. Post and core restorations made from conventional FRC post (Group 4) exhibited more microgaps (38.3%) at the examined interphase in the root canal. Microhardness values showed no difference between dual cure luting composite and SRFC in cervical and middle thirds but in apical third, SRFC exhibited drastic reduction. It was concluded that restoring immature anterior teeth with flowable SFRC as post-core material displayed promising performance in fatigue resistance and survival.

Uros Josic et al. in 2020⁽³⁷⁾ investigated the influence of fiber-post placement on fracture resistance of endodontically treated simulated immature human teeth. Twenty intact mandibular premolars were prepared till 80 size K files and instrumented at the apical end with sizes 4,5, and 6 Gates Glidden drills to simulate immature teeth. After apical plug placement with Biodentine (Septodont, France), they were randomly divided into two equal groups (n = 10): Group 1 (Control)-Gutta-percha cones placed with calcium hydroxide-based sealer; Group 2 (Fiber post)- size 3 FRC Postec plus (Vivadent) luted with self-adhesive composite cement (Speed CEM). The teeth were then subjected to a fatigue test. Fracture resistance was tested using an Instron universal testing machine. Results showed no statistically significant difference in fracture resistance ($p = 0.054$)

and fracture modes ($p = 0.582$) between the two groups. This was explained by the considerable amount of coronal structure preserved during specimen preparation. It was concluded that fiber post-placement did not significantly influence fracture resistance or fracture modes in endodontically treated simulated immature human teeth.

Pawan Darak et al., in 2020⁽³⁸⁾, compared the fracture resistance and the pattern of fracture (favorable/ unfavorable) during single visit apexification versus complete obturation using MTA and Biodentine in simulated immature teeth. Forty-five maxillary central incisors were randomly divided into four experimental ($n = 10$) and one control group ($n = 5$). Group 1: Complete canal obturation with MTA, Group 2: 5 mm apical plug of MTA and canal obturated with gutta-percha and AH Plus sealer, Group 3: Complete canal obturation with Biodentine, Group 4: 5 mm apical plug of Biodentine and the canal obturated with gutta-percha and AH Plus sealer. The control group was entirely filled with GP & AH plus sealer. All samples were subjected to fracture testing in a universal testing machine. Group 1 showed higher fracture resistance than group 3, but it was not statistically significant ($P > 0.05$). Group 1 and 3 performed significantly better than Group 2 and 4 ($P < 0.05$), but no statistically significant difference was seen between Group 2 and Group 4. All experimental groups showed a horizontal fracture at the level of cemento-enamel junction or oblique fractures

extending up to the cervical third without any statistically significant difference between them. The samples in the control group showed unfavorable fractures extending beyond the middle third root level. It was concluded that the better reinforcing effect of both complete MTA and Biodentine group may be due to their bioactive nature, similar modulus of elasticity to dentin, and their ability to form a hydroxyapatite layer between the dentine and material.

Girija Suresh Sajjan et al. in 2020⁽³⁹⁾ evaluated the adhesive quality of structurally compromised roots with different intracanal rehabilitation techniques, such as fiber post, biological post, and Smart dentin replacement (SDR). Thirty maxillary central incisors were prepared with Peeso reamers (n=10) & divided into three groups: Group I - Fiber post (DT light post, Bisco, USA) + flowable composite (Tetric N Flow, Ivoclar Vivadent, USA), group II - Biological post + dual-cure resin cement (Rely X, 3M, USA), and group III - Smart dentin replacement (SDR, Dentsply, USA) as post material. Pushout bond strengths were measured using a universal testing machine. Results showed that Group III displayed statistically significant higher pushout bond strengths than Groups II and I. The possible reason for this finding was ascribed to fewer interfaces present on account of it being a single material (i.e.,) there were no interfaces among the post and core materials. The degree of conversion could have also contributed to the result as the

material was placed in two increments and cured separately, resulting in the whole restorative complex working like a single unit. They concluded that Smart dentin replacement is a better material for intracanal rehabilitation of teeth with flared canals in terms of pushout bond strength compared with other groups. DT light post + flowable composite could be used to reinforce weakened roots and is the least technique sensitive.

Alhajj et al. in 2020⁽⁴⁰⁾ compared the pushout bond strength of two different types of posts cemented with two different luting cements at different root levels. Forty-eight single-rooted permanent human teeth were treated endodontically followed by post space preparation. The samples were divided into four groups (n= 12); Two different types of post [GC everStick POST (ES) and Parapost Fiber LuxTM (PF)] and two different types of cement [G-CEMTM (G) and RelyXTM Unicem (R)] were used. Pushout bond strength (PBS) test was performed using a universal testing machine. Results showed that the PBS of RelyXTM Unicem cement at both coronal and middle root levels were significantly much higher than G-CEMTM cement ($p < 0.001$). No significant difference was found between ES and PF posts ($P = 0.058$). The possible reason could be the formation of micromechanical retention and chemical adhesion to the hydroxyapatite structure and the well-known moisture-resistant property that leads to the superior bond strength values of Rely X cement. They concluded that the type of cement had a significant

effect on pushout bond strength with RelyX™ & G- CEM, whereas the type of post did not have significant effect on PBS.

Eram et al. in 2020 ⁽⁴¹⁾ compared the fracture resistance of MTA, Biodentine, and Bioaggregate as an apical plug and backfill material in immature permanent teeth using Finite Element Method. Maxillary central incisors were used for simulation and the canals were prepared using Peeso reamers. Analysis was done in seven different models (Model 1): control group having an immature tooth model without any reinforcement material; (Model 2): 4 mm apical plug of Mineral trioxide aggregate (MTA) [ProRoot MTA Dentsply, USA]; (Model 3): 4 mm apical plug of Biodentine [Septodont, France] (Model 4): 4 mm apical plug of Bioaggregate [Innovative Bioceramix Inc, Canada]; (Model 5): entire canal filled with MTA; (Model 6): entire canal filled with Biodentine; (Model 7): entire canal filled with Bioaggregate. Force was applied at an angle of 130° to the long axis of tooth. Stress distribution at CEJ was measured using the Von Mises stress criteria. It was found that the 4 mm apical plug using MTA showed higher fracture resistance when compared to the 8.5 mm backfill using MTA. It was found that when MTA was replaced as backfill material by Biodentine and Bioaggregate, the Von Mises stress increased by 64% and 94%, respectively, with the maximum stress reported at the cervical region.

Isabel Mello et al. in 2020⁽⁴²⁾ evaluated whether the methods used to treat endodontically and restore anterior immature teeth with a necrotic pulp had an influence on their resistance to fracture. Following root canal preparation, 80 teeth were assigned into 5 groups according to the obturation method and coronal restoration used: A1 – apexification + composite restoration in the crown area (3M ESPE, Canada), A2 – apexification + composite restoration in the crown and 3 mm into the root, group IR – immediate revascularization + composite restoration in the crown, group SR – successful revascularization + composite in the crown area, and control group (CG) – mature tooth treated with gutta percha and sealer + composite restoration in the crown area. Teeth were mounted in acrylic blocks and subjected to compressive forces in a universal testing machine. Both fracture strength and the location of fracture were recorded. Results showed no statistically significant differences in the fracture resistance or fracture location among the 5 groups. Therefore, it was concluded that the treatment options used to treat non-vital immature teeth provided the same resistance to fracture.

Sogukpinar et al in 2020⁽⁴³⁾ evaluated the effects of MTA and newly-developed calcium-silicate-based MTA derivatives in single-session apexification procedure in 270 simulated immature upper incisors. Teeth were randomly divided ($n = 45$) into positive control (Ca (OH)_2 , negative control with intact teeth and experimental

groups that used ProRoot MTA (MTA-PR), MM-MTA, NeoMTA-Plus, and Biodentine (BD) (Septodont, France). Teeth were prepared and filled according to the respective groups. Fracture resistance (FR) test was performed at 2 weeks, 2 months, and 1 year. Results showed that at the end of the second week, FR was significantly higher in the BD group when compared to the Ca(OH)_2 group ($p=0.006$) but not significant compared to the control group. At the end 2 monthS, FR of BD group was significantly higher compared to the MM-MTA and Ca(OH)_2 groups ($p=0.012$ and $p<0.001$) respectively. At the end of first year, FR of the BD, MM-MTA, NEO, MTA-PR, and Ca(OH)_2 groups were found to be significantly lower compared to the negative control group ($p \text{ value}<0.001$). This was attributed to denaturation of the tooth over time due to the root canal filling, showing similar effects to Ca(OH)_2 .

Amizic et al., in 2019⁽²⁸⁾, investigated the micro pushout bond strength of both individually formed (everStick Post) fiber-reinforced composite (FRC) and prefabricated (GC Fiber Post) fiber-reinforced composite (FRC) posts in relation to root canal dentin cemented with three different self-adhesive composite cements. Forty-two single-rooted human mandibular premolars were selected and decoronated. The teeth were divided into two groups ($n = 21$): (everStick Post or GC Fiber Post) and further into 3 subgroups ($n = 7$) based on cements (G-CEM LinkAce, SpeedCEM, or RelyX U200). Specimens were then sectioned perpendicularly

and divided at the cemento-enamel junction into two root levels: coronal or apical. Results showed that bond strength was significantly affected by both post type and root level ($p < 0.05$) but not by type of self-adhesive cement ($p > 0.05$). EverStick Post showed significantly higher bond strength in comparison to the GC Fiber Post ($p > 0.05$). The apical level of the luted posts yields lower bond strengths than the coronal level. Failures were predominantly seen in adhesive at the cement-dentin interface. They found that there is more intimate contact of individually formed FRC posts to the root canal walls. They reasoned that the shape of the post resembles the shape of the canal leading to thinner cement layers that produce fewer defects, bubbles, and voids that can cause cracks or decrease adhesion.

Prerak Doshi et al in 2019⁽⁴⁴⁾, evaluated the fracture resistance of 80 endodontically treated human maxillary central incisors restored with carbon fiber posts, glass fiber posts and everStick posts under static loading. Teeth in control group were restored with composite and teeth in experimental groups were randomly divided as follows: Group II—carbon fiber group (Angelus, Brazil), III— glass fiber group (Coltene whaledent, USA), and IV—EverStick (E-glass) post group (GC Europe). Root canal treatment was completed in all the samples followed by post and core placement. All specimens were subjected to static loading until fracture and the mode of fracture was recorded. The main mode of fracture was repairable as there

was debonding of the core in all the fiber posts. Teeth in control group showed highest fracture resistance and teeth restored with EverStick posts showed higher fracture resistance than those restored with glass fiber or carbon fiber posts under static loading. The possible reason could be that since the EverStick fibers are fanned out in the coronal aspect, it increases the area of adhesion with the core. Additionally, the flexural strength and elasticity of these posts is similar to dentin, due to which stresses are evenly distributed throughout the length of the root. They concluded that the E-glass fiber post showed a higher fracture resistance than the glass fiber or carbon fiber posts.

Amr Elnaghy et al. in 2019⁽⁴⁵⁾ evaluated the fracture resistance of 140 human maxillary incisors that were simulated to mimic immature teeth using Biodentine (BD) (Septodont, France) and fiber post (FP) (Parapost, USA) compared with various root canal-filling materials under aging conditions. The teeth were randomly divided into seven groups (n = 20). Negative control received no treatment. The root canals were filled with a 4-mm apical plug of Biodentine and restored intraradically with BD, BD + FP, composite resin, composite resin + FP, orthogutta-percha. Positive controls were instrumented but received no restoration. Teeth were subjected to thermocycling and subjected to cyclic loading before the fracture resistance test. Fracture resistance was tested using an Instron Universal Testing machine. Intraradicular reinforcement with BD +

FP and composite resin + FP enhanced the fracture resistance of simulated immature teeth more than the other experimental groups. Therefore, it could be postulated that the monoblock formed by BD + FP system enhanced the fracture resistance of simulated immature permanent teeth under aging conditions.

Pegah Sarraf et al., in 2019⁽⁴⁶⁾, compared the fracture resistance of 70 immature bovine roots, when using ProRoot MTA (Dentsply, US), Calcium-enriched mixture (CEM) cement, and Biodentine (Septodont, France) as root filling materials. The incisors were divided into five groups based on root filling (n=14): Biodentine, ProRoot MTA, CEM Cement, gutta-percha points with AH26 sealer, and the control group (dry cotton wool). All samples were subjected to load in a universal testing machine until fracture. Biodentine and ProRoot MTA groups had greatest fracture resistance compared to other groups with significant differences compared with the control group ($p < 0.005$). The possible reasons for better results with Biodentine could be the apatite formation on both cement -dentine interface and also within interfacial dentin.

Raouf W Ali et al in 2019⁽⁴⁷⁾ evaluated fracture resistance of simulated immature teeth after regenerative endodontic procedure (REP) using tricalcium silicate cements (TSCs) as cervical plugs. Internal canal diameter of bovine incisors was standardised to 2mm and treated with a REP protocol consisting of NaOCl and EDTA

irrigation, intracanal medication with triple-antibiotic paste for 14 days followed by a TSC cervical seal and composite restoration. Teeth were then divided into four groups (n=10) according to the material used to fill the canal: Mineral-Trioxide-Aggregate (MTA) (Angelus), Biodentine (Septodont, France), TotalFill. Teeth filled with guttapercha (GP) and intact teeth served as controls. All teeth were subjected to an increasing compressive force at a rate of 0.05 mm/s until fracture. All treated teeth exhibited significantly lower fracture resistance compared to intact teeth but no significant difference was found between the TSC groups. They concluded that TSCs applied at the cervical area of simulated immature teeth treated with REP did not reinforce fracture resistance.

Supatra Danwittayakorn et al. in 2019⁽⁴⁸⁾ compared the incidence of fatal root fractures in immature endodontically treated teeth with MTA apexification (ProRoot MTA, Switzerland) and restored with reinforcing materials like resin composite/ fiber post (DT Light post, Schaumburg) or non-reinforcing materials such as gutta-percha or MTA. Records for necrotic immature teeth treated with MTA apexification from 1996 to 2017 were collected. A total of 111 teeth in 95 patients treated with MTA apexification were identified according to the inclusion criteria. Intraradicular materials, preoperative & treatment factors were obtained from dental charts and radiographs. Results showed that the incidence of root fracture in reinforced teeth was 5.5%, which was not significantly different

($p > 0.05$) from the non-reinforced teeth (8.3%). In the reinforced group, the incidence of root fracture in teeth with a fiber post and composite core was 4.8% (1/21 teeth) and 5.9% (2/34 teeth), respectively, which was not significantly different ($P > 0.05$). It was concluded that immature teeth treated with MTA apexification and restored with either reinforcing or non-reinforcing intraradicular materials had a similar rate of root fracture. The authors claimed that pre-operative external inflammatory root resorption and patient age more than 15 years were the predisposing factors that significantly increased the incidence of root fracture.

Hanan M. Arb et al. in 2018⁽⁴⁹⁾ evaluated fracture resistance of 50 human maxillary central incisors that were simulated to mimic immature teeth and reinforced with two different bulk-fill flowable composite resins namely, Smart dentine replacement (SDR) (SureFil SDR; Dentsply/Caulk, Konstanz, Germany) or Filtek bulk-fill flowable (FBF) (3M ESPE, Saint Paul, Minnesota, USA) after root-end closure with mineral trioxide aggregate (MTA) (Angelus, Londrina, State of Paraná, Brazil) or Biodentine (BD) (Septodont, Saint-Maur-des-Faussés, France). Simulation of immature teeth was performed using Peeso reamers and randomly divided into five groups ($n = 10$): Group 1 (control): no filling material, Group 2: MTA as an apical filling and backfilled with SDR, Group 3: MTA as an apical filling and backfilled with FBF, Group 4: Biodentine as an apical filling and backfilled with SDR,

and Group 5: Biodentine as an apical filling and backfilled with FBF. The load was applied using universal testing machine with a cross head speed of 1 mm/min on the palatal surface. Statistically significant differences were found among all tested groups ($P < 0.001$) except for group 2 versus 4 ($P = 0.948$) and group 3 versus 5 ($P = 0.786$). The mean fracture load value for SDR group was significantly higher than that of FBF groups, suggesting better fracture resistance of SDR backfilling over FBF. This may be due to higher filler loading in SDR (68% by weight) compared with FBF (64.5% by weight), improving SDR's mechanical properties. It was concluded that either MTA/Biodentine as apical plug filling material in simulated immature teeth with bulk fill composite resin backfilling enhanced their fracture resistance.

Cechella et al in 2018,⁽⁵⁰⁾ evaluated the sealing ability provided by Biodentine and mineral trioxide aggregate (MTA) apical plugs, with or without phosphate-buffered saline (PBS) intracanal dressing, using a glucose leakage method. The length of 100 root segments was standardized followed by apical retrograde preparation. They were randomly divided into 4 groups ($n = 25$): G1 – Biodentine; G2 - Biodentine + PBS intracanal dressing; G3 - MTA and G4 - MTA + PBS intracanal dressing. All root segments were prepared to evaluate the glucose leakage after 2 months and the amount of glucose leakage was quantified by a spectrophotometer. Samples that received Biodentine apical plug showed higher traces of

glucose ($p < 0.05$). The exposure to intracanal PBS did not influence the sealing provided by Biodentine and MTA. They concluded that Biodentine had lower sealing ability than MTA.

Jamshidi et al., in 2018⁽⁵¹⁾ assessed the impact and fracture strength of immature teeth treated with mineral trioxide aggregate (MTA) plug and fiber post versus revascularization. 160 human maxillary central incisors were selected with equal dimensions of root length. All the samples were then randomly divided into 10 groups ($n = 10$) with Fracture (F) and impact (I) were included in each interventions such as Group 1: Negative control group/fracture (F); Group 2: Negative control group/impact (I); Group 3: Positive control group/F; Group 4: Positive control group/I; Group 5: MTA group/F: MTA apical plug and reinforced with fiber post ($n = 20$); Group 6: MTA group/I: MTA apical plug and reinforced with fiber post ($n = 20$); Group 7: Revascularizing group/F: simulated immature teeth under revascularization treatment ($n = 20$); Group 8: Revascularizing group/I ($n = 20$); Group 9: Revascularized group/F: simulated immature teeth with accomplished revascularization treatment ($n = 20$) Group 10: Revascularized group/I: simulated immature teeth with accomplished revascularization treatment ($n = 20$). The root length was standardized to 12 mm, and #1 to #6 Peeso reamers were passed through the apex, and a long-shank round diamond bur (retrograde) was used for simulation of immature teeth. All the samples were restored with 5 mm apical plug and treated

with interventions used, and then subjected to Fracture Strength Testing using universal testing machine and Charpy Impact Test. The fracture and impact strength of the negative control group was significantly higher than that of the other groups ($P < .05$), but the positive control group was not significantly different from that of the 3 experimental groups (ie, the MTA, revascularizing, and revascularized groups) ($P > .05$). The results showed that none of the tested modalities could significantly increase simulated immature teeth' impact and fracture strength.

Linsuwanont et al., 2017⁽²⁴⁾ compared the fracture resistance of simulated immature teeth treated with MTA (ProRoot MTA, Tulsa) apical plug reinforced with fiber post (Ultradent), composite resin, Mineral Trioxide Aggregate (MTA), or gutta-percha. Fifty-six human maxillary central and lateral incisors were selected and divided into six groups ($n = 10$ for each group except $n = 6$ for the simulated immature group). Group 1 - intact teeth; Group 2 - simulated immature teeth; Group 3 - fiber post group; Group 4 - composite resin group; Group 5 - MTA group; and Group 6 - gutta-percha group. The root canals of 46 teeth were enlarged using TF Twisted Files, followed by Peeso reamers. The remaining teeth received MTA apexification, and the root canals of each group were filled with MTA, fiber post, composite resin, and gutta-percha. All teeth samples were thermocycled for 500 cycles at 5°C and 55°C with a 30-second dwell time and 5-second transfer time. The cyclic and

static loading for fracture tests were performed in an Instron universal testing machine. All teeth samples were fractured at the cervical area of the root. The fiber post, composite resin, and MTA groups showed higher fracture resistance than the simulated immature teeth group. No significant difference was found between the gutta-percha and the simulated immature teeth groups. MTA apexification and root filling with gutta-percha and AH Plus sealer did not increase the strength of the simulated immature teeth. Gutta-percha had much lower modulus of elasticity than dentin, 0.074–0.079 and 14.0–18 GPa, respectively. Filling the access cavity with composite resin does not provide a reinforcement effect to the cervical area of the root. Intraradicular reinforcement with fiber post, MTA, or composite resin after MTA apexification increased the fracture resistance of simulated immature teeth.

Nadig et al., in 2017⁽⁵²⁾, evaluated the effects of reinforcement on dual-cure composite resin and biodentine on immature root dentin and also to find if these materials bring any alterations in root canal dentin influencing the tooth strength with time. Sixty extracted human maxillary central incisors with simulated immature apex were selected and divided into three groups of 20 each. Cone-beam computed tomography (CBCT) analysis were subjected to confirm the dentin thickness around 1.5 mm. Group I (control n = 20) - 4 mm biodentine apically placed and backfilled with gutta-percha using Obtura II. Group II (n = 20) - 4 mm biodentine apically placed

and backfilled with dual-cured composite resin. Group III (n = 20) - complete obturation with biodentine. The access openings of all groups were filled with nanocomposite (Filtek Z350 XT; 3M ESPE, USA) 2 mm below CEJ. About ten samples from each group were randomly divided into two subgroups. One group (n = 10) tested immediately, and remaining 10 samples stored in phosphate-buffered solution (PBS) and further tested after 3 months for fracture resistance and chemical analysis of dentin. Results found that there is no significant difference found when the samples tested immediately between the groups. After 3 months of aging, only biodentine group showed a significant reduction in fracture resistance with increased Ca/P ratio of root dentine. The higher mean fracture resistance was recorded in paracore group followed by gutta-percha and Biodentine group respectively. The difference in mean fracture resistance was found to be significantly different between the groups ($p < 0.01$). On comparing immediate and delayed testing of Biodentine samples, the difference between them was found to be statistically significant ($p < 0.001$) where there was no significant difference in other two groups. The structurally altered dentin noted beneath the biodentine, which is due to high alkalinity of hydrated biodentine. This occurs due to caustic denaturing and permeability of organic collagen component of interfacial dentin, further leads to decreased tooth strength of the biodentine samples after 3 months. Another reason for the decreased tooth strength could be the solubility of biodentine, due to higher

uptake of ions by the root canal dentin, further alters the physical properties of biodentine. After 3 months of aging, Biodentine group has shown drastic reduction in fracture resistance, and uptake of minerals is responsible for decreased tooth strength needed further evaluation. and hence, it cannot be recommended as a reinforcement material in immature teeth with thin dentinal walls.

Girish et al. in 2017⁽⁵³⁾ compared the influence of MTA (ProRoot MTA, Dentsply, Germany) and biodentine on fracture resistance of simulated immature teeth when used as apical plug or as obturating material. Sixty single-rooted mandibular premolar teeth were randomly divided into five groups (n = 12 in each group). Group 1 served as a negative control; 2 and 4 - samples were filled with 5 mm of MTA and Biodentine apical plug respectively and backfilling was done with gutta-percha with AH Plus sealer. Group 3 and 5 samples were completely obturated with MTA and Biodentine, respectively. Fracture resistance was tested using the universal testing machine with a vertical load was applied until the root fractured at a crosshead speed of 0.5 mm/min. The results showed that complete root canal obturation with MTA or Biodentine had significantly higher fracture resistance ($P < 0.05$) than apexification with MTA or Biodentine. The possible reason could be due to their similar elastic modulus of elasticity to that of dentin and microleakage encountered with gutta percha backfilling.

Emre Bayram et al. in 2016⁽⁵⁴⁾ evaluated the fracture strength of immature teeth upon coronal placement with with three different materials, namely Mineral Trioxide Aggregate (MTA) (Angelus, Brazil), Bioaggregate (BA) (Diadent Group, Canada), and Biodentine (Septodont, France). Forty extracted human premolar teeth were randomly divided into one control (n = 10) and three above-mentioned experimental groups (n = 10). The Instron Universal Testing Machine used to determine the maximum load to fracture the tooth by placing the tip 3 mm incisal to the cemento-enamel junction. The results showed no significant differences observed among the MTA, BA, and biodentine groups, which may be attributed to the similar composition and structure of the three calcium silicate-based cements. Therefore, they concluded that all three materials effectively strengthened the immature teeth.

Zhabuawala et al., in 2016⁽⁵⁵⁾ evaluated the reinforcing ability of dual-cure composite resin and Biodentine on immature root dentin immediately and after three months of aging. Sixty extracted human maxillary central incisors were randomly divided into three groups (n = 20 in each group): Group I (control) - 4 mm of Biodentine apical plug backfilled with thermoplasticized gutta-percha. Group II - 4 mm apical plug of Biodentine and then backfilled with dual-cure composite resin (ParaCore). Group III - filled with Biodentine. Then each group was randomly divided into two subgroups; Specimens were stored for one week in subgroup A, phosphate-

buffered saline solution for three months in subgroup B. Universal Testing Machine was used to analyze the fracture resistance testing with a load applied from the palatal surface. The results showed higher mean fracture resistance was recorded in the ParaCore Group, followed by Biodentine and gutta-percha group, respectively, in immediately tested samples. Higher mean fracture resistance was recorded in the ParaCore group followed by gutta-percha and Biodentine group in delayed tested samples after three months of aging. The difference between immediate and delayed testing of Biodentine samples was statistically significant. After three months of aging, only the Biodentine group showed a significant reduction in fracture resistance without a substantial reduction in the other two groups. They conclude that the biodentine group has dramatically reduced fracture resistance after three months of aging. Due to caustic denaturing and increased permeability by the alkaline and poor solubility, the altered dentin could lead to decreased tooth strength of the Biodentine samples after three months of aging.

Evren Ok et al. in 2016⁽⁵⁶⁾ compared the fracture resistance of simulated immature teeth restored with an apical barrier of mineral trioxide aggregate (MTA) (Angelus, Brazil), Biodentine (Septodont, France), and calcium-enriched mixture (CEM) (Yektazist Dandan, Iran). Fifty-two human maxillary central incisors were standardized, followed by simulations of roots into immature apices. The

specimens were then randomly divided into three experimental groups (n = 13) and one control group (n = 13). MTA, Biodentine, and CEM were placed to apical 4 mm of the simulated immature roots in experimental groups. The samples were stored at 37°C and 100% humidity for one week. The universal testing machine was used at a speed of 1 mm/min, and a load was applied to the crown of all teeth. The results showed that there is no statistically significant differences were found among MTA, CEM, and Biodentine ($P > 0.05$), and these groups demonstrated higher fracture resistance than control group ($P < 0.05$). They concluded that using any of the MTA, Biodentine, and CEM as an apical plug and restoring with fiber post and composite resin increases the fracture resistance of immature teeth.

Sivieri-Araujo et al. in 2015⁽⁵⁷⁾ evaluated the fracture resistance of simulated immature teeth after different intra-radicular treatments. Fifty central incisors were selected with similar dimensions, followed by root canal preparation performed using a bur in crown-apex and apex-crown direction. The samples were distributed into five groups (n=10): Positive control - no root canal flaring or filling; Negative control - teeth were sectioned, and their root canals were flared; Direct anatomical glass fiber post - #2 Reforpost main glass fiber post relined with composite resin; Double tapered conical glass fiber posts - #3 Exacto glass fiber post; and #2 Reforpost main glass fiber + Reforpin accessory glass fiber posts.

In experimental groups, 4.0-mm apical plugs were placed with MTA Angelus. The specimens were submitted to compressive fracture strength test at a crosshead speed of 0.5 mm/min in a servo-hydraulic mechanical testing machine. Results showed that the control groups showed lower fracture strength than the experimental groups. Double tapered conical glass fiber posts presented the highest resistance among the experimental groups. The possible reason could be a more homogeneous filling obtained using double tapered conical glass fiber posts. They concluded that the flaring procedures produced a detrimental effect on the fracture resistance of the bovine teeth. When compared with the control groups, double tapered conical glass fiber and direct anatomical posts were the best type of reconstruction to restore immature teeth after placement of MTA apical plugs.

Mehmet Bani et al., 2015⁽⁵⁸⁾ evaluated the apical microleakage of Biodentine and MTA orthograde apical plugs and compared the effect of thickness of these biomaterials on their sealing ability. Eighty maxillary anterior teeth were selected, and both Biodentine and MTA placed in 1–4 mm thickness as apical plugs in the canal. The evaluation of canal microleakage was done by the fluid filtration technique. The results showed that the amount of apical microleakage was significantly lower for 3 and 4 mm apical plugs compared to 1 and 2 mm subgroups of Biodentine and MTA ($p < 0.05$). They found that the apical sealing ability of Biodentine was

similar to MTA at any apical plug thickness and it revealed that reduction of the apical plug thickness significantly increases apical microleakage. They concluded that the 3 and 4 mm thickness of apical plugs revealed a good sealing ability regardless of the both biomaterials.

Vineeta Nikhil et al. in 2015⁽⁵⁹⁾ compared the fracture resistance of simulated immature teeth restored with four different types of the filling system includes gutta-percha and AH Plus, glass fiber posts (GFP), experimental dentine posts (DP), and intracanal composite resin (ICR) after a 5 mm apical MTA placement. Fifty maxillary canines were standardized with length and simulated using Peeso reamers followed by placement of 5 mm of MTA apical barrier. They were divided into five groups as follows(n = 10 in each group): Group 1: AH Plus + gutta-percha, Group 2: GFP luted with PARACORE dual-cure resin; Group 3: DP luted with PARACORE dual-cure resin; Group 4: PARACORE dual-cure resin, Group 5: Control. Each specimens were subjected for fracture resistance testing by a universal testing machine. The results showed that Glass fiber post and PARACORE exhibited the highest fracture resistance, followed by DP luted with PARACORE dual-cure resin, PARACORE dual-cure resin, and gutta-percha. In contrast, it shows statistically significant differences between all the compared groups, except between gutta-percha and PARACORE. This finding might be related to a similar modulus of elasticity of fiber posts and

dentin and even distribution of force along the root. Fiber posts have also been shown to increase the flexural properties of the core composite surrounding the Post. The author suggested that GFP and DP can be preferred for additional reinforcement of immature teeth.

Amr M. Elnaghy et al., in 2016⁽⁶⁰⁾. evaluated the long-term fracture resistance of Biodentine (BD) and white mineral trioxide aggregate (WMTA) as apical barriers for regenerative endodontic procedures (REPs) in simulated immature teeth. Sixty human maxillary anterior teeth were standardized in both length and faciolingual dimensions. The samples were divided into four groups where the positive control group (n=15) did not received any treatment. The remaining teeth were simulated to approximate immature teeth, instrumented and disinfected according to AAE considerations for REPs, and randomly filled (n=15) with either WMTA or Biodentine or kept unfilled (negative control). The coronal access cavities of all specimens were sealed with glass ionomer cement followed by composite resin. The teeth were stored in phosphate-buffered saline solution (PBS) for 12 months until the testing. Each specimen was then subjected to universal testing machine at a cross head speed of 0.5 mm min^{-1} , and the fracture resistance were recorded at the peak load to fracture. All teeth fractured horizontally or obliquely through the cervical area of the root. The results showed that positive control group had the highest resistance to fracture and differed significantly ($P < 0.05$) from

other experimental groups. There was no significant difference found between BD and WMTA ($P > 0.05$). They explained that the enhanced fracture resistance of BD and WMTA compared with negative control group could be because of the development of hydroxyapatite-like layer between dentin and Tri Calcium Silicate Material through the hydration reaction in the presence of synthetic tissue fluid (i.e., PBS).

Karapinar-Kazandag et al. in 2016⁽⁶¹⁾ assessed the fracture resistance of simulated immature tooth roots restored with flowable composite resin, posterior composite resin, or MTA and to evaluate the fracture patterns that may occur in roots restored with the aforementioned materials. One hundred extracted human maxillary central and lateral incisors were standardized with root lengths and randomly divided into five groups ($n = 20$ in each group); Group 1 served as negative control where roots received no treatment. In groups 2–5, simulation of teeth done using Peeso reamers. All the specimens underwent dressing with calcium hydroxide (Ca(OH)_2), and incubation done for seven days. After the incubation period, the removal of Ca(OH)_2 was attained in all specimens. Canals in positive control group (Group 2) were left unfilled, and canals in the remaining groups were filled with MTA, BisFil 2B flowable Composite Resin, or BisFil II posterior Composite Resin, respectively. The samples were subjected to the Instron universal testing machine at a 5mm/min cross head speed. The results showed

that the mean load to fracture in Group 2 (630.01 ± 199.13 N) was significantly lower than in Group 1 (896.98 ± 311.79 N), confirming the simulated immature's fracture susceptibility roots. For the experimental groups, the mean load to fracture ranged from 684.02 N to 775.71 N, with no significant difference between either of groups 3, 4, and 5 and The pattern of root fracture was interpreted as: No type IV fractures (confined within the embedding resin) were observed, type III fractures (partially extending into the embedding resin) occurred much more frequently than type II (at the limit of the embedding resin) fractures. BisFil II is a self-curing packable composite resin characterized by high tensile and compressive strengths due to high filler content (84% by weight). Filling the entire root canal with MTA might be a convenient approach to mitigate the roots' susceptibility to fracture. They concluded that the root canal filling with MTA and two CR materials might reinforce the roots to levels comparable to intact roots.

Ameet J Kurthukoti et al in 2015⁽⁶²⁾ compared the fracture resistance and mode of failure of simulated traumatized permanent central incisors restored with three different post systems. A total of 40 recently extracted human maxillary central incisors with similar dimensions were decoronated 2 mm above the cemento-enamel junction and endodontically treated. Ten specimens were randomly selected as the Group I — Control group (core built teeth without intraradicular posts). The remaining 30 teeth were equally divided

(n= 10) and restored with zirconia (Group II), fiber re-inforced composite (FRC) (Group III), and biologic dentin posts (Group IV) using resin bonded cement and their cores built-up. These samples were embedded in acrylic resin and then secured in a Universal Testing Machine and subjected to fracture resistance testing. The location of failure in the specimens was evaluated using a stereomicroscope. Intergroup comparison revealed that the control group and zirconia post group (522 ± 110 N) demonstrated the least fracture resistance, while dentin post group (721 ± 127 N) the highest. There was no statistically significant difference between fiber post and dentin post groups. Fractures that were repairable was observed in fiber post and dentin post groups, whereas mostly unrestorable, catastrophic fractures were observed in the zirconia post group. They attributed that the fiber post will acts as shock absorber, dissipating most of the stresses on the final restoration with only small fraction being transmitted to the dentinal walls. Demonstrating favorable fractures. They concluded that restoring with fiber post results in favourable fractures which is amenable to retreatment whereas with zirconia post resulted in catastrophic fractures making difficult for retreatment.

Behnam Bolhari et al in 2015⁽⁶³⁾, evaluated the fracture resistance of simulated immature teeth, obturated with Gutta-percha or Resilon and reinforced by either composite resin or fiber post. Eighty-four human maxillary incisors were selected and teeth in all groups were

prepared using Peeso reamers followed by placement of 4 mm apical plug of white ProRoot-MTA. They were divided into seven groups (n=12): Group 1: backfill with gutta-percha+ AH-26 sealer, Group 2: backfill with Resilon + Epiphany, Group 3: backfill with gutta-percha and AH26 to 3mm below the CEJ+ composite resin, Group 4: backfill with Resilon and Epiphany to 3 mm below the CEJ + composite resin, Group 5: backfill with gutta-percha and AH 26 to 6 mm below the CEJ + fiber post [Reforpost], Group 6: backfill with Resilon and Epiphany to 6 mm below the CEJ + fiber post and Group 7 (control group) wherein canals were left unfilled. Specimens were then subjected to oblique load using Instron Testing Machine in a lingual - labial direction at a cross head speed of 5.0 mm/min. The results showed that the experimental groups had a significantly more fracture resistance than the control group ($P < 0.05$). No significant effect of the obturation material ($P > 0.05$) or the restorative method ($P > 0.05$), and their interaction effect was not significant either. They found that filling the middle third of immature root canals with Resilon after sealing the apical third with MTA plug and reinforcing the coronal part with composite resin, has the potential of increasing the fracture resistance of the cervical area of immature teeth. They concluded that the use of fiber posts in immature teeth, may be the most favourable clinically applicable technique.

Britto Junior et al., in 2014⁽⁶⁴⁾, evaluated the fracture resistance and stress distribution of simulated immature teeth root filled with an apical barrier of MTA and restored with composite resin, fibre post or relined fibre post. Sixty bovine incisors were selected with similar dimensions followed by enlarging the root canals using diamond bur. 5-mm apical plug of MTA was placed and the teeth were randomly divided to one of following groups: Gutta percha – root canal filled with gutta-percha and endodontic sealer; Composite resin – the root canal was filled with light-cured composite resin inserted incrementally; Fiber post – a fibre post Exacto size 3 (Angelus) was cemented into the root canal with a self-adhesive resin cement, RelyX U100; and Relined fiber post – the fibre post relined with composite resin prior to cementation. The fracture resistance tests were performed using a universal testing machine at a cross head speed of 0.5 mm min^{-1} until fracture. Fracture pattern was evaluated according to the position of the fracture and stress distributions were verified by finite element analysis. The results showed that the teeth restored with relined fibre posts and fibre posts were associated with the highest fracture resistance than the composite resin group ($P = 0.015$), while the GP group had the lowest values ($P < 0.001$). The fractures types involved in cervical and middle thirds of all roots. Gutta percha group had high levels of stress concentration in the cervical and middle third of roots. No significant difference was found amongst the stress concentration in the composite resin, fibre post and

relined fibre post groups. The possible reason could be due to an adhesive material with a similar elastic modulus to dentine could improve the fracture resistance and stress distribution of immature teeth. They concluded that simulated immature teeth with open apices filled with an MTA apical plug and restored with fibre posts were a better adhesive strategy for restoring immature teeth than restoration with gutta-percha and sealer.

Huseyin Sinan et al. in 2014⁽⁶⁵⁾ evaluated the fracture resistance of simulated immature teeth that had been backfilled with Biodentine (Septodont, Saint Maurdes Fausses, France), fiber post (3M ESPE), and gutta-percha/sealer (Dentsply Maillefer) combination after Biodentine apical plug placement. Seventy-five human maxillary central incisor teeth with similar dimensions were selected and simulation of immature teeth apices were done with #6 Peeso reamer. All the teeth were divided into five groups (n = 15) wherein Group 1 served as a negative control which received no treatment. The apical 4 mm of remaining samples (60 teeth) were filled with Biodentine followed by backfilling was performed: Group 2 – no backfilling (positive control), Group 3 – Backfill with gutta-percha, Group 4 – Backfill with Rely X fiber post, and Group 5 – Backfill with Biodentine. Specimens were then subjected to fracture testing using the Instron universal testing machine with load applied from the palatal surface at a crosshead speed of 1 mm/min until it fracture. Results showed that the mean fracture

values of negative control and Rely X fiber post were significantly higher than the other groups ($P < 0.05$). This may be related to the similar modulus of elasticity for fiber posts and dentin. One possibility for no difference between the fiber post group and the unprepared group may be because the fiber posts may more evenly distribute forces along the root. To conclude that backfilling with fiber post after an apical Biodentine plug provided the highest fracture resistance among all experimental groups.

Rayyan et al in 2014 ⁽⁶⁶⁾ compared the fracture resistance of weakened endodontically treated teeth after reinforcement using different restorative techniques. Fifty maxillary central incisors were endodontically treated, decoronated at M-D cemento-enamel-junction and randomly divided into five equal groups ($n = 10$), group A: Coronal and intra-radicular cores using SDR (Dentsply, Weybridge, UK), group B : Coronal and intraradicular cores using Gradia Core (GC Corporation, Japan) and GC fiber post (GC Corporation, Japan), group C: Coronal and intraradicular cores using Xenious (StickTeck Ltd, Turku, Finland), group D: Coronal and intraradicular cores using flowable composite (Wave, SDI, Australia) and GC fiber post, and finally group E: Cast post and core. Which was cemented using resin cement (Rely X U 200, 3M ESPE, USA). All the specimens were subjected to compressive load using a universal testing machine at a crosshead speed of 1.00 mm/min. The results showed that the group A scored the highest

mean value of (739.15 N), followed by group D (510.29 N), then group B (422.92 N), group C came next (288.16 N), and the least results were registered in group E (285.03 N) with a statistical significant difference between groups A and C. They concluded that the use of cast post should not be used to strengthen structurally compromised and weakened roots. Consequently, smart dentine substitute could be used alone to reinforce weakened roots or a combination of flowable composite resin and fiber post can also help in reinforcing frail roots.

Idil Dikbas et al. in 2014⁽⁶⁷⁾ assessed the fracture resistances of simulated immature maxillary anterior teeth with roots that have been backfilled using three different post systems with mineral trioxide aggregate (MTA) apical plug. Forty-eight anterior maxillary teeth were selected, and each root's length was standardized followed by simulation of teeth using Peeso reamers and placement of 4 mm of MTA apical plug. They were divided into four groups (n = 12 in each group): Group 1 (Control): AH Plus sealer + Gutta-percha, Group 2: Glass fiber posts (Size – 3 FRC Postec Plus post). Group 3: Quartz fiber posts (DT Light post size - 2), Group 4: Zirconia posts (Cosmopost). The three post systems were cemented using self-adhesive resin cement. The load was applied lingually at a 1 mm/min crosshead speed in a universal testing machine. The results imply that all experimental groups had significantly higher fracture resistance than the control group ($P <$

0.01). However, no statistically significant difference was noted between the experimental groups ($P > 0.05$). In addition, they reported that the Prefabricated fiber-reinforced resin posts have a lower modulus of elasticity than metal posts, decreasing the risk of root fracture, thereby reinforcing the immature teeth. To conclude, all post systems exerted a similar reinforcing effect to a simulated immature tooth and can be preferred in situations requiring additional reinforcement.

Giovannetti et al., in 2012⁽⁶⁸⁾ assessed the adhesive potential of SDR was measured with the pushout test. Thirty single-rooted premolars were selected followed by endodontic preparation using crown down technique. Roots were then randomly divided into 5 equally sized groups ($n = 6$) based on the type of fibre post types were tested: Radix Fiber Post, DT Light Post, ER Dentin Post, DT Light SL, and FibreKleer. 2 subgroups of roots were randomly formed based on the cement type to be used for post luting (1) XP Bond/Self-Cure Activator (Dentsply De-Trey, Konstanz, Germany); subgroup (2) XP Bond/SureFil SDRTM (Dentsply De Trey, Konstanz, Germany). Results showed that the cement type did not have a significant effect on post retention ($p = 0.54$). DT Light Post exhibited significantly higher retentive strength than DT Light SL and FibreKleer. Significantly higher pushout strengths were recorded at the coronal third than at the middle and apical levels. The post–cement interaction was significant ($p = 0.002$). Posts luted

with SDR most often failed at the cement–post interface. SDR, a new light-cured flowable resin composite originally proposed for bulk filling of posterior restorations, when used to lute fibre posts achieved retentive strengths similar to those of Calibra.

Jindalet al.,in 2012⁽⁶⁹⁾, compared thereinforcing effect of different post systems in the restoration of endodontically treated human anterior teeth at two different lengths of post space preparation- an in vitro study. 135 human incisors were endodontically treated, and divided into four experimental groups based on the post system to be used: Glass fiber post (GFP) and stainless steel post (SSP), titanium post (TTP), cast metal post (CMP). Each group was divided into two sub-groups according to the length of post space preparation: 5mm and 10mm. All the samples were restored with metal crowns. The fracture resistance was measured by applying loads at an angle of 135° to the long axis of teeth in an instron universal testing machine. Fracture mode was analyzed for all the samples. The results revealed that stainless steel post (SSP) group at 10mm post space length showed the significantly (“P-value< 0.05”) highest fracture resistance (793.7787 N). Decrease in post length resulted in the decrease in fracture resistance in all the groups reduced to values even lesser than the control (437.8733N). They concluded that the different post systems used in the study were able to reinforce endodontically treated teeth only at 10mm post space length.

Anna-Maria Le bell ronnlof⁽⁷⁰⁾ evaluated the load-bearing capacity and microstrain of incisors restored with different posts. The roots were divided into groups: (1) prefabricated serrated titanium posts, (2) prefabricated carbon fiber-reinforced composite posts, (3) individually formed glass fiber-reinforced composite posts with the canal full of fibers, and (4) individually formed “split” glass fiber-reinforced composite posts. The posts were cemented and composite crowns were made. Intact human incisors were used as reference. All roots were embedded in acrylic resin cylinders and stored at room temperature in water. Static load was applied under a loading angle of 45° using a universal testing machine. On half of the specimens microstrain was measured with strain gages and an acoustic emission analysis was carried out. Failure mode assessment was also made. Results showed that the group with titanium posts showed highest number of unfavorable failures compared to the groups with fiber-reinforced composite posts. They reported that with fiber-reinforced composite posts the failures may more often be favorable compared to titanium posts, which clinically means repairable failures.

Schmoldt et al., in 2011⁽²³⁾ evaluated the fracture resistance after thermocycling of simulated immature teeth restored with composite, mineral trioxide aggregate (MTA), gutta-percha, or a fiber post. Eighty-four bovine mandibular incisors were divided into seven groups (n = 12) and standardized with suitable length followed by

instrumented with LightSpeed LSX files until size #120. Each canal was then prepared with ParaPost drills up to a size #7 to prepare an internal diameter of 1.75 mm. Negative controls received no treatment. After placing the 4-mm apical barrier of MTA, the canals were filled with their respective test materials to the facial cemento-enamel junction. All teeth were then subjected to thermocycling for 500 cycles at 5°C and 55°C with a 30-second dwell time and 5-second transfer time. Each root was tested using an Instron Universal Testing Machine with an application of load on the lingual surface, perpendicularly 3 mm incisal to the CEJ with a chisel-shaped tip at a crosshead speed of 5.0 mm/min, and the peak load to fracture was recorded. Results showed that the teeth restored with a fiber post showed significantly increased fracture resistance compared with all other groups. Negative control groups fractured through the noninstrumented canal space, whereas the positive controls fractured through the empty instrumented canal space. Teeth restored with a fiber post also fractured in the cervical area, but no fiber posts fractured. Teeth restored with MTA, composite, and gutta-percha fractured through the prepared canal space and the test material. This finding might be related to a similar modulus of elasticity of fiber posts and dentin. Fiber posts might more evenly distribute forces along the root. This even distribution might explain why teeth restored with a fiber post in this study had only partial crown fractures at or above the CEJ and might help explain why no posts fractured during testing. Because of the large diameter

of these simulated immature teeth, the posts did not fit snugly into the canals. They found that the thermocycled composite was not significantly stronger than gutta-percha and MTA. The only material that reported as significant for strengthening the simulated immature teeth was the fiber-reinforced composite with a fiber post as they had similar modulus of elasticity to that of dentin.

Tuna et al in 2011⁽⁷¹⁾ assessed the long-term fracture resistance of human immature permanent teeth filled with BioAggregate (BA), mineral trioxide aggregate (MTA) and calcium hydroxide (CH). Total of 28 immature premolars were standardized with length of root and was randomly assigned to four groups: Group I: DiaRoot BA (DiaDent, Burnaby, BC, Canada), Group II: Angelus MTA (MTA-A; Angelus, Londrina, Brazil), Group III: ProRoot MTA (MTA-PR; Dentsply, Tulsa, OK, USA), Group IV: CH (Sultan Chemists Inc., Englewood, NJ, USA). The root of each tooth was then embedded in an acrylic resin block. All specimens were loaded at a crosshead speed of 1 mm min)¹ in an Instron testing machine, and the peak loads up to fracture were recorded. Results showed that the BA group exhibited the highest fracture resistance, and the CH group showed the lowest resistance to fracture. Significant differences ($P < 0.05$) in fracture resistance were found between the DiaRoot-BA and CH groups and between the MTA-A and CH groups. They concluded that DiaRoot-BA-filled immature teeth demonstrate higher fracture resistance than other groups at one

year. Considering the long-term risk of cervical root fracture associated with immature teeth, the use of DiaRoot-BA as a root canal filling is more advantageous.

Soares et al., 2011⁽⁷²⁾ evaluated the effect of resin cement type and fiberglass post configuration on bond strength to root dentine at different depths within the canal. Ninety-six bovine mandibular single-rooted incisor teeth were root-filled and prepared to receive either a parallel-sided and serrated fiberglass post (Reforpost No. 3) or a tapered and smooth conical fiberglass post (Exato Conico No: 3). They were randomly divided into four groups (n = 12) according to the resin cement used: dual-cured resin cement (Rely X ARC), two self-adhesive resin cement such as Rely X Unicem and MaxCem, and a self-cured resin cement – Cement Post. The roots of each groups were cross-sectioned to obtain two 1-mm-thick discs from the cervical, middle and apical third regions of the prepared root. All the specimens were positioned on the test machine submitted to compression loading in an apex to crown direction at a speed of 0.5 mm min⁻¹ until failure. The RelyX Unicem significantly shown as higher bond strength values ($P < 0.001$) along with the root dentine. The RelyX ARC and Cement-Post had similar bond strength values in the cervical third, and the bond strength values decreased significantly ($P < 0.001$) in an apical direction for the RelyX ARC. The bond strength was shown similar for both post configurations [fiberglass post or a tapered and

smooth conical fiberglass post] regardless of the resin cement and canal region. RelyX Unicem composed of bifunctional methacrylate groups, whose acid nature allows for tooth demineralization and infiltration by means of the adhesive system, resulting in micromechanical retention. It is represented by the bond strength of fibreglass posts to internal root dentine was influenced by the luting agents and location but not by the post configuration. The cementation success of fibreglass posts depends on achieving effective and long-last bonding in the post–resin cement–root dentine complex. To conclude that the self-adhesive RelyX Unicem cement yielded a significantly greater ($P < 0.001$) bond strength value when cementing the fiberglass posts.

Tanalp et al., in 2011⁽⁷³⁾ compared the fracture resistance of immature teeth with MTA apical plug followed by root canal obturation methods using AH Plus, MetaSEAL, MTA Fillapex sealers + lateral compaction technique, and Unicore quartz fiber post. Fifty single-rooted maxillary anterior teeth were standardization with respect to the length followed by simulation of teeth with immature apices. They were randomly assigned into five groups ($n = 10$): Group 1 served as control with no backfilling, Group 2: AH Plus + gutta-percha by the lateral compaction technique, Group 3: MetaSEAL + gutta-percha; methacrylate- based obturation, Group 4: MTA Fillapex + gutta-percha lateral compaction, Group 5: UniCore Fiber posts luted using PermaFlo

DC. All the specimens were subjected for fracture testing with a compressive load at 1 mm min⁻¹. Group 5 obtained the highest fracture resistance, whereas Group 4 yielded the lowest values. Mean fracture value of Group 5 was significantly higher than Group 2 (P = 0.02), Group 3 (P = 0.004), and Group 4 (P = 0.0001), respectively. Fiber posts become more popular with beneficial properties such as good esthetics, easy application, modulus of elasticity similar to dentin, chance of removal using their own special drills in case of retreatment, and the possibility of building a core during the same appointment the post is inserted. PermaFlo DC is a flowable composite material recommended by the manufacturer to be used when UniCore fiber posts are to be luted. This study speculates the beneficial effect of composite resins with that fiber posts, yields higher resistance values compared to other methods.

Brandon seto et al in 2013⁽⁷⁴⁾ evaluated the type and depth of restoration that would be effective in simulated immature maxillary anterior teeth in terms of fracture resistance and mode of failure. Seventy-five human maxillary anterior teeth were standardized with length followed by simulation of teeth using Peeso reamers and 3-mm-diameter engineering twist drill extended the preparation 3 and 7 mm below the facial cemento–enamel junction (CEJ). They were divided into seven different groups: Group 1: Negative control: intact teeth; Group 2: Positive control: 3 mm, no restoration; Group

3: Positive control: 7 mm, no restoration; Group 4: 3-mm composite; Group 5: 3-mm quartz fiber post; Group 6: 7-mm composite; Group 7: 7-mm quartz fiber post. Fracture resistance was performed on an Instron machine with a crosshead speed of 5 mm min⁻¹, and the maximum load at which the fracture occurred was recorded. The results showed that Group 1 showed the highest fracture resistance. Among the experimental groups, 4 and 5 showed the highest fracture resistance, which were significantly different from groups 6 and 7, respectively. They concluded that using either dual-cure composite or a quartz fiber post with composite resin to a depth of 3 mm would significantly strengthen the roots in immature teeth.

Hemalatha et al., 2009⁽²²⁾ compared the reinforcing ability of Resilon, gutta percha and Ribbond in endodontically treated roots of immature teeth. Sixty-five human maxillary anterior teeth were collected and standardized with length followed by simulation of immature teeth using Peeso reamers and placement of 4–5 mm white Pro Root mineral trioxide aggregate apical plug. All the teeth were divided into three experimental groups (n=20) and one control group (n = 5). Group I served as control group wherein root canals instrumented but not filled; Group II – backfilled with thermoplastisized gutta-percha using AH plus sealer; Group III – reinforced with Resilon using epiphany sealer; Group IV – reinforced with Ribbond fibers using Panavia F luting cement.

Fracture resistance testing done under Universal Testing Machine with a load applied on lingual surface at a crosshead speed of 5.0 mm min⁻¹. The results revealed that the control group exhibited lowest load value to fracture and group IV exhibited the highest load value to fracture. Comparison between Group IV and III and between Group IV and II revealed a highly significant difference ($P > 0.001$). They concluded that teeth reinforced with Ribbond fibers using Panavia F luting cement showed the highest resistance to fracture. They found that the stiffness of Resilon is much too low to allow that material to strengthen roots. If an endodontic filling material reinforces or strengthens endodontically treated teeth, the material should have physical properties equal to that of dentin.

Kim L. Wilkinson et al. in 2007⁽⁷⁵⁾ evaluated the fracture resistance obtained by filling root canals with Resilon, gutta-percha, a flowable composite resin, or a hybrid composite resin of simulated immature teeth. Seventy-two mandibular sheep incisors with similar dimensions were selected and randomly divided into six groups, ($n = 12$). Except negative controls, all the samples were subjected to simulation using LightSpeed LSX instrument until a size 120. The positive control canals were left unfilled and negative controls received no treatment, Group 3 - Backfill with Thermoplasticized Gutta-Percha and AH Plus Sealer, Group 4 - Backfill with RealSeal and RealSeal Root Canal Sealant, Group 5 - Backfill with Flowable Composite, Group 6 - Backfill with a Hybrid Composite. Instron

Universal Testing Machine was used to apply lingual perpendicular load 3 mm incisal to the CEJ at a crosshead speed of 5.0 mm/min. Results showed that all groups fractured either horizontal or oblique through the cervical area of the root. The fracture resistance of the BisFil II hybrid composite resin group was significantly superior to the unrestored positive controls ($p < 0.017$) and the gutta-percha group ($p < 0.012$). The increased shrinkage is associated with flowable composites because of their lower filler percentage and high root canals configuration (C-factor) lead to less predictable bonding than the hybrid composite group. The placement of a self cured, highly filled composite resin substantially increased the fracture resistance of the thin walled, simulated immature roots.

Bortoluzzi et al., in 2007⁽²⁵⁾, evaluated the fracture resistance of bovine incisors submitted to different reinforcement treatments using reforpost, mineral trioxide aggregate (MTA), and gutta-percha with mineral trioxide aggregate (MTA) apical plug. Forty bovine incisors were standardized with similar dimensions in length. They were assigned to four groups($n=10$): Group I-control (without filling); Group II-apical MTA plug + filling with gutta-percha and endodontic sealer; Group III filling with MTA; Group IV-apical MTA plug + filling with MTA + metallic post (Reforpost I). Fracture resistance testing was done in a servo-hydraulic universal testing machine at a crosshead speed of 0.5 mm min⁻¹. The results showed that Group IV presented the highest fracture resistance

(32.7N) and differed significantly from the other groups ($P < 0.05$) with no significant difference was observed between Group II and Group III ($P > 0.05$). They reported that the roots reinforced with a metallic post/MTA had fracture strength almost four times higher than the control group and twice that of roots filled with gutta-percha and sealer. Additionally, the study showed that in Group IV, the pattern changed to coronal fractures. When the fracture involved the cervical third of the root, it was noted that the post/MTA 'pillar' withstood the loading efforts and did not break. They concluded that using MTA + metallic post as an intra-radicular reinforcement treatment increased the fracture resistance.

Charles H. Stuart et al., in 2006⁽⁷⁶⁾ compared the reinforcement and strengthening ability of a Resilon (Pentron, Wallingford, CT), gutta-percha (Dentsply Tulsa Dental), and a self-curing composite resin (Bisfil 2B) (Bisco, Schaumburg, IL) in endodontically treated roots of immature teeth. Sixty single rooted maxillary anterior teeth as well as mandibular canines and premolars were collected followed by standardization of length. The samples were divided into five groups ($n = 12$) wherein Group 1 served as negative control which received no treatment. Except the negative control group, teeth in all groups were prepared using K3 files and peeso reamers followed by placement of 4 mm barrier using MTA. The roots of three experimental groups were backfilled with gutta-percha, Resilon, or Bisfil 2B and the positive control group was left

unfilled. The load was applied using an Instron universal testing machine at a crosshead speed of 5.0 mm/min and the data were recorded. The negative controls and BisFil 2B groups exhibited the highest load to fracture values. They conclude that for more developed teeth (< 1.5 mm canal diameter), Resilon and gutta-percha placement coronal to the MTA barrier in combination with a coronal access composite may provide sufficient root strength and further study is needed to verify the strengthening effect for the less developed teeth (> 1.5 mm canal diameter).

Andreasen et al., in 2006⁽⁷⁷⁾ compared the two material's effectiveness in terms of root dentin's fracture resistance. Thirty immature sheep mandibular incisors were selected and further evaluated for the fracture resistance after various treatment modalities as a root filling using calcium hydroxide (CH) or a mineral trioxide aggregate material (MTA). All the specimens were divided into four experimental groups. (a) Saline group (n=9): the teeth were preserved in saline for 100 days at 6°C. (b) CH group (n=6): the root canals were filled with CH and sealed apically with IRM and stored as above. (c) MTA group (n=7): the canals were filled with MTA and stored as above. (d) CH + MTA group (n=8): canals were filled with CH and sealed with IRM. The CH was replaced with MTA After 30 days, and stored. At the end of 100-day storage period, all teeth samples were tested for fracture strength at the cervical area using Instron testing machine. The results showed

that a decrease in fracture resistance with CH in the root canals under storage for 100 days, compared to teeth stored in intracanal saline and teeth with 30 days of CH and then filled with MTA, and those filled with MTA in the canals. To conclude, there was no significant decrease in strength of the root within an observation period of 100 days when CH was kept in the canals of immature teeth for only 30 days followed by root filling with MTA. This finding may be of importance in the decision of treatment plans for teeth with pulpal necrosis and immature root formation.

Carvalho et al., in 2004⁽⁷⁸⁾, evaluated the fracture resistance obtained by reinforcing the root canal walls with zirconium fiber post or composite resin, in simulated immature teeth. Fifty-six bovine incisors with similar dimensions were selected and the roots were enlarged with Gates-Glidden burs and tapered rounded bur no. 721 to simulate an immature tooth. They were divided into four groups (n = 14 in each group): Group 1: the root canals were reinforced with a light-cured composite resin using a translucent curing post (Luminex system); Group 2: root reinforcement with zirconium fiber post; Group 3 (positive control): received obturation with gutta-percha cones and sealer 26 cement but did not received root reinforcement; G4 (negative control): roots not weakened and did not receive reinforcement. All the specimens were submitted after one week, to test the compression strength using an Instron machine with a crosshead speed of 1 mm min⁻¹ until it

fractured. The results showed that in Group1 and 2, presented similar fracture resistance ($P > 0.05$) and were significantly different from the control groups ($P < 0.05$). Group G4 (negative control) was significantly more resistant ($P < 0.05$) than all other groups. They found that treated teeth with dentin bonded all composite post and coronal filling had more resistance to compression at 45^0 , presenting an additional resistance of 59% in comparison with the group without root reinforcement. They concluded that the use of root reinforcements with zirconium fiber post or composite resin can increase the structural resistance of the weakened teeth, decreasing the risk of the fracture.

MATERIALS AND METHODS

MATERIALS: (Figure 1)

1. Contra angle micromotor Handpiece (Waldent,EB-FY3285)
2. Airotor handpiece (NSK- 108527)
3. Micromotor (Marathon,India)
4. Digital Vernier Calliper (X0011J0PMF- ZHART, India)
5. Carborundum disk (C03/190)
6. GG Drills (LOT P21C055900, P19L025900)(Mani, India)
7. Peeso Reamers (P20F005300, P21E030900) (Mani, India)
8. Dental implant drills (NPRS504000002 - Spiral tools, Pune, India)
9. Round bur (LOT D21E155330)(Mani, India)
10. EX 24 (D21E097600)(Mani, India)
11. Hand files – # 10 size K files (Mani, Japan) (#83016).
12. 2.5 ml syringes (Unolok, India)
13. Biodentine (LOT: B27525) (todont, Saint-Maur-des-fosses, France)
14. Buchanan pluggers (REF 0770197; REF:SUPXX00139, India)
15. Dappen dish
16. Everstick Post (GC India Pvt. Ltd) (LOT: 191119A)
17. Stick resin (PROD 100026) (GC India Pvt. Ltd)
18. Etchant (LOT EGO40721)(Dentsply, India)
19. Smart Dentin Replacement compules with gun (LOT: 00081200) (Dentsply De Trey, Konstanz, Germany)

20. Prime and bond NT (LOT: 2109001177) (Dentsply De Trey, Konstanz, Germany)
21. Rely X Ultimate Resin cement (LOT: 8169395)(3M ESPE, Germany)
22. Filtek Z350 XT (3M ESPE. Germany) (7018A3B)
23. Light body impression material (Zhermack, India)
24. Light curing unit (Smartlite focus., Dentsply De Trey, Konstanz, Germany)
25. 3% Sodium Hypochlorite (NaOCl; VIP vensons, India) (B.No:21295)
26. 17% Ethylene diamine tetraacetic acid (LOT: 2110; REF: WALXX00527, India)
27. 0.9% Normal saline (93QE204001) (Fresenius Kabi India Pvt.Ltd)

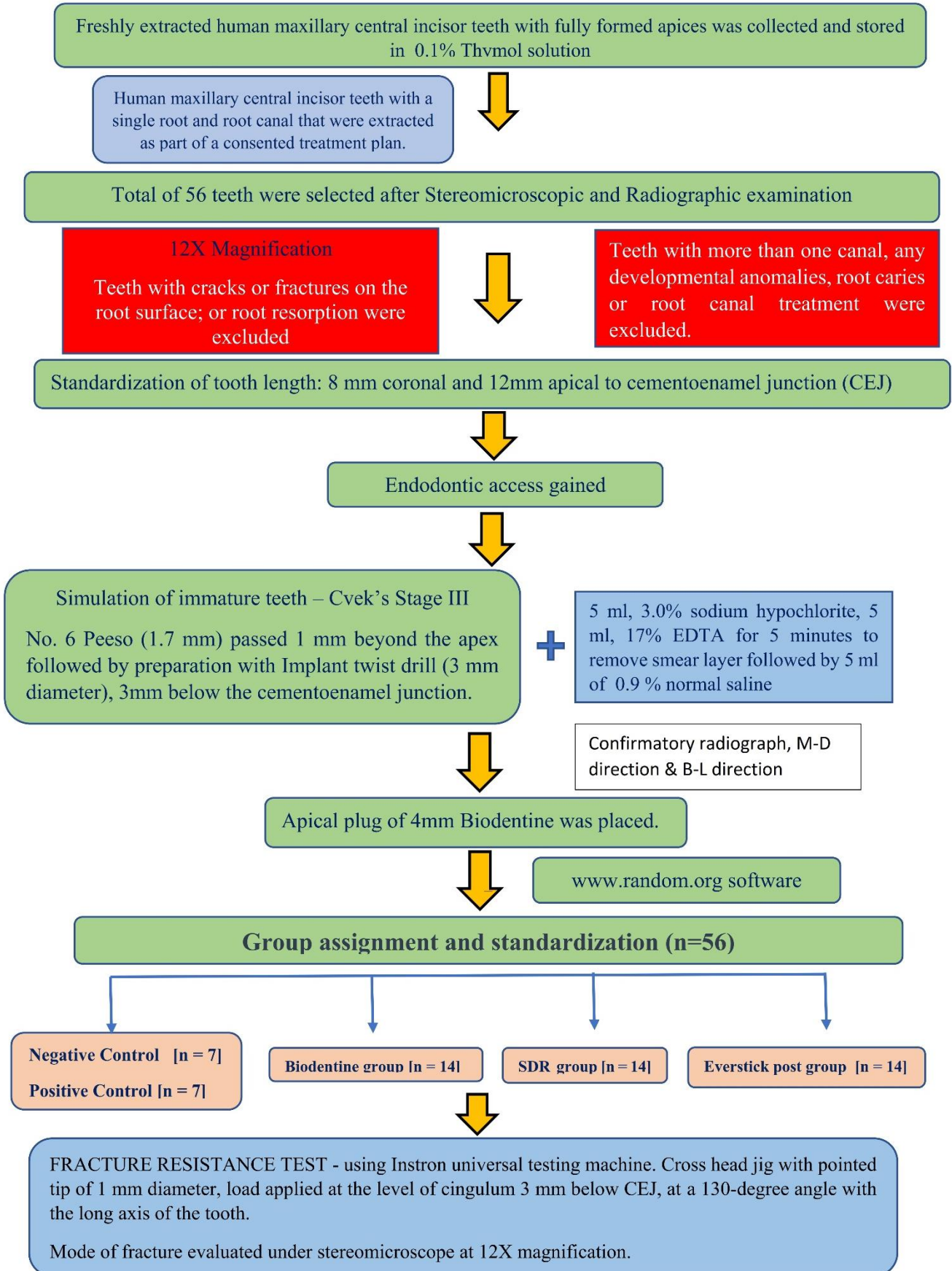
EQUIPMENTS:

1. Amalgamator (Smaco, China)
2. Stereomicroscope (LEICA M 205A, Germany) (Figure 4)
3. Instron E3000 Electropuls [Model:V1.4 (MSW- 15362), No: E3BMTB18972 UTM, England].



Figure 1: Armamentarium

FLOWCHART OF METHODOLOGY



STUDY APPROVAL: This study was approved by Institutional Review Board & Human Ethics Committee Review Board (Ref No: Sathyabama University/183/IRB-IBSEC/SIST)

Study Design: In-vitro

SAMPLE SIZE CALCULATION:

The sample size was calculated based on a study by Hemalatha et al.,(22) with a given effect size of 1.3, an alpha error of 0.05, and a power beta of 0.90 into an a priori sample test from the t-tests family. Sample size was calculated using G*Power software (3.1.9.3 for Macintosh; Heinrich Heine, Universität Dusseldorf, Dusseldorf, Germany). The results demonstrated the need for a minimum of 14 samples per group.

t tests - Means: Difference between two independent means (two groups)

Analysis:A priori: Compute required sample size

Input: Tail(s) = Two

Effect size d = 1.34

α err prob = 0.05

Power (1- β err prob) = 0.90

Allocation ratio N2/N1 = 1

Output: Noncentrality parameter δ =

3.4163431

Critical t = 2.0638986

Sample size group 1 = 14

Sample size group 2 = 14

Sample size group 3	= 14
Sample size group 4	= 14
Total sample size	= 56
Actual power	= 0.9060473

SAMPLE SELECTION:

After obtaining approval from the Institutional Human Ethical Committee of Sathyabama university, freshly extracted human maxillary central incisors with fully formed apices were collected (Figure 2) from department of Oral and Maxillofacial Surgery, Sathyabama Dental College and Hospital. All teeth were cleaned of gross debris and rinsed under running water and then stored in 0.1% thymol solution until further use (Figure 3).^(79,80) Teeth of similar coronal and radicular dimensions, with a crown length of 8mm or more and a root length of 12mm or more; and teeth with mean width of 5.6 ± 0.5 mm faciolingually and 6.3 ± 0.4 mm mesiodistally at the cemento - enamel junction (CEJ) were selected. The dimensions were measured using digital vernier calliper.⁽⁴⁹⁾ All teeth were examined under a stereomicroscope (LEICA M 205A, Germany) (Figure 4) at 12x magnification, to rule out presence of cracks, fractures, caries, restorations or resorption in the root surface (Figure 5A & 5B). Digital radiographs were obtained in mesiodistal and buccolingual directions of all samples. Any teeth with more than one canal, developmental anomalies or root canal treatment were excluded (Figure 6 & 7). After exclusion, a total of 56 teeth meeting the inclusion criteria were selected (Figure 8).

SAMPLE PREPARATION

To standardize the tooth length, the incisal edges of all specimens were cut with a diamond disc to a length of 8 mm from the cementoenamel junction (CEJ) (Figure 9a) and the roots were sectioned 12 mm apical to the CEJ (Figure 9b & 9c). Seven standardized human maxillary central incisor teeth were randomly assigned to negative control group using www.random.org software.

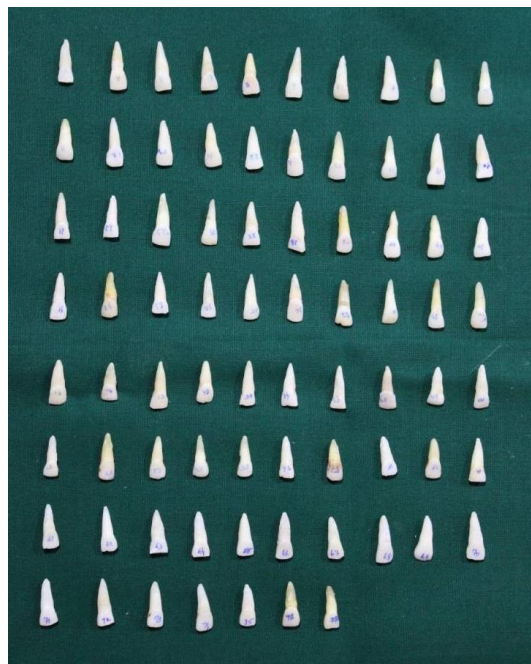


Figure 2: Extracted teeth samples



Figure 3: Samples stored in 0.1% thymol solution



Figure 4: Stereomicroscope (LEICA M205A)

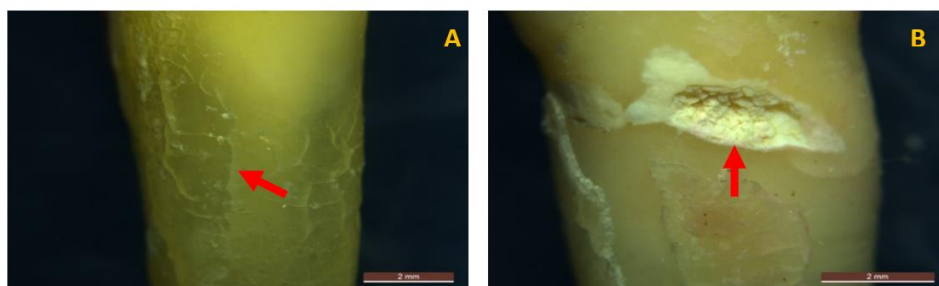


Figure 5A & 5B: (Red arrow indicate samples with cracks and resorbed area) -Stereomicroscopic evaluation

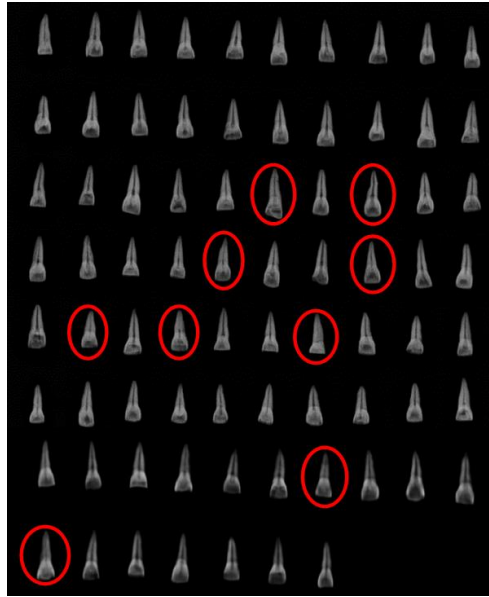


Figure 6: Digital radiographs of samples in Bucco - Lingual direction (Red ring indicates excluded samples)

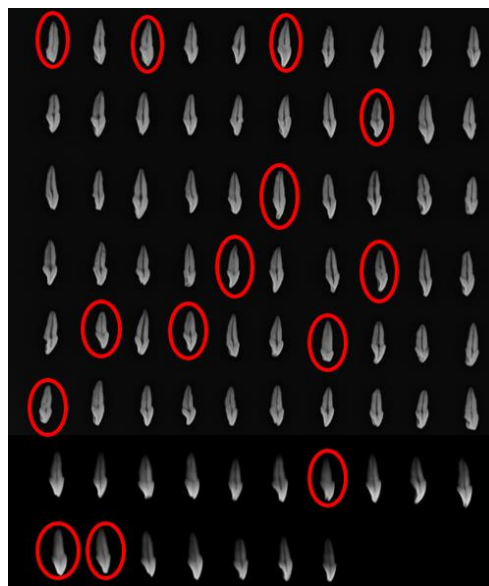


Figure 7: Digital radiographs of samples in Mesio – Distal direction (Red ring indicates excluded samples)

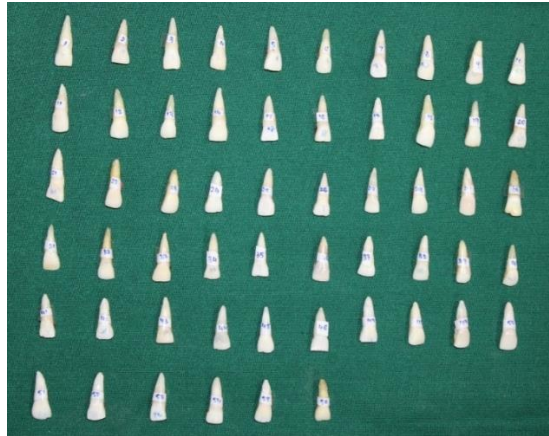


Figure 8: Included samples

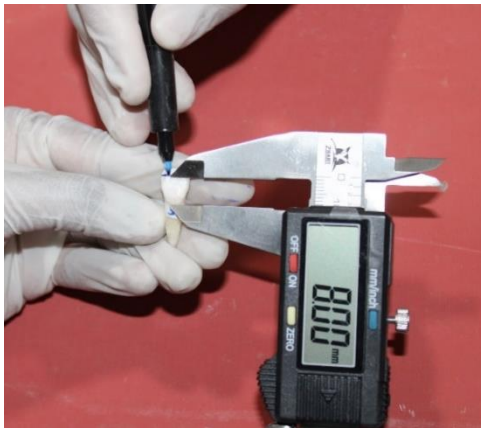


Figure 9a: Standardization of crown length



Figure 9b: Standardization of root length



Figure 9c: Diamond disc used to section the crown and root length

Simulation of immature teeth

Coronal access was made using No 4 round diamond bur and Ex24 bur (Non-end cutting tapered fissure) (Mani) (Figure 10) in a high-speed airtor handpiece (NSK) under water coolant. The canal space was enlarged with Gates Glidden drills (Mani, India) from size 1 to 5. To simulate immature teeth, (Figure 11a) the root canals were instrumented with Peeso reamers (No 1 -6) (Mani India) until a no. 6 Peeso reamer (1.7 mm) could be passed 1 mm beyond the apex (Figure 11b). A size 3 implant drill (Spiral tools, Pune, India) of 3 mm diameter (Figure 11c) was used to extend the preparation of the canal 3mm below the cemento enamel junction⁽⁸¹⁾. This preparation resulted in root-to-canal width ratio of approximately 1:1 in the mesiodistal direction at the CEJ, to simulate Cvek's stage III of root development [Appendix A]. After instrumentation, each root was irrigated with 5 ml of 3.0% sodium hypochlorite and 5 ml of 17% EDTA for 5 minutes to remove smear layer, followed by a final rinse with 5ml of 0.9% of normal saline. Radiographs were taken mesiodistally to verify the remaining dentin thickness at the level of cemento enamel junction (Figure 12). Biodentine (Septodont, Saint-Maur-defosses, France) was mixed according to the manufacturer's recommendations. Liquid from a single-dose container was emptied into a powder-containing capsule. It was mixed for 30 s at 4000–4200 rpm using a dental amalgamator (Figure 15 a & b). An apical plug of 4-mm of Biodentine was placed using Schilders MTA carrier and compacted with Buchanan hand pluggers. Radiographs were taken to confirm the length and density of Biodentine apical plug in all teeth (Figure 13).



Figure 10: Access cavity preparation



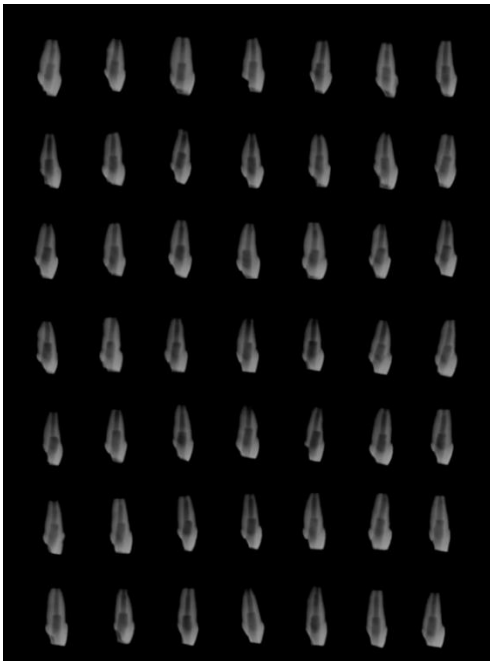
Figure 11a: Preparation with Peeso reamers



**Figure 11b: Peeso reamers passed
1mm beyond apex**



**Figure 11c: Simulation of teeth using
Number 3 Implant drill**



**Figure 12: Digital radiograph in
mesio – distal direction to confirm
1:1 canal to root width ratio**



**Figure 13: Digital radiograph
confirming Biodentine apical
plugs**

Group assignment:

Randomization method: The simulated samples with Biodentine apical plug were randomly assigned using the software www.random.org into four groups, three experimental groups (n=14) according to the material used to reinforce the simulated immature central incisor teeth, and positive control group (n=7) (Box: 1).

GROUPS:**BOX: 1**

GROUPS	One Control and 3 Experimental groups
Negative Control	Standardized intact teeth
Positive Control	Simulated immature teeth + Biodentine apical plug + canals left unfilled
Biodentine	Simulated immature teeth + Biodentine apical plug + canals filled with Biodentine
SDR	Simulated immature teeth + Biodentine apical plug+ canals filled with SDR
<u>Everstick post</u>	Simulated immature teeth +Biodentine apical plug + canals filled with Everstick post

Biodentine Group:

Liquid from a single-dose container was emptied into a powder-containing capsule. It was mixed for 30 s at 4000–4200 rpm using a dental amalgamator according to the manufacturer's (Figure 14a & b) recommendation. The entire root canal was filled with

Biodentine [Septodont, Saint Maur des Fosses, France] which was condensed using Buchanan hand pluggers to a level of 2 mm below the CEJ (Figure 15). Fifteen minutes after placement of Biodentine, the access cavity was pre-treated with 37% phosphoric acid for 15 seconds and rinsed followed by application of bonding agent and light cured. Composite build-up was done with light polymerizable composite resin Filtek Z- 350 (3M ESPE) and light cured for 20 seconds. Radiographs were taken to ensure adequate homogeneous root filling without voids (Figure 16).



Figure 14a: Amalgamator



Figure 14 b: Biodentine

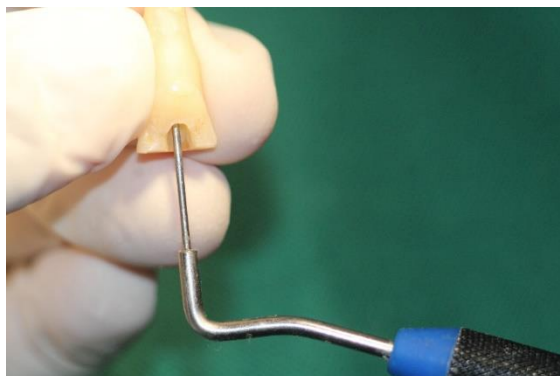


Figure 15: Condensation using Buchanan Pluggers

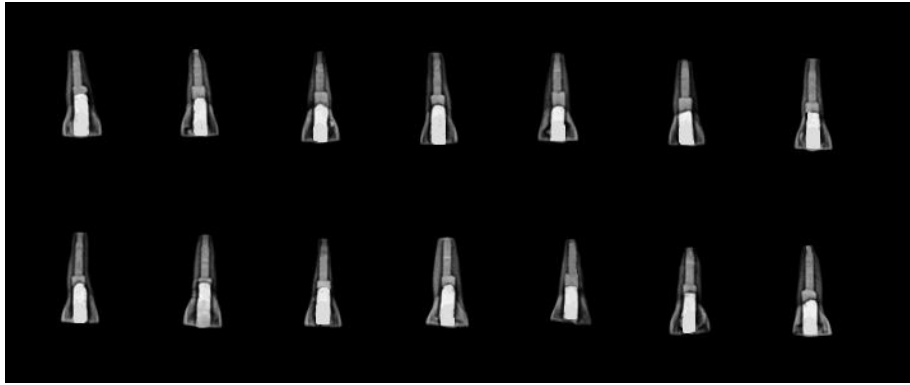


Figure 16: Digital radiograph – Biodentine group

Smart Dentin Replacement (SDR) Group:

The root canal space was etched with 37% phosphoric acid for 15 seconds, rinsed and blot dried using paper points, followed by application of Prime and Bond NT adhesive (Dentsply De Trey, Konstanz, Germany) using an applicator tip and light cured for 20 seconds. The bulk fill flowable SDR (Dentsply De Trey, Konstanz, Germany) compule was loaded in a special gun and the applicator tip was inserted into the root canal (Figure 17a). The canals were filled in 4mm increments within 2 mm of the CEJ and each increment was light cured for 20 seconds (Figure 17b). Access cavity was restored with light polymerizable composite resin Filtek Z- 350 (3M ESPE) and light cured for 20 seconds. Teeth were digitally radiographed to verify the absence of voids and length of SDR fillings (Figure 18).



Figure 17 a: Placement of SDR material



Figure 17b: Light curing done for 20 seconds

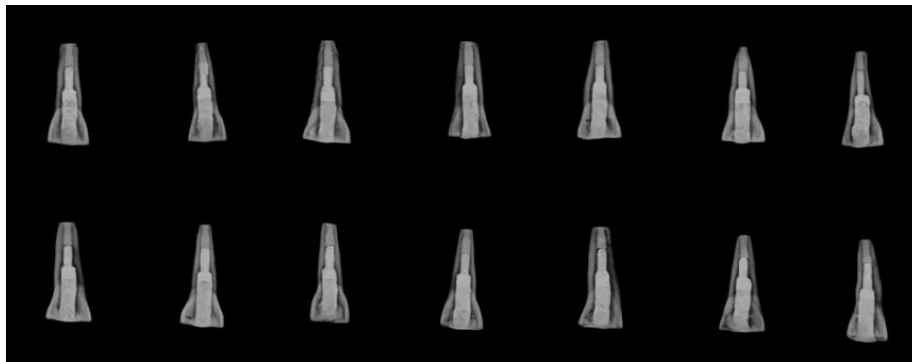


Figure 18: Digital radiograph after placement of SDR material

Everstick post Group:

Each individual post was formed from one fiber bundle of 1.2 mm diameter and two fiber bundles of 0.9 mm diameter of Everstick Post (GC India Pvt. Ltd) cut to required length of 12 mm (Figure 19a). The individually formed fiber post, was treated with light polymerizable dimethacrylate monomer resin consisting of BisGMA and TEGDMA [Stick Resin] for 5 minutes (Figure 19b) in the dark and then light-cured for 10 seconds (Figure 19c). Everstick Post was luted into the root canal with a self-adhesive Universal resin cement Rely X Unicem and light cured for 20 seconds (Smartlite focus., Dentsply De Trey, Konstanz, Germany). No surface pretreatment of

the root dentin walls was performed for this group, as the manufacture's recommendation did not warrant any. Pretreatment done with 37% phosphoric acid for 15 seconds and rinsed followed by application of bonding agent and light cured. Approximately 4mm of composite build-up was done on the post head with light polymerizable composite resin Filtek Z- 350 (3M ESPE) and light cured for 20 seconds.



Figure 19a: Individually formed fiber post

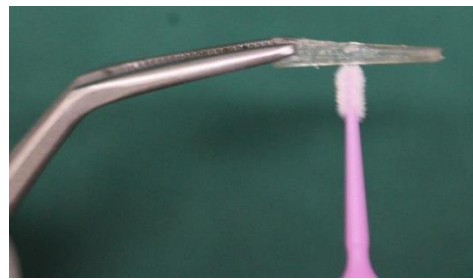


Figure 19b: Application of stick resin



Figure 19c: Light curing done

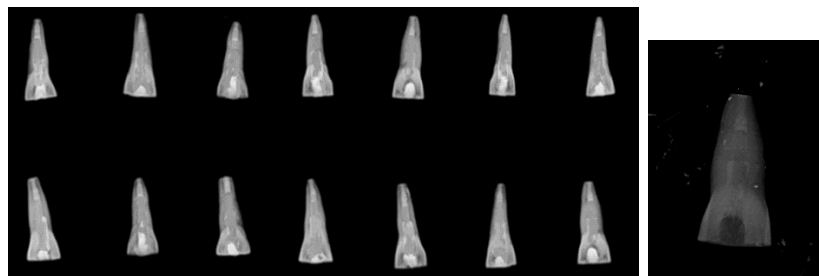


Figure 19d: Digital radiographs after placement of Everstick post.

All samples were placed in sealed containers with damp cotton wool rolls and wrapped in gauze and were stored at 37°C in 100% relative humidity for 3 days.

Sample preparation for fracture resistance test

To simulate the periodontal ligament (0.2–0.3 mm), all samples' roots were wrapped in a single layer of aluminium foil (Figure 20a) 2 mm below the CEJ. Each root was embedded in a standard cylindrical mould filled with acrylic resin to create an artificial socket exposing 2 mm of root below the level of the CEJ. The roots were removed from acrylic mould, followed by the removal of aluminium foil (Figure 20b) after which the inner surface was cleaned. A low consistency light body silicon rubber base impression material (Zhermack, India) was injected into the socket (Figure 20 c), then the root was repositioned carefully (Figure 20 d).



Figure 20a: Teeth wrapped with aluminium foil



Figure 20b: Cylindrical moulds with acrylic resin – after removal of aluminium foil

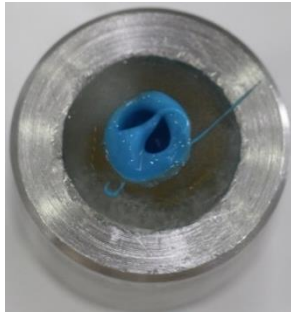


Figure 20c: Insertion of light body impression material

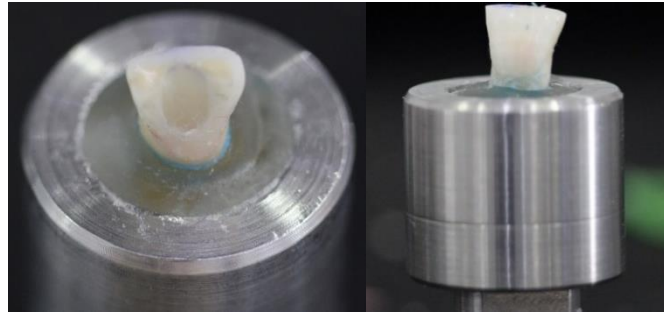


Figure 20d: Tooth repositioned in socket

FRACTURE RESISTANCE TEST

Fracture resistance testing was performed in an Instron universal testing machine (INSTRON E3000 UTM ELECTROPULS, England) (Figure 21) in compressive mode of load applied at 130° to the long axis of the tooth. The load was applied at a point 3mm below the cemento-enamel junction on the palatal surface of the crown. A custom-made metallic jig (Figure 22) with tip diameter of 1mm, attached to the upper movable compartment of the testing machine, traveling at a cross-head speed of 1 mm/min (Figure 23) was exerted until failure occurred; load at failure was recorded in Newtons (38). The data was recorded using BLUEHILL UNIVERSAL Model:V1.4 (MSW- 15362).



Figure 21: Instron E3000 UTM Electropuls



Figure 22: Custom made jig



Figure 23: 130° angle to the long axis of tooth

Evaluation of mode of fracture:

After fracture testing, the teeth were removed from the acrylic resin moulds. All teeth were examined under stereomicroscope (LEICA M 205A, Germany) at 12X magnification for evaluation of fracture modes according to modified classification by Santos et al. [Box no: 2] [Appendix B] as

Box No: 2 Mode of fracture classified by Santos et al

Type I	Resin/Core fracture
Type II	Cervical root fracture
Type III	Mid root fracture
Type IV	Apical root fracture
Type V	Vertical root fracture

STATISTICAL ANALYSIS

Statistical analysis was performed using EPI-INFO (version 7.2.2.6, CDC license: Atlanta, Georgia US: public domain) software. Normality of the data was tested using Kolmogorov-Smirnov test (P-value > 0.005) (Table 1). Levene's test confirmed the homogeneity of variance among the groups (P-value > 0.005) (Table 2). Mean and Standard deviations were tabulated based on the maximum load to fracture. One-way ANOVA, a parametric test, was used to analyze the differences in the maximum force applied to the control and experimental groups. The post hoc Tukey test was used to analyze the multiple comparisons between all groups. Chi-square test was used to identify differences in mode of fracture between the groups. Significance level was fixed at 5% ($\alpha = 0.05$) (p-value < 0.05).

RESULTS

Forty nine simulated immature human maxillary central incisors with Biodentin apical plug were randomly divided into three experimental groups (n= 14), namely, Biodentine, Smart Dentin Replacement, and Everstick post, and positive control group (n=7); and standardised intact teeth served as negative control (n=7). All samples were subjected to fracture resistance testing using an Instron universal testing machine, and maximum load at failure was recorded in Newtons, and the data were statistically analysed.

Table 1: Normality distribution

Kolmogorov-Smirnov Statistic	Df	Sig.
.073	56	.200

*(p value > 0.005) Data were normally distributed

Table 2: Test of Homogeneity of variance

Levene Statistic	df1	df2	Sig.
1.324	4	51	.274

*(p value > 0.005) Variance among groups are approximately equal

FRACTURE RESISTANCE TEST:

The mean value and standard deviation of maximum load at fracture in Newtons are listed for all groups in Table 3. Among the experimental groups, the Biodentine group showed the highest load

required to fracture (Mean=755.51 N $\pm$ 122.11), and it was the only group with a comparable load to fracture, to that of the negative control group (Mean=811.77 N $\pm$ 169.69); and was closely, followed by the SDR group (Mean=647.69 N $\pm$ 144.36). On the contrary, the positive control group required the lowest load to fracture (Mean = 298.96 N $\pm$ 84.98). One way ANOVA test revealed a statistically significant difference between the groups (p-value = 0.001) Table 3.

Tukey post hoc test for multiple group comparison was applied, as shown in Table 4. The Positive control group showed the least load required to fracture when compared with all other groups, which was statistically significant (p-value < 0.05). No statistically significant difference was observed in the maximum load required to fracture between the Negative control, Biodentine, and SDR groups (p-value > 0.05). All three experimental groups showed a significantly higher load required to fracture compared to the positive control group (p-value > 0.05). Among the experimental groups, the Everstick post group showed the least mean load required to fracture, which was statistically significant compared to the Biodentine group (p-value < 0.05). Graphical representation of mean value for fracture resistance as shown in Graph 1.

Table 3: Mean load to fracture and standard deviation of all groups:

Group	N	Mean (Newton)	Std. Deviation	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
Negative Control	7	811.77	169.69	654.83	968.71
Positive Control	7	298.96	84.98	220.37	377.55
Bio-dentine	14	755.51	122.11	685.00	826.01
SDR	14	647.69	144.36	564.34	731.04
Everstick Post	14	535.04	149.44	448.75	621.32
P value	.001*				

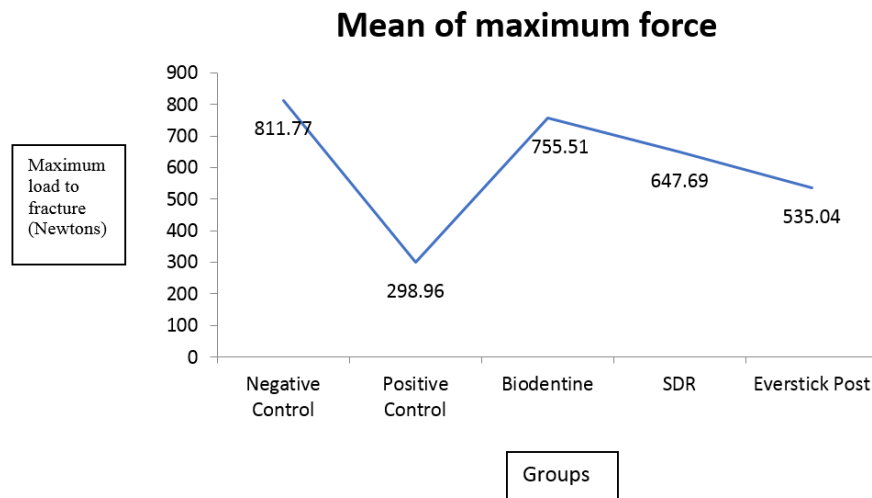
*p value < 0.05, Statistically significant difference of maximum load to fracture between groups

Table 4: Multiple comparisons using post-hoc Tukey test

Group		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Negative Control	Positive Control	512.81	73.76	.001*	304.23	721.39
	Bio dentine	56.26	63.88	.903	-124.37	236.90
	SDR	164.08	63.88	.092	-16.55	344.72
	Everstick Post	276.73	63.88	.001*	96.10	457.37
Positive Control	Bio dentine	-456.55	63.88	.001*	-637.18	-275.91
	SDR	-348.73	63.88	.001*	-529.36	-168.09
	Everstick Post	-236.08	63.88	.005*	-416.71	-55.44
Biodentine	SDR	107.82	52.16	.250	-39.67	255.31
	Everstick Post	220.47	52.16	.001*	72.98	367.96
SDR	Everstick Post	112.65	52.16	.212	-34.84	260.14

*(p value >0.05) - negative control, Biodentine and SDR groups

*(p- value< 0.05) - positive control and Everstick post

Graph 1: Mean of maximum load to fracture among groups**MODE OF FRACTURE:**

Fracture modes were evaluated under stereomicroscope and categorised according to the modified classification described by Santos Filho et al.⁽³³⁾ Overall frequency distribution of fracture mode is tabulated in Table 5 and the frequency distribution of fracture modes among the groups is presented in Table 6. The Chi-square test revealed a statistically significant difference in fracture modes between the groups (p -value < 0.05) (Table 6). Overall out of the 56 samples, vast majority of samples showed Type III fracture (78.6%), followed by Type I (8.9%), Type V (7.1%), and Type II (5.4%) (Table 6). In the Biodentine group all samples (100%) had Type III fractures. From Table 6, it is evident that there is a significant association between group and Type of fracture (P -value < 0.05). Representative images for mode of fracture is shown in Figure 24:

Table 5: Overall frequency

Mode of Fracture	Frequency	Percent
Type I	5	8.9
Type II	3	5.4
Type III	44	78.6
Type V	4	7.1
Total	56	100.0

Overall frequency for mode of fractures using Chi square test

**Table 6: Cross-tabulation between Group and Type of fracture
using Chi-square test**

Group	Type I	Type II	Type III	Type IV	Type V	Total	P-value
Negative Control	3(42.9)	1(14.3)	3(42.9)	0	0	7(100)	.003*
Positive Control	0	0	7(100)	0	0	7(100)	
Bio-dentine	0	0	14(100)	0	0	14(100)	
SDR	2 (14.3)	1(7.1)	11(78.6)	0	0	14(100)	
Everstick Post	0	1(7.1)	9(64.3)	0	4(28.6)	14(100)	

* (p-value < 0.05)

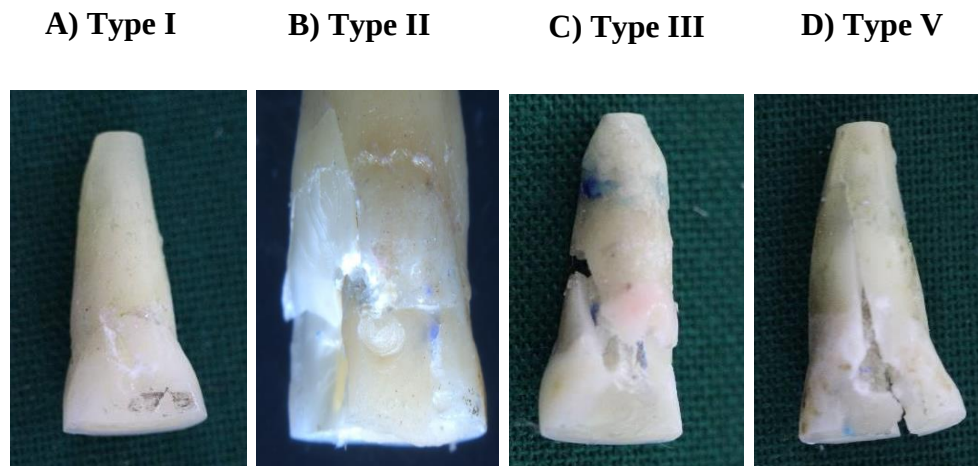


Figure 24: Representative images of mode of fracture classifies according to Santos et al.,

A) Type I -Negative control group, B) Type II -SDR group), C) Type III - Biodentine group, D) Type V -Everstick post group

DISCUSSION

The open apex typically occurs when the pulp undergoes necrosis as a result of caries or trauma before root growth and development are complete. This presents a unique situation as these teeth are not direct candidate for conventional root canal treatment.⁽¹⁾ The developmental stage of root formation may be a critical factor in determining the course of action. Cvek has classified the teeth with immature apex based on the root development stage and the canal's diameter at the apex. Traumatized immature teeth in Cvek's stage III of root development pose a clinical dilemma, as conventional endodontic treatment is not possible in these cases because of the open apex. and suitable root length.⁽⁸²⁾ Apexification with placement of an artificial apical barrier using bioactive materials called the "apical barrier technique" is popular treatment choice for these teeth because of the favorable root length, shortened treatment time and predictable outcomes.^(7,8) Although placement of an apical barrier with bioceramic materials like MTA, Biodentine, etc., offers the advantage of immediate apical stop against which the obturating material may be compacted to achieve good apical seal but neither the barrier nor the obturating material provide any reinforcement to the thin root dentinal walls.^(53,54,60) Many times, these teeth succumb to failure in long term evaluations, due to fracture despite good periapical healing.⁽⁸³⁾ Hence, there is a pressing need to

reinforce immature permanent teeth treated with apexification at the cervical level to improve longevity.⁽⁵²⁾ Various attempts have been made in the past to reinforce immature permanent teeth using different types of posts, composite resins, bioceramic materials etc., with mixed results.^(24,44,53,54,59,64,75) None of these materials were able to restore the strength of the immature teeth to that of a fully developed natural teeth.^(23,54,59,64)

The most common material of choice for single visit apexification was mineral trioxide aggregate [MTA].⁽⁸⁾ The use of MTA had gained popularity due to its biocompatibility, good sealing ability, antimicrobial properties, ability to set in the presence of moisture, and induction of hard tissue deposition. However, the drawbacks of MTA include long setting time, poor handling characteristics, lower resistance to compression, low flow capacity, limited resistance to washout before setting and the possibility of staining tooth structure.^(84,85)

Biodentine, a silicate-based bioactive cement was introduced with dentine-like mechanical properties to improve several drawbacks associated with the earlier calcium silicate cement, while enhancing its physical and mechanical properties.⁽³¹⁾ Biodentine, when used as an apical plug has shown comparable sealing ability to that of MTA. In-vitro studies and some case reports have shown favourable outcomes following apexification with Biodentine.^{(57,85–}

⁸⁷⁾ The amount of apical microleakage was significantly lower, with 3 and 4 mm apical plugs of Biodentine.⁽⁵⁸⁾ Previous studies, have shown that the filling of the entire root canal with Biodentine could strengthen the remaining tooth structure.^(54,71) A few studies that have evaluated and compared the reinforcement of immature teeth filled completely with Biodentine have shown promising outcomes.⁽⁵²⁻⁵⁴⁾ Consequently, Biodentine was used in this study as the apical plug and evaluated for its reinforcement ability as a root filling material.

Smart dentin replacement was one of the first bulk-fill flowable composite material to be introduced⁽³⁹⁾. Based on its properties, such as lower polymerization shrinkage, greater depth of cure and self-levelling feature, it was tried as a post material to rehabilitate weakened root canals and scored the highest fracture resistance results.⁽⁶⁶⁾ Besides, the claim of a self-levelling adaptation, the new flowable composite features a ‘polymerization modulator’ that, according to the manufacturer, provides the resin with a stress decreasing ability.^(68,89)

EverStick post is a soft, flexible, and un-polymerized glass fiber post consisting of a unidirectional fiber bundle with diameter available in sizes 0.9, 1.2 mm and 1.5 mm, with an interpenetrating polymer network (IPN), which strengthens the bond between the post and the resin, creating a monoblock. Everstick fibers can be

individually adapted to the shape of the root canal. Additional strips of the post can be added in a lateral condensation like technique to completely fill and adapt to the canal. This unique technique of this post enables its use in large, oval, or even curved canals without need for additional canal preparation to receive the post. As flexural strength and elasticity of these posts is similar to dentin, it is believed that stresses will be evenly distributed throughout the length of the root. ⁽⁴⁴⁾

So far in the literature, no evidence is available comparing the reinforcement ability of these materials in human immature permanent teeth following one step apexification. Therefore, this study was aimed at evaluating the fracture resistance of simulated immature permanent teeth with Biodentine apical plug; restored with Biodentine, SDR and Everstick post as reinforcement materials.

In the present study, maxillary central incisor teeth were selected to simulate the clinical conditions as they are most susceptible to trauma in young patients.⁽¹⁾ Freshly extracted human maxillary central incisor teeth were collected and stored in 0.1% thymol solution or distilled water throughout the study period to maintain dentin's viscoelastic property.⁽⁸⁰⁾ Teeth with standardised dimension of 5.6 ± 0.5 mm faciolingually and 6.3 ± 0.4 mm

mesiodistally at the level of CEJ were selected to ensure simulation of Cvek's stage III and standardization.⁽⁶⁵⁾

The included teeth were modified to simulate Cvek's stage III of root development as these are the teeth that qualify for apexification procedure when rendered nonvital in the clinical situation. Simulation of immature teeth has been achieved using various techniques, such as shortening of roots and orthograde widening of the canals using Peeso reamers, engineering twist drills, large files or by retrograde preparation.^(22,60,65) In this study, the root tips were sectioned to retain 12 mm of root length, a size 6 Peeso was passed 1 mm beyond the apex and a size 3 implant drill (3mm diameter) was used 3mm apical to the CEJ. This procedure consistently produced samples, that resulted in an aperture of 1.7mm, simulating an open apex and root-to-canal ratio of 1:1 in a mesiodistal dimension at CEJ, closely simulating Cvek's stage III root development.⁽²²⁾ Apical openings of less than 1.5 mm or root dentin thickness above 2.63mm were found insufficient to simulate weakened immature permanent teeth^(10,22,52,90). Throughout the instrumentation procedure for simulation, irrigation with normal saline was performed to avoid deleterious increase in temperature that may adversely affect the properties of root dentin.⁽⁹¹⁾

For measurement of fracture resistance of teeth, Instron universal testing machine is the accepted standard.⁽⁸¹⁾ Each mounted

sample was fixed in a jig that ensured a loading angle of 130 degrees to the long axis of the tooth. This angle was chosen because it simulates the average angle of contact between maxillary and mandibular incisors in Class I occlusion. ^(65,76,78) Soares et al, showed that PDL simulation had a significant effect on fracture resistance in a similar ex-vivo laboratory model.⁽⁹²⁾ In this study, an attempt to simulate periodontal ligament was done using thin layer of polyvinylsiloxane impression material which sports modulus of elasticity similar to human periodontal ligament. ⁽²²⁾ A gap of 2 mm between the top of the acrylic mounting and the CEJ was maintained to mimic the physiologic space found between the crest of the alveolar bone to the CEJ, where the fracture is likely to occur when horizontal forces act on the tooth crown.⁽²²⁾ For all of the above, the present model was suitable for testing the hypothesis.

In this study, the positive control group (mean 298.96 ± 84.98) fractured with the least load which was statistically significant compared to all the other groups ($p\text{-value} < 0.05$). In this group, samples were prepared to simulate single step apexification with Biodentine but were left unfilled. These results corroborate the evidence that bioceramic apical plugs do not reinforce immature teeth. The negative control group consisting of shortened intact permanent central incisor teeth required the maximum load to fracture (Mean 811.77 ± 169.69). All materials tested resulted in varying degrees of reinforcement of simulated immature teeth. The

results of this study are supported by Girish et al.,⁽⁵³⁾ in which no significant difference was observed in fracture resistance of teeth restored with Biodentine and SDR, compared to the negative control group (p-value > 0.05). The results of our study indicate that both Biodentine and SDR when used as an intracanal filling material following single step apexification were able to restore the fracture resistance of weakened immature permanent teeth very close to that of intact natural teeth within the tested conditions (p-value > 0.05). Among the materials evaluated for reinforcement of immature permanent teeth, Biodentine group (mean 755.51 ± 122.11) showed maximum resistance to fracture. Biodentine has shown to significantly strengthen simulated immature permanent teeth in other invitro studies.^(53,54) Biodentine is considered 'dentin replacement material' as it shows properties of flexural strength, modulus of elasticity and microhardness similar to that of natural dentin resulting in uniform distribution of forces.⁽³²⁾ Loss of bound water from dentin in pulpless teeth may result in reduction of flexural strength.⁽⁹³⁾ Atmeh et al and Han et al., have demonstrated biomineralisation and presence of 'mineral infiltration zone' in dentin surface proximal to biodentin.^(94,95) Furthermore, these authors have also described movement of water from Biodentine into the subjacent dentin substrate. The alkalinity of Biodentine is said to result in degradation of collagen bonds in dentin and the loss of banding in collagen structure allows for diffusion of water and ions such as calcium, silica and carbonate into the interfacial dentin

resulting in a mineral infiltration zone. The effect of rehydration, remineralisation of dentin substrate, chemical bond in addition to the similarities in the biomechanical properties of biodentine to dentin, may have added to the fracture resistance of simulated immature permanent teeth completely obturated with Biodentine.

A 5 to 15 year follow up of 83 teeth in 72 patients treated with MTA apical barrier and adhesive restorations with or without post, from a private endodontic practice reported that 96% of teeth treated with MTA apical barrier technique and intracanal adhesive restorations healed and were functional⁽¹⁹⁾. Many invitro studies have also shown the ability of composite resins to reinforce simulated immature teeth in experimental conditions.^(23,56,75) In this study, SDR group has shown fracture resistance comparable to intact teeth (p-value > 0.05). SDR is a bulkfill composite with excellent adaptation due to its self levelling properties and claim to exhibit low shrinkage stress.⁽⁶⁸⁾ The translucency of the material coupled with the high intensity light curing device allows for better polymerisation and better physical and mechanical properties.^(26,39) SDR has performed well when used for intracanal rehabilitation of weakened roots.^(49,66) The significant increase in fracture resistance in SDR group (Mean = 647.69 N $\pm$ 144.36) in this study may be attributed to the reduced number of interfaces; and the etch and rinse adhesive pretreatment, resulting in a ‘monoblock effect’. Additionally, these resins are patented under “Stress Decreasing

Resin” technology, thus negating the compounding effects of polymerization shrinkage stress within the root canal.

The Everstick post group has shown the least fracture resistance (Mean = 535.04 ± 149.44) among the experimental groups, which was statistically significant compared to Biodentine group (p-value < 0.05). Although, Everstick Post was expected to behave like a monoblock, most samples in this group failed at the post - dentin interface and separation of the post fibres was also observed under the stereomicroscope. This finding is in contradiction with one other study where the samples were endodontically treated teeth that were not structurally compromised.⁽⁴⁴⁾ The reason for adhesive failure could also be related to lack of pretreatment of the prepared root canal surfaces in this group prior to cementation with the self-adhesive resin cement.⁽⁴⁴⁾ Although the self-adhesive resin cement contains bifunctional phosphoric acid methacrylate groups, their weaker acidic pH may not have been sufficient to obtain adequate smear layer removal.

The fracture modes of samples in all the groups were categorised according to Santos et al, in which Type 1 was considered restorable and all others were considered unrestorable fractures. Regarding the mode of fracture, 3 out of 7 samples in negative control and 2 out of 14 samples in SDR group showed only

cracks in the crown part of the tooth structure (Type I). Most frequently encountered type of fracture was type III, mid-root level which were unrestorable. This finding was in agreement to that of Yasin et al⁽³⁴⁾. Although the Biodentine group showed highest resistance to fracture among the experimental groups the fracture mode in all samples (100%) were Type III similar to that of the positive control group. Everstick Post group was the only group that showed failure by vertical root fracture (28.6%). None of the fracture lines passed through the restorative materials in any of the groups signifying adhesive type of failure.

LIMITATIONS

1. Although, every effort was made to closely simulate immature permanent teeth in this study, it may not exactly reproduce clinical conditions, physical properties of the tissue and its composition.
2. Clinical failures of endodontically treated immature permanent teeth occur due to cyclic fatigue or recurrence of a traumatic event. The testing conditions used in this study did not replicate either.
3. Ageing of the tooth samples may have provided insight on long term performance of these materials.
4. Within the limitations of this study, all materials evaluated reinforced the simulated immature permanent teeth, but none were able to create a monoblock effect. Future clinical studies are required to assess the reinforcement ability of these restorative materials in function.

SUMMARY

This in vitro study compared the fracture resistance of simulated immature human maxillary central incisors reinforced with Biodentine, Smart Dentin Replacement and Everstick post with a Biodentine apical plug. Fifty-six human maxillary central incisors were selected based on inclusion/exclusion criteria. Crown and root length of samples were standardised by sectioning both coronal and apical ends. To simulate Cvek's stage III of root development, peeso reamers were used until size 6 was taken beyond the apex, followed by preparation with a dental implant drill of 3mm diameter, 3mm apical to the CEJ. A 4mm apical plug was placed using Biodentine and the samples were randomly divided into four groups (n = 14); one control and three experimental groups. Negative control group (n=7) - Intact teeth with no treatment, Positive control group (n=7) - the canals were left unfilled, Biodentine Group – canals were filled with Biodentine, SDR group – canals were filled with SDR, Everstick post group – canals were filled with Everstick post. All the samples were subjected to fracture testing in an Instron universal testing machine at an angle of 130° to the long axis of tooth and the maximum load to fracture was recorded. The mode of fracture was evaluated under stereomicroscope. The mean maximum load was statistically analysed using one way ANOVA and post hoc Tuckey tests; and the fracture mode was analysed using Chi-square test. The results showed that all experimental groups showed significant increase in

fracture resistance compared to positive control group. Both Biodentine group and SDR group had fracture resistance similar to that of the negative control group with no statistically significant difference. Biodentine group showed the highest fracture resistance among the experimental groups and was significantly higher than SDR group. Most frequent location of fracture observed in all experimental groups was mid root fracture which was similar to that of positive control group. Within the limitations of this study, it may be concluded that Biodentine, SDR and Everstick Post were all able to reinforce simulated immature teeth. Biodentine showed highest increase in fracture resistance but 100% of the failures were unrestorable.

CONCLUSION

Within the limitations of this study, it is concluded that

- ✓ All restorative materials tested were able to significantly reinforce simulated immature permanent teeth.
- ✓ Both, Biodentin and SDR were able to improve the fracture resistance of the simulated immature permanent teeth comparable to that of an intact natural tooth.
- ✓ Fracture resistance of Everstick Post group was lesser compared to Biodentine group.
- ✓ Mid-root level fracture was the most frequent type of failure encountered in all reinforced teeth.

BIBLIOGRAPHY

1. Lam R. Epidemiology and outcomes of traumatic dental injuries: a review of the literature. *Australian dental journal*. 2016;61:4–20.
2. Warren M, Widmer R, Arora M, Hibbert S. After hours presentation of traumatic dental injuries to a major paediatric teaching hospital. *Australian dental journal*. 2014;59(2):172–9.
3. Bastone EB, Freer TJ, McNamara JR. Epidemiology of dental trauma: a review of the literature. *Australian dental journal*. 2000;45(1):2–9.
4. Dharmani CK, Pathak A, Sidhu HS. Prevalence of traumatic dental injuries to anterior teeth in 8–12-year-old schoolchildren of Patiala City, Punjab, India: an epidemiological study. *International journal of clinical pediatric dentistry*. 2019;12(1):25.
5. Nagarajappa R, Ramesh G, Uthappa R, Kannan SPK, Shaikh S. Risk factors and patterns of traumatic dental injuries among Indian adolescents. *Journal of dental sciences*. 2020;15(1):96–103.
6. Yu CY, Abbott PV. Responses of the pulp, periradicular and soft tissues following trauma to the permanent teeth. *Australian dental journal*. 2016;61:39–58.
7. McClanahan SB, Crepps JT, Maranga MC, Worrel ED, Behnia A. American Association of Endodontists. Glossary of

- Endodontic Terms. American Association of Endodontists
Chicago, IL, USA; 2020.
8. Singh RK, Shakya VK, Khanna R, Singh BP, Jindal G, Kirubakaran R, et al. Interventions for managing immature permanent teeth with necrotic pulps. The Cochrane Database of Systematic Reviews. 2017;2017(6).
 9. Frank AL. Therapy for the divergent pulpless tooth by continued apical formation. The Journal of the American Dental Association. 1966;72(1):87–93.
 10. Cvek M. Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with gutta-percha. A retrospective clinical study. Dental Traumatology. 1992;8(2):45–55.
 11. Valera MC, Albuquerque MTP, Yamasaki MC, Vassallo FNS, da Silva DA e SA, Nagata JY. Fracture resistance of weakened bovine teeth after long-term use of calcium hydroxide. Dental Traumatology. 2015;31(5):385–9.
 12. Kahler SL, Shetty S, Andreasen FM, Kahler B. The effect of long-term dressing with calcium hydroxide on the fracture susceptibility of teeth. Journal of endodontics. 2018;44(3):464–9.
 13. Lee B-N, Moon J-W, Chang H-S, Hwang I-N, Oh W-M, Hwang Y-C. A review of the regenerative endodontic treatment procedure. Restorative dentistry & endodontics. 2015;40(3):179–87.

14. Alobaid AS, Cortes LM, Lo J, Nguyen TT, Albert J, Abu-Melha AS, et al. Radiographic and clinical outcomes of the treatment of immature permanent teeth by revascularization or apexification: a pilot retrospective cohort study. *Journal of endodontics*. 2014;40(8):1063–70.
15. Silujjai J, Linsuwanont P. Treatment outcomes of apexification or revascularization in nonvital immature permanent teeth: a retrospective study. *Journal of endodontics*. 2017;43(2):238–45.
16. Kahler B, Rossi-Fedele G, Chugal N, Lin LM. An evidence-based review of the efficacy of treatment approaches for immature permanent teeth with pulp necrosis. *Journal of endodontics*. 2017;43(7):1052–7.
17. Torabinejad M, Nosrat A, Verma P, Udochukwu O. Regenerative endodontic treatment or mineral trioxide aggregate apical plug in teeth with necrotic pulps and open apices: a systematic review and meta-analysis. *Journal of endodontics*. 2017;43(11):1806–20.
18. Tong HJ, Rajan S, Bhujel N, Kang J, Duggal M, Nazzal H. Regenerative endodontic therapy in the management of nonvital immature permanent teeth: A systematic review—outcome evaluation and meta-analysis. *Journal of endodontics*. 2017;43(9):1453–64.
19. Ree MH, Schwartz RS. Long-term success of nonvital, immature permanent incisors treated with a mineral trioxide

- aggregate plug and adhesive restorations: a case series from a private endodontic practice. *Journal of endodontics*. 2017;43(8):1370–7.
20. Rabie G, Trope M, Tronstad L. Strengthening of immature teeth during long-term endodontic therapy. *Dental Traumatology*. 1986;2(1):43–7.
21. Katebzadeh N, Dalton BC, Trope M. Strengthening immature teeth during and after apexification. *Journal of Endodontics*. 1998;24(4):256–9.
22. Hemalatha H, Sandeep M, Kulkarni S, Yakub SS. Evaluation of fracture resistance in simulated immature teeth using Resilon and Ribbond as root reinforcements—an in vitro study. *Dental Traumatology*. 2009;25(4):433–8.
23. Schmoldt SJ, Kirkpatrick TC, Rutledge RE, Yaccino JM. Reinforcement of simulated immature roots restored with composite resin, mineral trioxide aggregate, gutta-percha, or a fiber post after thermocycling. *Journal of Endodontics*. 2011;37(10):1390–3.
24. Linsuwanont P, Kulvitit S, Santiwong B. Reinforcement of simulated immature permanent teeth after mineral trioxide aggregate apexification. *Journal of Endodontics*. 2018;44(1):163–7.
25. Bortoluzzi EA, Souza EM, Reis J dos S, Esberard RM, Tanomaru-Filho M. Fracture strength of bovine incisors after intra-radicular treatment with MTA in an experimental

- immature tooth model. International endodontic journal. 2007;40(9):684–91.
26. Orłowski M, Tarczydło B, Chałas R. Evaluation of marginal integrity of four bulk-fill dental composite materials: in vitro study. The Scientific World Journal. 2015;2015.
27. Evans M. Ingle's Endodontics 7. 2020;
28. Amižić IP, Baraba A, Ionescu AC, Brambilla E, Ende AV, Miletić I. Bond strength of individually formed and prefabricated fiber-reinforced composite posts. J Adhes Dent. 2019;21(6):557–65.
29. Makarewicz D, Le Bell-Rönnlöf A-MB, Lassila LV, Vallittu PK. Effect of cementation technique of individually formed fiber-reinforced composite post on bond strength and microleakage. The open dentistry journal. 2013;7:68.
30. Tabiyar KM, Logani A. The Apical Extent of Mineral Trioxide Aggregate Apical Barrier Does not Influence the Treatment Outcome in a Nonvital Immature Permanent Anterior Tooth: A Split-Mouth Clinical Study. European Endodontic Journal. 2021;6(1):44.
31. Malkondu Ö, Kazandağ MK, Kazazoğlu E. A review on biodentine, a contemporary dentine replacement and repair material. BioMed research international. 2014;2014.
32. Arora V, Nikhil V, Sharma N, Arora P. Bioactive dentin replacement. J Dent Med Sci. 2013;12(4):51–7.

33. Santos-Filho PCF, Castro CG, Silva GR, Campos RE, Soares CJ. Effects of post system and length on the strain and fracture resistance of root filled bovine teeth. *International endodontic journal*. 2008;41(6):493–501.
34. Yasin R, Al-Jundi S, Khader Y. Effect of mineral trioxide aggregate and biodentine™ on fracture resistance of immature teeth dentine over time: in vitro study. *European Archives of Paediatric Dentistry*. 2021;22(4):603–9.
35. Santos T da SA, Abu Hasna A, Abreu RT, Tribst JPM, de Andrade GS, Borges ALS, et al. Fracture resistance and stress distribution of weakened teeth reinforced with a bundled glass fiber–reinforced resin post. *Clinical oral investigations*. 2022;26(2):1725–35.
36. Fráter M, Sárý T, Néma V, Braunitzer G, Vallittu P, Lassila L, et al. Fatigue failure load of immature anterior teeth: influence of different fiber post-core systems. *Odontology*. 2021;109(1):222–30.
37. Josic U, Radovic I, Juloski J, Beloica M, Popovic M, Alil A, et al. Can Fiber-post Placement Reinforce Structurally Compromised Roots? *The journal of adhesive dentistry*. 2020;22(4):409–14.
38. Darak P, Likhitkar M, Goenka S, Kumar A, Madale P, Kelode A. Comparative evaluation of fracture resistance of simulated immature teeth and its effect on single visit apexification versus complete obturation using MTA and biodentine.

- Journal of Family Medicine and Primary Care. 2020;9(4):2011.
39. Sajjan GS, Sahu KK, Varma KM, Sigadam A, Chennanjali K. A Comparative Evaluation of Pushout Bond Strength of Comprehensive Techniques for Intracanal Rehabilitation of Structurally Compromised Roots: An In Vitro Study. Journal of Operative Dentistry and Endodontics. 2020;5(1):2.
40. Alhajj MN, Salim NS, Yanti Johari MS, Abdul-Muttlib NA, Ariffin Z. Push-out Bond Strength of Two Types of Dental Post Luted with Two Types of Cement at Two Different Root Levels. Acta Stomatologica Croatica. 2020;54(3):263.
41. Eram A, Zuber M, Keni LG, Kalburgi S, Naik R, Bhandary S, et al. Finite element analysis of immature teeth filled with MTA, Biodentine and Bioaggregate. Computer Methods and Programs in Biomedicine. 2020;190:105356.
42. Mello I, Michaud P-L, Butt Z. Fracture Resistance of Immature Teeth Submitted to Different Endodontic Procedures and Restorative Protocols. Journal of Endodontics. 2020;46(10):1465–9.
43. Sogukpinar A, Arikan V. Comparative evaluation of four endodontic biomaterials and calcium hydroxide regarding their effect on fracture resistance of simulated immature teeth. European Journal of Paediatric Dentistry. 2020;21(1):23–8.

44. Doshi P, Kanaparthi A, Kanaparthi R, Parikh DS. A comparative analysis of fracture resistance and mode of failure of endodontically treated teeth restored using different fiber posts: an in vitro study. *J Contemp Dent Pract.* 2019;20(10):1195–9.
45. Elnaghy A, Elsaka S. Fracture resistance of simulated immature roots using Biodentine and fiber post compared with different canal-filling materials under aging conditions. *Clinical Oral Investigations.* 2020;24(3):1333–8.
46. Sarraf P, Nekoofar MH, Sheykhrezae MS, Dummer PM. Fracture resistance of immature incisors following root filling with various bioactive endodontic cements using an experimental bovine tooth model. *European journal of dentistry.* 2019;13(02):156–60.
47. Ali MRW, Mustafa M, Bårdsen A, Bletsa A. Fracture resistance of simulated immature teeth treated with a regenerative endodontic protocol. *Acta biomaterialia odontologica Scandinavica.* 2019;5(1):30–7.
48. Danwittayakorn S, Banomyong D, Ongchavalit L, Ngoenwiwatkul Y, Porkaew P. Comparison of the effects of intraradicular materials on the incidence of fatal root fracture in immature teeth treated with mineral trioxide aggregate apexification: A retrospective study. *Journal of Endodontics.* 2019;45(8):977–84.

49. Arb HM, Darrag AM, Ghoneim WM. Fracture resistance of simulated immature teeth reinforced with different composites after root-end closure. *Tanta Dental Journal*. 2018;15(4):255.
50. Cechella B, de Almeida J, Kuntze M, Felipe W. Analysis of sealing ability of endodontic cements apical plugs. *Journal of Clinical and Experimental Dentistry*. 2018;10(2):e146.
51. Jamshidi D, Homayouni H, Majd NM, Shahabi S, Arvin A, Omidi BR. Impact and fracture strength of simulated immature teeth treated with mineral trioxide aggregate apical plug and fiber post versus revascularization. *Journal of Endodontics*. 2018;44(12):1878–82.
52. Zhabuawala MS, Nadig RR, Pai VS, Gowda Y, Aswathanarayana RM. Reinforcing Effects of Calcium Silicate-based Cement and Dual Cure Composite Resin in Simulated Immature Teeth with an Open Apex: An in vitro Study. *International Journal of Clinical Pediatric Dentistry*. 2017;10(4):351.
53. Girish K, Mandava J, Chandra RR, Ravikumar K, Anwarullah A, Athaluri M. Effect of obturating materials on fracture resistance of simulated immature teeth. *Journal of Conservative Dentistry: JCD*. 2017;20(2):115.
54. Bayram E, Bayram HM. Fracture resistance of immature teeth filled with mineral trioxide aggregate, bioaggregate, and biodentine. *European journal of dentistry*. 2016;10(02):220–4.

55. Zhabuawala MS, Nadig RR, Pai VS, Gowda Y. Comparison of fracture resistance of simulated immature teeth with an open apex using Biodentine and composite resin: An in vitro study. *Journal of Indian Society of Pedodontics and Preventive Dentistry*. 2016;34(4):377.
56. Ok E, Altunsoy M, Tanriver M, Capar ID, Kalkan A, Gok T. Fracture resistance of simulated immature teeth after apexification with calcium silicate-based materials. *European journal of dentistry*. 2016;10(02):188–92.
57. Sivieri-Araujo G, Tanomaru-Filho M, Guerreiro-Tanomaru JM, Bortoluzzi EA, Jorge ÉG, Reis JM dos SN. Fracture resistance of simulated immature teeth after different intra-radicular treatments. *Brazilian Dental Journal*. 2015;26:211–5.
58. Bani M, Sungurtekin-Ekçi E, Odabaş ME. Efficacy of biodentine as an apical plug in nonvital permanent teeth with open apices: An in vitro study. *BioMed research international*. 2015;2015.
59. Nikhil V, Jha P, Aggarwal A. Comparative evaluation of fracture resistance of simulated immature teeth restored with glass fiber posts, intracanal composite resin, and experimental dentine posts. *The Scientific World Journal*. 2015;2015.
60. Elnaghy AM, Elsaka SE. Fracture resistance of simulated immature teeth filled with Biodentine and white mineral

- trioxide aggregate—an in vitro study. *Dental Traumatology*. 2016;32(2):116–20.
61. Karapinar-Kazandag M, Basrani B, Tom-Kun Yamagishi V, Azarpazhooh A, Friedman S. Fracture resistance of simulated immature tooth roots reinforced with MTA or restorative materials. *Dental Traumatology*. 2016;32(2):146–52.
62. Kurthukoti AJ, Paul J, Gandhi K, Rao DB. Fracture resistance of endodontically treated permanent anterior teeth restored with three different esthetic post systems: An in vitro study. *Journal of Indian Society of Pedodontics and Preventive Dentistry*. 2015;33(4):296.
63. Bolhari B, Amiri EM, Kermanshah H, Ghabraei S, Jamei A. Fracture resistance of simulated immature teeth obturated with Gutta-Percha or Resilon and reinforced by composite or post. *Journal of Dentistry (Tehran, Iran)*. 2015;12(2):125.
64. Brito-Júnior M, Pereira RD, Veríssimo C, Soares CJ, Faria-e-Silva AL, Camilo CC, et al. Fracture resistance and stress distribution of simulated immature teeth after apexification with mineral trioxide aggregate. *International endodontic journal*. 2014;47(10):958–66.
65. Topçuoğlu HSİ, Kesim B, Düzgün S, Tuncay Ö, Demirbuga S, Topçuoğlu G. The effect of various backfilling techniques on the fracture resistance of simulated immature teeth performed apical plug with Biodentine. *International Journal of Paediatric Dentistry*. 2015;25(4):248–54.

66. Rayyan MM. Comprehensive techniques for intraradicular rehabilitation of weakened anterior teeth. DENTAL JOURNAL. 2014;60(1289):1297.
67. Dikbas I, Tanalp J, Koksak T, Yalnız A, Güngör T. Investigation of the effect of different prefabricated intracanal posts on fracture resistance of simulated immature teeth. Dental Traumatology. 2014;30(1):49–54.
68. Giovannetti A, Goracci C, Vichi A, Chieffi N, Polimeni A, Ferrari M. Post retentive ability of a new resin composite with low stress behaviour. Journal of dentistry. 2012;40(4):322–8.
69. Jindal S, Jindal R, Gupta K, Mahajan S, Garg S. Comparative evaluation of the reinforcing effect of different post systems in the restoration of endodontically treated human anterior teeth at two different lengths of post space preparation-an in vitro study. Journal of Dentistry (Tehran, Iran). 2013;10(2):124.
70. Le Bell-Rönnlöf A-M, Lassila LV, Kangasniemi I, Vallittu PK. Load-bearing capacity of human incisor restored with various fiber-reinforced composite posts. dental materials. 2011;27(6):e107–15.
71. Tuna EB, Dinçol ME, Gençay K, Aktören O. Fracture resistance of immature teeth filled with BioAggregate, mineral trioxide aggregate and calcium hydroxide. Dental Traumatology. 2011;27(3):174–8.

72. Soares CJ, Pereira JC, Valdivia A, Novais VR, Meneses MS. Influence of resin cement and post configuration on bond strength to root dentine. *International endodontic journal*. 2012;45(2):136–45.
73. Tanalp J, Dikbas I, Malkondu Ö, Ersev H, Güngör T, Bayırlı G. Comparison of the fracture resistance of simulated immature permanent teeth using various canal filling materials and fiber posts. *Dental Traumatology*. 2012;28(6):457–64.
74. Seto B, Chung K-H, Johnson J, Paranjpe A. Fracture resistance of simulated immature maxillary anterior teeth restored with fiber posts and composite to varying depths. *Dental Traumatology*. 2013;29(5):394–8.
75. Wilkinson KL, Beeson TJ, Kirkpatrick TC. Fracture resistance of simulated immature teeth filled with resilon, gutta-percha, or composite. *Journal of Endodontics*. 2007;33(4):480–3.
76. Stuart CH, Schwartz SA, Beeson TJ. Reinforcement of immature roots with a new resin filling material. *Journal of Endodontics*. 2006;32(4):350–3.
77. Andreasen JO, Munksgaard EC, Bakland LK. Comparison of fracture resistance in root canals of immature sheep teeth after filling with calcium hydroxide or MTA. *Dental traumatology*. 2006;22(3):154–6.
78. Carvalho CAT, Valera MC, Oliveira LD, Camargo CHR. Structural resistance in immature teeth using root

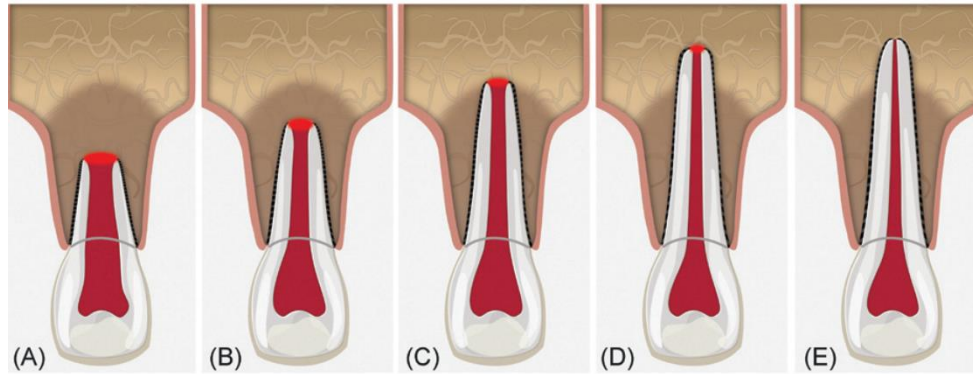
- reinforcements in vitro. Dental Traumatology. 2005;21(3):155–9.
79. Aydın B, Pamir T, Baltacı A, Orman MN, Türk T. Effect of storage solutions on microhardness of crown enamel and dentin. European journal of dentistry. 2015;9(02):262–6.
80. Secilmis A, Dilber E, Gokmen F, Ozturk N, Telatar T. Effects of storage solutions on mineral contents of dentin. Journal of dental sciences. 2011;6(4):189–94.
81. Hemalatha H, Sandeep M, Kulkarni S, Yakub SS. Evaluation of fracture resistance in simulated immature teeth using Resilon and Ribbond as root reinforcements--an in vitro study. Dental traumatology : official publication of International Association for Dental Traumatology. 2009 Aug;25(4):433–8.
82. Plascencia H, Díaz M, Gascón G, Garduño S, Guerrero-Bobadilla C, Márquez-De Alba S, et al. Management of permanent teeth with necrotic pulps and open apices according to the stage of root development. Journal of clinical and experimental dentistry. 2017;9(11):e1329.
83. Seghi RR, Nasrin S, Draney J, Katsube N. Root fortification. Pediatric Dentistry. 2013;35(2):153–9.
84. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review—part III: clinical applications, drawbacks, and mechanism of action. Journal of endodontics. 2010;36(3):400–13.

85. Chang S-W. Chemical characteristics of mineral trioxide aggregate and its hydration reaction. *Restorative dentistry & endodontics*. 2012;37(4):188–93.
86. Nayak G, Hasan MF. Biodentine-a novel dentinal substitute for single visit apexification. *Restorative dentistry & endodontics*. 2014;39(2):120–5.
87. Pradeep K, Mohata P, Butula RV. Biodentine: novel endodontic material for single step apexification: A case report. *South African Dental Journal*. 2018;73(7):452–5.
88. Khetarpal A, Chaudhary S, Talwar S, Verma M. Endodontic management of open apex using Biodentine as a novel apical matrix. *Indian Journal of Dental Research*. 2014;25(4):513.
89. Ilie N, Hickel R. Investigations on a methacrylate-based flowable composite based on the SDR™ technology. *Dental Materials*. 2011;27(4):348–55.
90. Desai S, Chandler N. The restoration of permanent immature anterior teeth, root filled using MTA: a review. *journal of dentistry*. 2009;37(9):652–7.
91. Sim TPC, Knowles JC, Ng Y-L, Shelton J, Gulabivala K. Effect of sodium hypochlorite on mechanical properties of dentine and tooth surface strain. *International endodontic journal*. 2001;34(2):120–32.
92. Soares CJ, Pizi ECG, Fonseca RB, Martins LRM. Influence of root embedment material and periodontal ligament simulation

- on fracture resistance tests. Brazilian oral research. 2005;19(1):11–6.
93. Kishen A. Mechanisms and risk factors for fracture predilection in endodontically treated teeth. Endodontic topics. 2006;13(1):57–83.
94. Han L, Okiji T. Uptake of calcium and silicon released from calcium silicate–based endodontic materials into root canal dentine. International endodontic journal. 2011;44(12):1081–7.
95. Atmeh AR, Chong EZ, Richard G, Festy F, Watson TF. Dentin-cement interfacial interaction: calcium silicates and polyalkenoates. Journal of dental research. 2012;91(5):454–9.

APPENDIX

APPENDIX A: Schematic illustration of Cvek's stages of root development.



(A) Group I, < 1/2 root length;

(B) Group II, 1/2 root length;

(C) Group III, 2/3 root length;

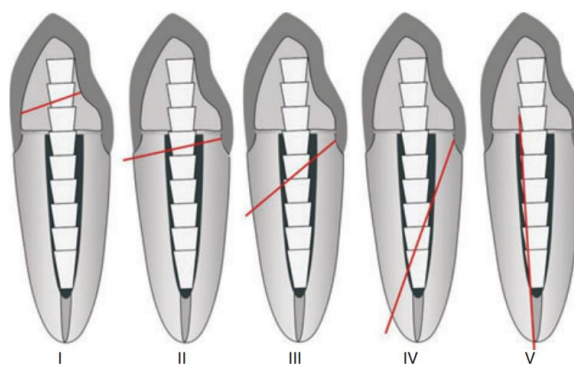
(D) Group IV, wide open apical foramen and nearly completed root length;

(E) Group V, closed apical foramen and completed root development.

--- Groups I, II and III shows wide and divergent apical openings.

--- Groups IV and V shows partially or completely mature teeth

APPENDIX B: Schematic illustration of the fracture mode classification:



Type I - Resin core or post fracture,

Type II - Cervical root fracture,

Type III - Mid root fracture,

Type IV - Apical root fracture,

Type V - Vertical root fracture

APPENDIX C: Plagiarism reports for individual sections

Introduction

app.grammarly.com/ddocs/1558168518

Untitled document

4% Plagiarism

Back to all suggestions

HIDE ASSISTANT

63 Overall score
See performance

Goals
Adjust goals

All suggestions

Correctness
48 alerts

Clarity
Mostly clear

Engagement
Very engaging

Get Expert Writing Help

4% Plagiarism

INTRODUCTION

Traumatic dental injuries are a common cause of tooth damage and loss in the young and adolescent age group. Injuries to permanent teeth often result from falls, road traffic accidents, violent acts, and participation in various sports.(1) Previous studies have shown that the maxillary anterior teeth are the most frequently involved in dental impact injuries.(2–5) When these injuries occur in the young and adolescent age group, it may lead to loss of pulp vitality and cessation of root development, resulting in an open apex and short roots with thin and weak root canal walls. These features of immature teeth further complicate root canal instrumentation and achieving a proper apical stop.(6) In clinical practice, the management of teeth with incomplete closure of the apex poses both

1,054 words

4 more suggestions

Review of literature

app.grammarly.com/ddocs/1558169398

Untitled document

9% Plagiarism

Back to all suggestions

HIDE ASSISTANT

75 Overall score
See performance

Goals
Adjust goals

All suggestions

Correctness
403 alerts

Clarity
Mostly clear

Engagement
Engaging

Get Expert Writing Help

9% Plagiarism

REVIEW OF LITERATURE

Yasin et al., in 2021(34), evaluated the effect of root filling with white mineral trioxide aggregate (WMTA) (Angelus, Brazil) and Biodentine (Septodont, France) on fracture resistance of simulated immature teeth over different time periods. Sixty single-rooted premolars were randomly divided into three groups; (n = 20) – two experimental and one control groups. The control group was further subdivided into positive and negative controls (n = 10). Root canals were prepared using ProTaper Universal rotary files (Dentsply Maillefer, Switzerland) upto size F3 and further prepared with Peeso reamers sizes 1–6 (Mani, Japan) to simulate immature apices. Following preparation, canals were completely filled with either MTA or Biodentine depending on the group and the ends were sealed with cavit-G

11,583 words

24 more suggestions

Materials and methods

Grammarly app.grammarly.com/ddocs/1558169162

Untitled document

1% Plagiarism

Back to all suggestions

MATERIALS AND METHODS

MATERIALS: (Figure 1)

1. Contra angle micromotor Handpiece (Waldent, EB-FY3285)
2. Airtor handpiece (NSK- 108527)
3. Micromotor (Marathon, India)
4. Digital Vernier Calliper (X0011J0PMF- ZHART, India)
5. Carborundum disk (C03/190)
6. GG Drills (LOT P21C055900, P19L025900) (Mani, India)
7. Peeso Reamers (P20F005300, P21E030900) (Mani, India)
8. Dental implant drills (NPRS504000002 - Spiral tools, Pune, India)
9. Round bur (LOT D21E155330) (Mani, India)
10. EX 24 (D21E097600) (Mani, India)
11. Hand files - # 10 size K files (Mani, Japan) (#83016).

2,116 words

3 more suggestions

64 Overall score
See performance

Goals
Adjust goals

All suggestions

Correctness
87 alerts

Clarity
Mostly clear

Engagement
Very engaging

Get Expert Writing Help

1% Plagiarism

Results and discussion

Untitled document

2% Plagiarism

Back to all suggestions

RESULTS

Forty nine simulated immature human maxillary central incisors with Biodentin apical plug were randomly divided into three experimental groups (n= 14), namely, Biodentine, Smart Dentin Replacement, and Everstick post, and positive control group (n=7); and standardised intact teeth served as negative control (n=7). All samples were subjected to fracture resistance testing using an Instron universal testing machine, and maximum load at failure was recorded in Newtons, and the data were statistically analysed.

Table 1: Normality distribution

Kolmogorov-Smirnov Statistic

Df

2,944 words

9 more suggestions

54 Overall score
See performance

Goals
Adjust goals

All suggestions

Correctness
170 alerts

Clarity
Mostly clear

Engagement
Engaging

Get Expert Writing Help

2% Plagiarism

Summary

The screenshot shows the Grammarly web interface. The document is titled "Untitled document" and has a 3% plagiarism score. The overall score is 55. The document content is as follows:

SUMMARY

This in vitro study compared the fracture resistance of simulated immature human maxillary central incisors reinforced with Biodentine, Smart Dentin Replacement and Everstick post with a Biodentine apical plug. Fifty-six human maxillary central incisors were selected based on inclusion/exclusion criteria. Crown and root length of samples were standardised by sectioning both coronal and apical ends. To simulate Cvek's stage III of root development, peeso reamers were used until size 6 was taken beyond the apex, followed by preparation with a dental implant drill of 3mm diameter, 3mm apical to the CEJ. A 4mm apical plug was placed using Biodentine and the samples were randomly divided into four groups (n = 14); one control and three experimental groups. Negative control group (n=7) - Intact teeth with no treatment, Positive control group (n=7) - the

The right sidebar shows the following metrics:

- Overall score: 55
- Goals: Adjust goals
- All suggestions: Correctness (24 alerts), Clarity (Mostly clear), Engagement (Very engaging)
- Get Expert Writing Help
- Plagiarism: 3%

Conclusion

The screenshot shows the Grammarly web interface. The document is titled "Untitled document" and has a 0% plagiarism score. The overall score is 87. The document content is as follows:

CONCLUSION

Within the limitations of this study, it is concluded that

- ü All restorative materials tested were able to significantly reinforce simulated immature permanent teeth.
- ü Both, Biodentin and SDR were able to improve the fracture resistance of the simulated immature permanent teeth comparable to that of an intact natural tooth.
- ü Fracture resistance of Everstick Post group was lesser compared to Biodentine group.
- ü Mid-root level fracture was the most frequent type of failure encountered in all reinforced teeth.

The right sidebar shows the following metrics:

- Overall score: 87
- Goals: Adjust goals
- All suggestions: Correctness (Looking good), Clarity (A bit unclear), Engagement (A bit bland)
- Get Expert Writing Help
- Plagiarism: 0%

A central message states: "Looks like your text is 100% original. We found no matching text in our databases or on the Internet."