การเสริมความแข็งแรงของรากฟันแท้ปลายรากเปิดที่ได้รับการรักษาด้วยวิธีเอเพกซิฟิเคชั่น: ทบทวนวรรณกรรม
Root Reinforcement of Immature Permanent Teeth Treated with Apexification: A Literature Review

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บทคัดย่อ

การรักษาด้วยวิธีเอ็มทีเอ เอเพกซิฟิเคชั่น (MTA apexification) เป็นหนึ่งในทางเลือกการรักษาฟันแท้ปลายรากเปิดที่มีการตายของเนื้อเยื่อใน อย่างไรก็ตามแม้จะพบว่าการรักษาดังกล่าวให้ผลการรักษาที่ดี ฟันแท้ปลายรากเปิดที่รักษาด้วยวิธีการดังกล่าวนั้น มีผนังเนื้อฟันที่บางและเสี่ยงต่อการเกิดการแตกหักของรากฟัน ในปัจจุบันมีการศึกษาเพื่อลดความเสี่ยงของการแตกหัก เพื่อให้ฟันที่ได้รับการรักษาด้วยวิธีเอเพกซิฟิเคชั่นสามารถคงอยู่ในช่องปากได้นานขึ้น นักวิจัยค้นพบวิธีการเสริมความแข็งแรงของรากฟันด้วยการใช้วัสดุหลายชนิดเพื่อเสริมในคลองรากฟันแท้ที่ปลายรากเปิด และการศึกษาในปัจจุบันมุ่งเน้นศึกษาถึงผลของวัสดุชนิดต่าง ๆ ต่อความแข็งแรงของฟันที่ได้รับการรักษาด้วยวิธีเอเพกซิฟิเคชั่น บทความนี้ได้รวบรวมข้อมูล

Abstract

Mineral trioxide aggregate (MTA) apexification is one of the treatment options for immature, permanent teeth with necrotic pulps. Although apexification may be successful, the canal walls of immature teeth are still thin and vulnerable to fracture. Attempts have been made to reduce the risk of fracture of such teeth so that they can remain in function for a longer period of time. Researchers have come across the idea of intraradicular reinforcement with various materials. The research trend nowadays is focused mainly on methods which yield the greatest strength to the immature teeth treated with apexification. This article

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เกี่ยวกับวิธีการและวัสดุที่ใช้ในการเสริมความแข็งแรงของฟันแท้ปลายรากเปิดที่ได้รับการรักษาด้วยวิธีเอเพกซิฟิเคชั่น

คำสำคัญ: เอเพกซิฟิเคชั่น ฟันแท้ปลายรากเปิด เอ็มทีเอ การเสริมความแข็งแรงของรากฟัน

reviews the reinforcement methods and materials used for reinforcing immature, permanent teeth with necrotic pulps treated with apexification.

Keywords: apexification, immature permanent teeth, mineral trioxide aggregate, reinforcement

Introduction

Traumatic dental injuries occur in both children and adults.(1) A 12-year review of the literature suggests that one fourth of school children and about one third of adults suffer from trauma to the permanent dentition.(1) Such injuries can bring about loss of pulp vitality before the development of the root is completed.(2) Immature teeth with necrotic pulps often cause difficulty for clinicians in performing root canal treatment, due to an inability to control the extrusion of root-canal-filling materials through the apex.(3) Furthermore, the thin dentinal walls of such immature teeth also compromise their survival rate. Apexification is a method that has been widely used to overcome the previously described situation, aiming to induce the natural apical closure or to create an apical plug.(3,4) After successful creation of an apical barrier, a conventional root canal filling material can be placed. And though the apexification may be successful, the dentinal walls are still thin and, therefore, susceptible to fracture.(5) The research trend nowadays is focused mainly on intraradicular reinforcement, in hope of disclosing materials or procedures which yield the greatest strength to the immature teeth treated with apexification. The teeth with greater strength mean that they can withstand greater force, thus reducing the risk of fracture, therefore, they can remain in function for a longer period of time.

Apexification

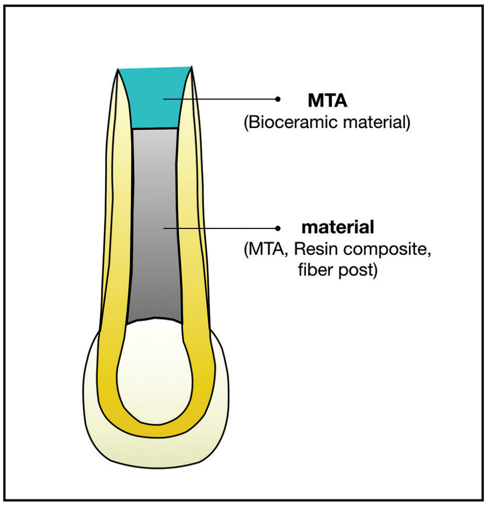
The traditional apexification procedure requires the use of calcium hydroxide as an intraradicular medicament. The time required for hard tissue formation at the apex is between 6 and 18 months.(5) During this period of time, calcium hydroxide might have to be repeatedly replaced because it can be washed out by tissue fluids through the wide-open apex.(5) A radiograph is made at the beginning of every follow-up appointment in order to evaluate the presence of calcific barrier. Calcium hydroxide apexification has a clinical and radiographic success rate ranging from 87% to 100% and 87% to 93.3%, respectively.(6-8)

Despite the high success rate and the favorable outcome of traditional calcium hydroxide apexification, there are some drawbacks, which need to be discussed.(9) Such drawbacks include an extended period of time required to form a hard tissue barrier, requiring patient compliance for 6 to 17 visits,(5,10) and it has been proved that long term usage of calcium hydroxide dressing weakens the root structure, and, therefore, increases the risk of root fracture.(11) To make up for these drawbacks, the concept of an immediate apical barrier has been introduced. Successful outcomes of immediate apical barrier formation have been observed without the need of inducing a natural apical barrier.(12) In the past, researchers have studied several materials, e.g. tricalcium phosphate, freeze-dried cortical bone, dentinal plugs, or even calcium hydroxide, to use as immediate apical barriers.(3,4,13,14) Recently, mineral trioxide aggregate (MTA) has been used extensively as an alternative to calcium hydroxide apexification, due to its superior characteristics: sealing ability and biocompatibility, for example.[15] The survival and clinical-radiographic success rates of MTA apexification have been reported to be 96.9% and 90.2% of cases, respectively, in one retrospective study,[16] and the long term (mean follow-up time, 8.29 years) survival and success rates have been reported to be 100% and 95.6% of cases, respectively.[17]

Even though the apexification procedure results in astounding clinical outcomes, the thin dentinal walls still present a major concern. Teeth with thin dentinal walls are vulnerable to root fracture, especially in the cervical region.[11] Such vulnerability may have to do with the fact that when forces are not loaded parallel to the long axis of the anterior teeth, marginal bone becomes a fulcrum. Together with thin dentinal walls in the cervical area of immature teeth, fractures often occur at this precise location.[18] In a retrospective clinical study, Cvek, in 1992, revealed that cervical root fracture occurs more frequently in immature teeth than in mature teeth.[19] Among such immature teeth, the stage of root development plays an important role in terms of incidence of fracture, which ranged from 77% in teeth with the least developed roots to 28% in teeth with the most developed roots.[19] Attempts have been made in order to reinforce the root structures and to prevent fracture.[20]

Root reinforcement

Various root-reinforcement methods for immature, permanent teeth are mentioned in the literature.[21,22] Such methods include intraradicular reinforcement with materials such as resin-modified glass ionomer (RMGI), composite resin, fiber post, MTA, or Biodentine. (Fig.1)



รูปที่ 1 *แสดงฟันแท้ปลายรากเปิดที่มีการตายของเนื้อเยื่อในและได้รับการรักษาด้วยวิธีเอเพกซิฟิเคชั่น และได้รับการเสริมความแข็งแรงของรากฟันด้วยวัสดุ เช่น เอ็มทีเอ เรซินคอมโพสิต หรือเดือยฟัน*

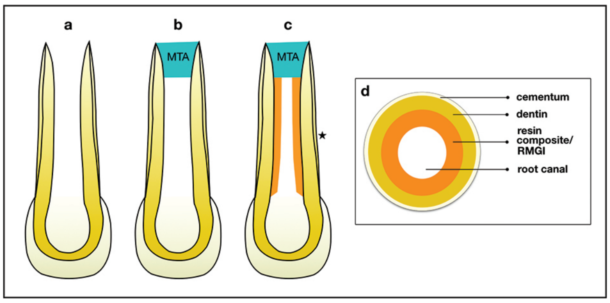
Figure 1 *Diagram showing an immature permanent tooth with necrotic pulp treated with MTA apexification. The tooth was reinforced with material such as MTA, composite resin, or fiber post.*

Intraradicular reinforcement

After establishing a successful MTA apical plug, root canals are usually obturated with gutta percha in conjunction with a root canal sealer. Cervical root fracture, one of the major complications associated with apexification, can be observed following the treatment. Cvek[19] has reported that the prevalence of cervical root fracture after gutta percha obturation is as high as 8.5%. Thus, intraradicular reinforcement should be considered.

Regarding intraradicular reinforcement, root canals can be obturated with various types of materials to protect them against possible fracture.[20] Early intraradicular reinforcement with RMGI or composite resin was carried out with the help of a translucent curing post to ensure that the entire length of the resin was polymerized. The post was removed afterwards; thus, the center of the root canal was usually left empty (Fig. 2). Following the continued development of resin materials, resin reinforcement is now performed by filling the entire root canal with self-cured or dual-cured composite resin. Moreover, fiber posts are also used to strengthen the root by cementing them to the root with resin cement. A new polycaprolactone-based material, Resilon, developed to replace gutta percha, is used to fill the root canal of immature teeth treated with apexification, in conjunction with a resin-based sealer.(20,23) Most recently, MTA and Biodentine have been used to fill the entire root canal of immature teeth for the same purpose.(24) In order to answer which material is the best in terms of strengthening immature roots, many experimental studies have focused largely on the fracture resistance of simulated immature teeth reinforced with these different materials.

As bioceramic materials have become available in the market in recent years, clinicians are interested to see if different materials used as an apical plug affect the fracture resistance of the tooth. Evren, *et al.*(25) compared the fracture resistance of MTA,



รูปที่ 2 *แสดง (a) ฟันแท้ปลายรากเปิดที่มีการตายของเนื้อเยื่อใน (b) ภายหลังจากการทำการกั้นปลายรากฟันด้วยเอ็มทีเอ (c) เสริมความแข็งแรงของรากฟันด้วยวัสดุเรซิน คอม-โพสิต หรือ อาร์เอ็มจีไอ (d) รูปตัดขวางของรากฟันที่ได้รับการเสริมความแข็งแรงด้วยวัสดุเรซิน คอมโพสิต หรือ อาร์เอ็มจีไอ*

Figure 2 *Diagram showing (a) immature permanent tooth with necrotic pulp. (b) after MTA apical plug placement. (c) intraradicular reinforcement with composite resin or RMGI. (d) cross-section of the tooth reinforced with composite resin or RMGI.*

Biodentine and calcium-enriched mixture (CEM) when used as an apical barrier. After the successful creation of barriers, all root canals were reinforced with glass-fiber posts (UniCore® size 4) and cemented with self-adhesive resin cement (Bifix SE; Voco, Cuxhaven, Germany). The load to fracture revealed that no significant differences were found between any materials. The authors concluded that MTA, Biodentine, and CEM can be used as an apical plug in immature teeth with equal effect, and speculated that the fracture resistance of the tooth tends to depend on the root canal wall thickness rather than the apical plug material.

Resin reinforcement

Early experimental studies focus mainly on the fracture resistance of endodontically treated teeth. One study compared eight different methods of restoring endodontically-treated teeth and reported that filling the root canal space with composite resin after acid etching yielded the greatest strength.(26) The authors suggested that the idea could be used in immature teeth with thin dentinal walls. Rabie, *et al.*(22) used the acid etching technique to restore the immature maxillary incisors and the results were satisfactory. Afterwards, researchers turned their attention toward the intraradicular reinforcement of immature teeth in hopes of discovering the best material to be used in such circumstances.

In 1998, Katebzadeh, *et al.*(27) simulated the thin dentinal walls of immature human central incisors and tested the reinforcing ability of composite resin. The root canals of the experimental teeth were either coated with composite resin (XRV Herculite, Dentin shade B2) or cemented with a metal post (Luminex®, Dentatus AB) using a resin cement. The results showed that the reinforced immature teeth can withstand greater forces, regardless of the materials used.

Despite such promising results from the use of a composite, other researchers(28) carried out an experiment similar to Katebzadeh's using an RMGI (Vitremer™ 3M Dental Products, St Paul, MN, USA) instead of a composite resin. They concluded that the RMGI can significantly increases the resistance to fracture of the immature teeth, and, therefore, can be used as an alternative to composite resin.

Furthermore, Rani, *et al.*(29) studied the reinforcing effect of an RMGI (Vitremer™ 3M), a flowable compomer (Prima Flow®), and a flowable composite resin (Filtek™ Z350) by coating each material onto the root canal walls of simulated immature human incisors after 15, 30, 90, and 180 days of the calcium hydroxide medicament. The results revealed that all materials substantially increased fracture resistance of the reinforced teeth compared with the non-reinforced teeth. At 180 days after calcium hydroxide medicament, the flowable composite resin yielded the greatest reinforcement effect among the materials; nonetheless, the reinforcing effect was not different between the RMGI and the flowable compomer. The authors pointed out that even though the failure load of the non-reinforced teeth was significantly reduced by almost 40% at the end of six months, significant reduction in the reinforcement values was not found in the flowable-composite-reinforced teeth at the end of 180 days compared with those at 15 days, indicating that flowable composite resin is effective in reinforcing the immature teeth.(29)

Attempts have been made to determine if different types of composite resin offer different reinforcing results.(2,30) Karapinar-Kazandag, *et al.*(2) experimented on simulated immature teeth by filling the entire root canal with either self-cured hybrid composite resin (BisFil II) or self-cured flowable composite resin (BisFil 2B). A significant difference in the fracture resistance was not found in the teeth reinforced with either of the materials. Wilkinson *et al.*(30), however, tested the same two composite resins and revealed that only the hybrid-composite-resin-reinforced teeth exhibited significantly greater fracture resistance than did the non-reinforced teeth. They explained that the fracture load of the flowable-composite-resin-reinforced teeth in their study was, in fact, similar to that of the hybrid-composite-resin-reinforced teeth. The large range of results within the flowable-composite-resin-reinforced tooth group, however, did not indicate a significant difference compared with the non-reinforced tooth group. This large variability was probably due to two factors: a low filler load in the flowable composite resin and the high C-factors of the root canals. These factors result in the shrinkage of the flowable composite resin which, in turn, affect the bonding and fracture load.(30)

There is a report on the effect of irrigating solution on fracture resistance of teeth restored with composite resin and glass ionomer.(31) Sodium hypochlorite (NaOCl), when used as a root canal irrigant, does not affect the fracture resistance of teeth subsequently restored with either a composite resin or a glass ionomer. However, chelating agents, such as lactic acid or Ethylenediamine tetraacetic acid (EDTA), when used as root canal irrigants, significantly increase the fracture resistance of such teeth.(31) These data highlight an important step that may help prolong the survival of composite-resin-reinforced teeth.

The limitation of using a composite resin is the inability to light-cure the entire length of the material within the root canal. Two methods are available to overcome the problem: transmitting the light through a clear plastic post(27) and using a self-cured or a dual-cured composite resin.(30) The first method merely coats the root canal wall, whereas the second method obturates the entire root canal space with a composite resin. In cases where a post is needed for the permanent restoration, the latter option is not applicable.

Post reinforcement

Metal, ceramic, and fiber posts are used in root-filled teeth for core-retention and root-reinforcement purposes. Regarding the root-reinforcement purpose, ceramic or metal posts are not frequently mentioned in the literature, despite their efficient reinforcement ability in immature teeth.(32,33) The main reason is because fiber posts are better, since they perform better than ceramic or metal posts in terms of fracture resistance.(34) Additionally, in scenarios where root fractures occur, teeth restored with fiber posts often show restorable fractures, whereas teeth with metal or ceramic posts often show catastrophic fractures.(34)

Fiber posts have been used in endodontically-treated teeth for core-retention purposes, long before they were used for reinforcement purposes in the immature teeth.(34) Schmoldt, *et al.*(35) evaluated the fracture resistance of simulated immature teeth restored with a composite resin (Pentron), ProRoot® MTA (Densply Tulsa Dental, Tulsa, OK), gutta percha, and a fiber post (FiberKor™ Pentron, Wallingford, CT). Only the teeth restored with a fiber post exhibited a significant increase in fracture resistance compared with all other materials. In addition, Tanalp, *et al.*(36) experimented on simulated immature roots and discovered that UniCore quartz fiber post-reinforced teeth provided the greatest fracture resistance compared to the teeth reinforced with all other tested materials. Linsuwanont, *et al*.(37) also confirmed the ability of fiber posts to reinforce immature teeth; however, they disclosed that the teeth reinforced with other materials, i.e., MTA or composite resin (dual-cure PermaFlo™ DC) provided a similar effect. A possible explanation for this disputable finding may have to do with the fact that thermocycling was performed in that particular study. Thermocycling is a method used to expose the teeth at different temperatures for hundreds of cycles to mimic the process in which the teeth are exposed to a fluctuation of temperature during eating and drinking. Thermocycling has been found to reduce the flexural strength of a composite resin.(38) The authors explained that this process is probably why a significant difference in the fracture resistance of teeth reinforced with different materials was not found in their study.(37)

The effects of reinforcing the root canal with multiple fiber posts have also been investigated. Kim, *et al.*(39) reported the use of a customized fiber post, multiple EverStick® glass fiber posts bonded to each other, as an intraradicular reinforcement material. They showed that teeth restored with a customized fiber post yield slightly greater fracture resistance than do teeth restored with a single fiber post. However, statistical differences were not found. The authors concluded that a customized fiber post does not offer any additional advantages over a single glass fiber post.

Several factors associated with posts have also been studied. Post fit is one such factor, and post length is a controversial factor. Büttel, *et al.*(40) evaluated the effect of post fit and post length on the fracture resistance of endodontically-treated teeth, and found that post fit has no influence on fracture resistance, and that long posts yield greater fracture resistance than do short ones. Seto, *et al*.(41) on the other hand, disclosed that by restoring an immature permanent tooth with a fiber post to a depth of 3 mm below the cemento-enamel junction (CEJ), the tooth can sustain greater force than can a tooth with a fiber post restored to a depth of 7 mm below the CEJ. They explained that immature teeth have a thinner dentinal wall apically; therefore, teeth with a shorter post can withstand greater force. Post type and post size are additional factors that have been studied. Kim, *et al.*(39) evaluated the effect of post type and post size on the fracture resistance of immature teeth. Their results revealed that post-reinforced teeth show significantly greater fracture resistance than do non-reinforced teeth. However, neither the post type nor post size affect the fracture resistance of immature teeth.

Resilon reinforcement

Resilon is a synthetic polycaprolactone-polymer-based material used for obturation of the root canals in a similar manner to that of gutta percha. It is used in conjunction with a dual-cure resin-based sealer.[20] Several studies have evaluated the reinforcing ability of resilon in the immature tooth.[20,23,30] Wilkinson, *et al.*[30] revealed that resilon-obturated teeth show a greater fracture resistance than do gutta-percha-obturated teeth; however, the difference was not significant. Furthermore, the difference in fracture resistance of both gutta-percha- and resilon-obturated teeth was not significant from that of non-obturated teeth, therefore, suggesting that neither resilon nor gutta percha have the ability to reinforce immature teeth.[30] Moreover, Hemalatha, *et al.*[23] agreed that neither resilon nor gutta percha can strengthen immature teeth.

MTA reinforcement

After MTA became available in the market, recent experimental studies have simulated the immature root not only by thinning the dentinal walls but by creating a 4-mm barrier of MTA at the apex to imitate the clinical situation after establishing an MTA apical barrier.[20,23,30,35,37] Additionally, MTA can also be used to fill the entire root canal space of immature teeth.[2,35,37] Cauwels, *et al.*[42] found that MTA-reinforced teeth show significantly greater fracture resistance than do non-reinforced teeth, suggesting that an MTA can be used to reinforce immature teeth. This result was later confirmed by Karapinar-Kazandag, *et al.*[2] and Linsuwanont, *et al*.[37] showing that MTA-reinforced teeth yield a greater fracture resistance than do non-reinforced immature teeth. Even though MTA has proven to be able to reinforce immature teeth, Linsuwanont, *et al.*[37] discovered that the reinforcing ability between MTA and gutta percha was not significantly different. This finding was speculated to be the effect of thermocycling on MTA since there is a report on MTA disintegration being observed after MTA-reinforced teeth underwent a thermocycling process.[43]

Despite the reinforcement ability of MTA, a few drawbacks need to be considered. When esthetics is a concern, MTA should not be used because it can cause tooth discoloration.[44] Moreover, in cases where a post is required for a permanent restoration, MTA reinforcement is not a practical method.[37]

Biodentine reinforcement

Apart from MTA, Biodentine has also been studied for its ability to fortify immature roots. It has been discovered that there is no difference in reinforcing ability between Biodentine, gutta percha, and a dual-cured composite resin, when tested immediately and three months after the reinforcement. However, only the teeth reinforced with Biodentine showed a statistically significant reduction in fracture resistance three months after the reinforcement.[45] In agreement, Topçuoglu, *et al*.[46] evaluated the fracture resistance of immature teeth reinforced with various materials, using Biodentine as an apical plug, and revealed that only teeth reinforced with a fiber post showed significantly greater fracture resistance than did teeth reinforced with Biodentine or gutta percha, or non-reinforced teeth.[46]

A more recent report by Sawyer, *et al.*[47] reported that the flexural strength of dentin exposed to Biodentine and MTA significantly decreases after two and three months, respectively. Moreover, Leiendecker, *et al.*[48] reported collagen degradation of the root dentin after exposure to Biodentine for an extended period of time. This degradation was speculated to be the reason why the strength of the Biodentine-reinforced teeth in the study of Zhabuawala, *et al.*[45] was drastically reduced after three months.

Due to the scarcity of studies available, using Biodentine as an intraradicular reinforcement material cannot be recommended.

Trends of future studies

Several limitations and drawbacks have been identified in the previous studies. In order to obtain the most reliable outcomes, influencing factors, such as dentinal wall thickness, simulation of the periodontal ligament and whether to use thermocycling, need to be considered.

Dentinal wall thickness

Stuart, *et al.*[20] simulated immature teeth by instrumenting the root canal of extracted teeth with a Peeso reamer with a diameter of 1.5 mm, leaving an average of 2.63 mm of dentinal wall thickness, and disclosed that this might have been insufficient to adequately weaken the tooth structure because a significant difference in reinforcing ability was not found between any of the testing materials. Therefore, they suggested that reinforcement of immature teeth with root canal diameters of 1.5 mm or less, and dentinal wall thicknesses of 2 mm or more, may not be necessary. Recent studies[23,24,45] then considered preparing the immature root canal with a 3 mm-diameter instrument to simulate stage three of Cvek's classification in order to obtain the root-to-canal ratio in the mesiodistal dimension at the CEJ of approximately 1:1.[19] Larger instrument was used to obtain the remaining dentinal wall thickness of around 1-1.5 mm.[45]

Themocycling process

The thermocycling process has been used in recent experimental studies,[29,35,37] since it has been found to affect the resistance to fracture of many intraradicular reinforcement materials: resin composite and MTA, for example.[38,43]

Simulation of periodontal ligament

Periodontal ligament simulation and root embedment materials used during an experiment are among the factors that may affect the outcomes of experiments. It has been established in a study by Soares, *et al.*[49] that both the periodontal ligament simulation and root embedment materials altered the fracture pattern of the experimental teeth; therefore, if fracture pattern is to be determined, simulation of periodontal ligament is necessary.

Conclusion

Despite successful outcomes of apexification of immature permanent teeth with necrotic pulps, a thin dentinal wall can still result in root fracture, especially in the cervical region. The incidence of root fracture in such teeth depends mostly on the stage of root development and the amplitude of force loads on the tooth. Prevention of such root fracture must be considered. A myriad of studies shows different results. The methodology of each study was extremely different in terms of sample source, direction of force loading, simulation of immature roots, etc. Comparing the results from these studies is, therefore, hardly possible. The best solution, however, seems to be pointing towards intraradicular reinforcement with dentin adhesive materials, such as composite resin or fiber posts with resin cement. Further studies should be conducted, replicating the clinical scenarios as closely as possible, so that the long-term reinforcing effect can be fully understood.

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