专家笔谈

# 激光在儿童口腔临床中的应用

王　艳　邹　静

**摘　要**

激光近年来被儿童口腔医生和学者们关注，并广泛应用于儿童口腔医学领域的龋病早期诊断、龋病预防与治疗、窝沟封闭前的牙面预处理、乳牙及年轻恒牙的牙髓治疗、软组织手术、牙齿矫治等方面。大量研究表明激光的靶向性、微创性和舒适性等特点符合微创牙科的理念，可降低齿科畏惧、增加儿童的配合度，还作为许多常规手术的替代方案。本文就近年来国内外关于激光在儿童口腔临床中的应用作一综述。

**关键词**　激光；儿童口腔医学；硬组织；软组织

激光应用于口腔领域已有 50 多年的历史，近 20 年来逐渐被口腔医生和学者们关注，并应用于儿童口腔医学领域的龋病早期诊断、龋病预防、牙体修复及窝沟封闭前的牙面预处理、乳牙及年轻恒牙的牙髓治疗、软组织手术、牙齿矫治等方面。本文就近年来国内外关于激光在儿童口腔临床中的应用作一综述。

## 1　口腔医学领域常用激光种类

激光在口腔学科中的首次应用是用于口腔软组织手术，激光被用作手术刀，切割或消融组织。激光能量当到达组织表面时，可以被反射、散射、吸收或传输到周围的组织。常用的牙科激光包括 HO:YAG 激光，Nd:YAG 激光，CO2 激光，Er:YAG 激光，Nd:YAP 激光，Diode 激光（半导体激光），砷化镓（GaAs）激光（二极管激光），Er,Cr:YSGG 激光和氩激光（Argon laser）。根据其介质激光分为 4 大类：固体激光器、液体激光、气体激光和半导体激光。适用于医学和口腔医学激光波长范围为 193−10600nm。根据波长的不同，激光为深穿透型和浅穿透型两种。根据能量高低，分为低能量输出激光（也称之为“软激光”）和高能量输出激光（也称之为“硬激光”）。表 1 列出了

作者单位　四川大学华西口腔医院儿童口腔科
四川省成都市锦江区人民南路三段 14 号 610041

表 1 常用口腔临床激光

| 激光类型 | 波长 | 辐照模式 | 临床应用 |
| --- | --- | --- | --- |
| $CO_2$ 激光 | 10600nm | 脉冲模式或连续辐照模式 | 软组织切割<br>口腔溃疡的治疗<br>系带成形术或牙龈成形术<br>牙周手术中去除坏死上皮组织 |
| Nd:YAG | 1064nm | 脉冲模式 | 根管治疗治疗中辅助清理根管<br>牙周手术<br>去龋 |
| Er:YAG | 2940nm | 脉冲模式 | 去除龋坏组织<br>备洞<br>根管消毒<br>根尖手术、种植手术及拔牙术<br>牙齿漂白及脱敏<br>系带成形术 |
| Er,Cr:YSGG | 2780nm | 脉冲模式 | 釉质蚀刻<br>去龋<br>备洞<br>去骨<br>根管预备 |
| Argon | 572nm | 脉冲模式或连续辐照模式 | 树脂材料的固化<br>牙齿漂白<br>口腔溃疡的治疗<br>系带成形术或牙龈成形术 |
| Diode | 810/980nm | 脉冲模式或连续辐照模式 | 促进伤口愈合<br>系带成形术或牙龈成形术 |
| HO:YAG | 2100nm | 脉冲模式 | 治疗口腔病损<br>系带成形术或牙龈成形术 |

不同类型的口腔临床激光及其应用。

## 2 激光在儿童口腔临床中的应用

儿童口腔诊疗是否成功很大程度上取决于患儿是否配合治疗。由于儿童的特殊性，齿科畏惧症在儿童中的发病率高达 80% 以上。对牙钻等传统工具的恐惧是造成患儿齿科畏惧的重要原因之一。舒适牙科旨在尽量采用各种手段有效控制患者术前焦虑、术中疼痛及术后反应。激光治疗在很多情况下可减少局部麻醉的使用，大大减轻了患儿的恐惧和焦虑，使治疗在轻松的气氛下进行，无传统牙钻切割时的不适感，进行软组织切割时可有效地减少术中出血，保持术野清晰。同时具有杀菌作用，减少术后感染。切割软硬组织时由于对周围组织的损伤最小，可以明显减轻患者的肿胀疼痛等术后反应，大大缩短伤口愈合的时间。有研究表明，儿童在接受激光治疗过程中更加配合，可显著提高医疗质量，优化治疗过程。

### 2.1 口腔硬组织

#### 2.1.1 龋病的早期诊断

准确进行龋病的早期诊断有助于及时阻止或

逆转龋损进展，恢复牙体外形和功能，避免龋病及其并发症对于儿童口腔健康和身心健康的影响。近年研究表明激光荧光法（Laser Fluorescence，LF）可作为龋病早期诊断的一种辅助手段。波长为655nm 的激光作为一种诊断技术，可以检测口腔细菌和细菌副产物（卟啉类化合物）产生的荧光。DIAGNOdent 是使用 LF 技术的商业产品，已应用于临床，其检测结果呈现为 0 到 99 的数字，反映龋损严重程度 [1，2]。LF 读数与脱矿程度关联较弱，曾有研究表明，在体外形成的无菌性白斑病变不会产生明显的荧光增加 [3]。而相较于受细菌感染程度更低的牙釉质龋，牙本质龋与 LF 的关联程度更高 [4]。因此 LF 能更准确地诊断牙本质龋，而对釉质早期龋和牙齿脱矿的检测效果不佳 [5]。此外，牙菌斑、牙石及 / 或牙齿表面染色、牙齿组织脱水程度均可能影响测量结果 [6]。基于恒牙体外实验的系统评价表明 LF 技术能够具有诊断恒牙牙釉质和牙本质（牙合）面龋的能力 [7]，而体内实验尚有争议 [8]。对于乳牙（牙合）面龋，研究表明 LF 技术能够作为一种有效的辅助诊断手段 [9]。但对于 LF 技术应用于乳牙邻面龋，研究结论尚存在争议。部分研究表明 LF 技术的诊断正确率比咬翼片更高或类似 [10，11]，其检测进展至牙本质龋的准确率更佳 [12]，但也有研究认为其特异性和敏感性不及咬翼片 [13]。

波长为 488nm（蓝绿色）的氩激光（Argon laser）也是一种检测激光，可辅助釉质早期脱矿的检测、定量和监测。由于釉质自发荧光，基于此监测和定量检测与脱矿相关的荧光量丧失，被称为定量光导荧光（Quantitative–light induced fluorescence，QLF）技术 [14，15]。QLF 技术系统常使用微电极氙光灯加一个最大允许透过波长为370nm 光学滤过器组成，过滤后的蓝光激发牙体产生黄绿色荧光。当龋病病损存在时，光散射的增加使病灶在明亮的绿色背景上呈现为黑点。通过假设健康牙釉质荧光为 100% 进行重建，计算实际表面与重建表面的百分差来确定量化荧光损失。由此对牙齿荧光图像进行记录、数字化和定量分析。任何荧光下降超过 5% 的区域都被认为是病灶 [2]。体内外研究均证实了 QLF 技术对于龋病的早期诊断能力 [15–19]。与恒牙相比，它更有效地定量检测乳牙的脱矿 [20]。同时 QLF 技术还可以辅助诊断氟牙症 [21] 以及窝沟封密剂下的龋损 [22]。此外，还有学者通过研究证实 QLF 技术能够为龋损组织去除程度提供证据 [23]，判断树脂对于牙体组织的渗透程度 [24]，辅助判断早期龋预后 [25] 及监测继发龋的产生 [26]。

### 2.1.2 龋病预防

已有研究证实，激光能够提升牙齿对于龋病的抗力，预防龋病的产生。目前研究主要涉及 $CO_2$ 激光，Er：YAG 激光，Er，Cr：：YSGG 激光及 Nd：YAG 激光 [27]。临床研究发现使用 $CO_2$ 激光照射，可显著减少在正畸治疗托槽粘接过程中托槽周围釉质脱矿的发生 [28]。Nd：YAG 激光处理殆面窝沟后，可有效预防第一乳磨牙窝沟龋，其效果和窝沟封闭剂相当 [29]。这可能与激光处理牙釉质表面后，改变釉质中钙磷比例，形成更稳定的类似氟化物作用抵御酸的复合物，从而提高了牙齿的抗酸性；同时，釉质表面物理结构的改变还可能引起釉质表面电荷的改变，从而引起获得性膜成分改变，影响细菌在牙面定植，减少菌斑的形成，减少脱矿发生 [30]。近年来，有报道称激光照射联合局部应用氟化物提升釉质抗龋性能 [31–33]。激光辐照可以增强氟离子的作用，促进氟离子与牙釉质的相互作用，甚至增加氟离子留置时间 [34]。但也有研究提示激光联合氟化物局部应用并没有达到预期的防龋作用 [29，35]。激光以及其联合氟化物在龋病预防中的应用仍然需要更多的研究来证实。

### 2.1.3 龋病治疗

传统去龋方法在许多儿童和青少年中极有可能引发不适甚至齿科焦虑。虽然局部麻醉可以减轻患儿痛苦，但对针头的恐惧以及机械设备带来的噪音和不适仍有可能引起焦虑和不适。此外，当龋损较深时，传统的去腐可能导致牙体组织过度去除，增加牙髓暴露的风险 [36]。激光作为一种新型的微创去腐手段，去腐的过程中不会产生传统设备的噪音、压力或震动。已有研究表明在激光治疗期间，患者对于疼痛的感知减弱，可减少或避免局麻药物的使用 [37]。此外，激光具有杀菌作用，其热效应可促进细菌细胞结构的崩溃，减少管间和管周牙本质细菌数量，暴露牙本质小管而不影响周围组织，不会引起对牙髓活力产生不利的过高温度 [38，39]。但一项系统性评价显示激光与传统技术相比，需要较长的窝洞预备时间，在缺损修复、牙髓活力和术后敏感性等方面无显著差异 [40]。但目前证据等级较低，尚不足以支持激光替代传统去腐方法，需要更多随机临床试验来验证相关结论 [41]。

#### 2.1.4　牙面和窝洞处理

激光还可应用于窝沟封闭术中对牙面的处理，也可用于充填术前对窝洞的清洁和消毒。Berk 等[42]发现使用 Er,Cr：YSGG 激光蚀刻牙釉质与传统酸蚀剂处理牙面后，两组在扫描电镜下结果相似。如前所述，使用激光对于牙面进行处理，能够改变牙面的钙磷降低碳酸盐与磷酸盐的比例，形成更稳定、更少酸溶性的化合物，从而降低龋病的易感性[43−45]。此外，激光进行窝洞消毒或应用激光进行窝洞预备后的洞壁无玷污层的存在，极大地降低了继发龋的风险。目前关于激光能否取代酸蚀在牙面处理中的作用仍有争议。一份系统评价和 meta 分析表明，磷酸预处理比 Er：：YAG 激光和空气磨损更能减少（牙合）面窝沟封闭剂的微渗漏[46]。Er,Cr：YSGG 激光蚀刻在封闭剂留存率和患者接受度方面与酸蚀无显著差异[47，48]。酸蚀联合激光对牙面处理后窝沟封闭剂的留存率比单独使用酸蚀高[49，50]。此外，激光在经济学效益、患者接受度方面还有待进一步考量。

### 2.2　口腔软组织

近年来激光的应用研究发现，各种激光均可以代替传统方法来完成儿童口腔软组织手术，包括牙龈切除术、牙龈成形术、开窗助萌、系带成形术及治疗药物性牙龈增生、牙龈纤维瘤、黏液性囊肿、阿弗他溃疡等，并取得了较好的效果。激光相对于传统手术方法用于儿童口腔软组织切割时，可减少麻醉药物的使用，减少术区出血，增加患儿的配合度，减轻术后反应。Diode 激光应用于儿童软组织手术具有操作简便、减少缝合、辅助止血及术后恢复快等优点[51]。在研究系带成形术术后反应的临床研究中发现，Nd：YAG 激光与传统手术方式相比，激光治疗组患者在疼痛、咀嚼及说话等功能方面恢复更快。低功率激光治疗（low level laser therapy，LLLT）也称光生物调节，具有促进待修复组织生物调节的优点。此外，有病例报告显示：使用 LLLT 可促进患儿单纯疱疹性龈口炎病损的愈合[52]。

### 2.3　牙髓活力测试

激光多普勒血流检测仪（laser doppler flowmetry，LDF）是用氦氖或半导体二极管作为激光光源，据多普勒现象吸收由血细胞运动而发生频率漂移的反射光，根据反射光强度和频移大小来检测血细胞的流量和流速。LDF 探头同牙面垂直接触，发射激光透过牙釉质和牙本质小管进入髓腔，髓腔毛细血管内流动的红细胞对透射的激光产生多普勒频移，反射光线通过接收器输出频谱信号曲线。其结果能够反映牙髓血流量（pulpal blood flow，PBF）的变化，以客观数据、波形等为临床评估提供依据。LDF 最早是在 1977 年由 Holloway 和 Watkins 发明，而由 Gazelius 等将其应用于牙科诊疗领域。目前用于牙外伤、血运重建、正畸、牙齿美容修复治疗及正颌术后关于牙髓血流检测[53−56]。LDF 灵敏度高，但其测量值受诸多因素影响，如测试时间、姿势、血压、心率、情绪牙齿隔离方法、探针位置[57−59]，个体之间测量结果差异较大，限制了其在临床中的广泛应用。现有临床研究多基于自身前后对照，对患牙进行纵向追踪，而对于牙髓血流正常 LDF 值的参考范围仍然需要大量实验进行探索[60]。

### 2.4　乳牙牙髓治疗

激光在乳牙牙髓治疗中主要用于牙髓切断术和牙髓摘除术中。现有研究表明激光可用于处理乳牙牙髓切断术中的牙髓断面，其临床、影像学成功率和甲醛甲酚相当，但因不同研究所用激光的类型及参数的差异性，临床观察时间点的不同，仍需要更多的临床研究来探索应用乳牙牙髓切断术最佳激光类型及参数[61，62]。此外，随着新的生物活性材料如 iroot BP、Biodentine、CEM（calcium−enriched mixture）等的广泛应用，激光与其相比较是否具有优势仍然值得进一步探索。有研究也发现使用 LLLT 预处理牙髓断面，再覆盖生物活性材料 CEM 进行乳牙牙髓切断术具有较高的成功率[63]。激光技术在乳牙牙髓摘除术过程根管系统清洁中的应用研究报道较少。有研究报道 Diode 激光可清除乳牙根管内粪肠球菌的数量，同时不会破坏牙周组织结构[64]。Er：YAG 激光不能减少乳前牙根管中的粪肠球菌的数量，但与次氯酸酸钠联用具有良好效果[65]。

### 2.5　儿童牙齿矫治中的应用

激光在儿童牙齿矫治过程中的应用包括托槽粘接前牙面处理、去除托槽粘接剂、促进牙齿移动及缓解正畸治疗后的疼痛等。

#### 2.5.1　托槽粘接前的牙面处理和粘结剂的去除

在正畸治疗的过程中，托槽的稳定粘接至关重

要，托槽粘接于牙面是依赖于粘接剂渗透进入被酸蚀的牙釉质中实现的。激光可以蚀刻牙釉质表面，代替 37% 的磷酸获得一定程度的粘接。有研究发现激光蚀刻釉质和传统酸蚀具有相当的成功率[66]。但也研究者认为激光蚀刻釉质后托槽粘接强度不佳，造成托槽脱落率增加[67]。不同的研究结果可能与试验设计不同和激光参数不同相关。目前，激光蚀刻釉质表面仍非矫治过程托槽粘接常规采用方法。此外，由于矫治需要，常需要更换托槽的粘接位置，在矫治治疗结束后需要去除托槽。不当的托槽去除可能会损伤牙釉质。激光可以通过热软化、热消融以及光切除作用去除托槽及牙面的粘接剂。研究发现激光如 Er：YAG 激光可有效去除托槽粘接剂，而且对釉质损伤小[68]。

### 2.5.2 牙齿的移动

提高儿童矫治治疗过程中牙齿的移动速度可缩短治疗周期。近年来，不少学者认为激光照射可以促进牙齿移动。目前认为激光促进牙齿移动的可能原因包括：激光照射可以促进血管再生，加快血流速度，给牙周膜的改建提供营养支持；通过活化加快酶的催化反应，刺激成纤维细胞以及成骨细胞的活性，加速成骨细胞的分化。动物实验研究显示激光照射过的大鼠，其牙齿移动量明显高于对照组[69]；但也有学者有不同的研究结果，有研究也发现激光照射组与对照组动物在牙齿移动上差异不存在统计学意义，甚至阻碍了牙齿的移动[70]。这种差异可能是因为激光的参数或者强度大小引起结果的差异所致。目前部分临床研究发现 LLLT 可加速牙齿移动[71]，但仍需更多研究来证实。

### 2.5.3 缓解正畸治疗后的疼痛

疼痛是儿童牙齿矫治中最常见的不良反应之一。激光治疗可以缓解正畸治疗中牙齿移动时产生的疼痛。激光具有较强的生物学效应，通过降低肿瘤坏死因子、前列腺素 E2 等炎性因子，提高组织中 β－内啡肽及 5－羟色胺水平，使疼痛阈值升高，从而有效缓解牙齿矫治治疗过程中的疼痛。Deana 等[72]针对 LLLT 减轻正畸疼痛的有效性进行了系统回顾及 Meta 分析，分析结果显示 LLLT 可有效减轻正畸过程中的自发疼痛和咀嚼痛，但由于纳入研究的质量偏低，尚需要更多的临床随机试验来进一步证实。

## 3 结语

大量的研究表明激光在儿童口腔医学临床中有着广泛的应用，可作为许多常规手术的合适替代方案。激光用于儿童口腔治疗时，由于其靶向性、微创性及舒适性，可增加患儿的配合度。但由于激光照射治疗的各种机制、作用参数尚未达成统一，仍然需要儿童口腔医生及学者们对其应用进行更多的研究和探索。

## 参考文献


[1] Ko C-C, Yi D-H, Lee DJ, Kwon J, Garcia-Godoy F, Kwon YH. Diagnosis and staging of caries using spectral factors derived from the blue laser-induced autofluorescence spectrum. *Journal of dentistry* 2017; 67: 77-83.

[2] Gomez J: Detection and diagnosis of the early caries lesion. In: *BMC oral health*: 2015. BioMed Central: S3.

[3] Lussi A, Hibst R, Paulus R. DIAGNOdent: an optical method for caries detection. *Journal of dental research* 2004; 83: 80-83.

[4] Kidd E, Banerjee A, Ferrier S, Longbottom C, Nugent Z. Relationships between a clinical-visual scoring system and two histological techniques: a laboratory study on occlusal and approximal carious lesions. *Caries research* 2003; 37: 125-129.

[5] Minatel Braga M, Nicolau J, Rodrigues D, Martins CR, Imparato P, Carlos J, Medeiros Mendes F. Laser fluorescence device does not perform well in detection of early caries lesions in primary teeth: an in vitro study. *Oral health & preventive dentistry* 2008; 6.

[6] Shi X-Q, Welander U, Angmar-Månsson B. Occlusal caries detection with KaVo DIAGNOdent and radiography: an in vitro comparison. *Caries research* 2000; 34: 151-158.

[7] Rosa MI, Schambeck VS, Dondossola ER, Alexandre MC, Tuon L, Grande AJ, Hugo F. Laser fluorescence of caries detection in permanent teeth in vitro: a systematic review and meta-analysis. *Journal of Evidence-Based Medicine* 2016; 9: 213-224.

[8] Castilho LS, Cotta FV, Bueno AC, Moreira AN, Ferreira EF, Magalhães CS. Validation of DIAGNO dent laser fluorescence and the International Caries Detection and

Assessment System (ICDAS) in diagnosis of occlusal caries in permanent teeth: an in vivo study. *European journal of oral sciences* 2016; 124: 188-194.

[9] Kucukyilmaz E, Sener Y, Botsali MS. In vivo and in vitro performance of conventional methods, DIAGNOdent, and an electronic caries monitor for occlusal caries detection in primary teeth. *Pediatric dentistry* 2015; 37: 14E-22E.

[10] Menem R, Barngkgei I, Beiruti N, Al Haffar I, Joury E. The diagnostic accuracy of a laser fluorescence device and digital radiography in detecting approximal caries lesions in posterior permanent teeth: an in vivo study. *Lasers in medical science* 2017; 32: 621-628.

[11] Bizhang M, Wollenweber N, Singh-Hüsgen P, Danesh G, Zimmer S. Pen-type laser fluorescence device versus bitewing radiographs for caries detection on approximal surfaces. *Head & face medicine* 2016; 12: 30.

[12] Mepparambath R, Bhat SS, Hegde SK, Anjana G, Sunil M, Mathew S. Comparison of proximal caries detection in primary teeth between laser fluorescence and bitewing radiography: An in vivo study. *International journal of clinical pediatric dentistry* 2014; 7: 163.

[13] Souza LAd, Cancio V, Tostes MA. Accuracy of pen-type laser fluorescence device and radiographic methods in detecting approximal carious lesions in primary teeth-an in vivo study. *International journal of paediatric dentistry* 2018; 28: 472-480.

[14] Nazemisalman B, Farsadeghi M, Sokhansanj M. Types of lasers and their applications in pediatric dentistry. *Journal of lasers in medical sciences* 2015; 6: 96.

[15] Pretty IA. Caries detection and diagnosis: novel technologies. *Journal of dentistry* 2006; 34: 727-739.

[16] Zandoná AF, Santiago E, Eckert G, Fontana M, Ando M, Zero D. Use of ICDAS combined with quantitative light-induced fluorescence as a caries detection method. *Caries research* 2010; 44: 317-322.

[17] Tranæus S, Al-Khateeb S, Björkman S, Twetman S, Angmar-Månsson B. Application of quantitative light-induced fluorescence to monitor incipient lesions in caries-active children. A comparative study of remineralisation by fluoride varnish and professional cleaning. *European Journal of Oral Sciences* 2001; 109: 71-75.

[18] Yoon H-I, Yoo M-J, Park E-J. Detection of proximal caries using quantitative light-induced fluorescence-digital and laser fluorescence: a comparative study. *The journal of advanced prosthodontics* 2017; 9: 432-438.

[19] Jallad M, Zero D, Eckert G, Zandona AF. In vitro detection of occlusal caries on permanent teeth by a visual, light-induced fluorescence and photothermal radiometry and modulated luminescence methods. *Caries research* 2015; 49: 523-530.

[20] Ando M, Van Der Veen MH, Schemehorn BR, Stookey GK. Comparative study to quantify demineralized enamel in deciduous and permanent teeth using laser–and light–induced fluorescence techniques. Caries research 2001; 35: 464-470.

[21] Cuevas-Espinosa DM, Martinez-Mier E, Ando M, Castiblanco G, Cortés F, Rincon-Bermudez CM, Martignon S. In vitro validation of quantitative light-induced fluorescence for the diagnosis of enamel fluorosis in permanent teeth. *Caries research* 2017; 51: 515-526.

[22] Takamori K, Hokari N, Okumura Y, Watanabe S. Detection of occlusal caries under sealants by use of a laser fluorescence system. *Journal of clinical laser medicine & surgery* 2001; 19: 267-271.

[23] Lee J-W, Lee E-S, Kim B-I. Optical diagnosis of dentin caries lesions using quantitative light-induced fluorescence technology. *Photodiagnosis and photodynamic therapy* 2018; 23: 68-70.

[24] Min J-H, Inaba D, Kim B-I. Evaluation of resin infiltration using quantitative light-induced fluorescence technology. *Photodiagnosis and photodynamic therapy* 2016; 15: 6-10.

[25] Kim H-E, Kim B-I. Prediction of early caries prognosis after fluoride application based on the severity of lesions: An in situ study. *Photodiagnosis and photodynamic therapy* 2018; 23: 45-49.

[26] Diniz MB, Eckert GJ, González-Cabezas C, Cordeiro RdCL, Ferreira-Zandona AG. Caries detection around restorations using ICDAS and optical devices. *Journal of Esthetic and Restorative Dentistry* 2016; 28: 110-121.

[27] Karandish M. The efficiency of laser application on the enamel surface: a systematic review. *Journal of lasers in medical sciences* 2014; 5: 108.

[28] de Souza-e-Silva CM, Parisotto TM, Steiner-Oliveira C, Kamiya RU, Rodrigues LK, Nobre-dos-Santos M. Carbon dioxide laser and bonding materials reduce enamel demineralization around orthodontic brackets. *Lasers Med Sci* 2013; 28: 111-118.

[29] Raucci-Neto W, de Castro-Raucci LMS, Lepri CP,

Faraoni-Romano JJ, da Silva JMG, Palma-Dibb RG. Nd: YAG laser in occlusal caries prevention of primary teeth: a randomized clinical trial. *Lasers in medical science* 2015; 30: 761-768.

[30] Oho T, Morioka T. A possible mechanism of acquired acid resistance of human dental enamel by laser irradiation. *Caries research* 1990; 24: 86-92.

[31] Birardi V, Bossi L, Dinoi C. Use of the Nd: YAG laser in the treatment of Early Childhood Caries. *European Journal of Paediatric Dentistry* 2004; 5: 98-101.

[32] Zezell DM, Boari HGD, Ana PA, Eduardo CdP, Powell GL. Nd: YAG laser in caries prevention: a clinical trial. *Lasers in Surgery and Medicine: The Official Journal of the American Society for Laser Medicine and Surgery* 2009; 41: 31-35.

[33] Corrêa-Afonso AM, Bachmann L, de Almeida CG, Dibb RGP, Borsatto MC. Loss of structural water and carbonate of Nd: YAG laser-irradiated human enamel. *Lasers in medical science* 2015; 30: 1183-1187.

[34] González-Rodríguez A, de Dios López-González J, Del Castillo JDDL, Villalba-Moreno J. Comparison of effects of diode laser and CO 2 laser on human teeth and their usefulness in topical fluoridation. *Lasers in medical science* 2011; 26: 317-324.

[35] Moghadam NCZ, Seraj B, Chiniforush N, Ghadimi S. Effects of Laser and Fluoride on the Prevention of Enamel Demineralization: An In Vitro Study. *Journal of lasers in medical sciences* 2018; 9: 177.

[36] Schwendicke F, Frencken J, Bjørndal L, Maltz M, Manton D, Ricketts D, Van Landuyt K, Banerjee A, Campus G, Doméjean S. Managing carious lesions: consensus recommendations on carious tissue removal. *Advances in dental research* 2016; 28: 58-67.

[37] Femiano F, Femiano R, Femiano L, Aresu G, Festa VM, Rullo R, Perillo L. Effectiveness of low-level diode laser therapy on pain during cavity preparation on permanent teeth. *American journal of dentistry* 2018; 31: 267-271.

[38] Baraba A, Kqiku L, Gabrić D, Verzak Ž, Hanscho K, Miletić I. Efficacy of removal of cariogenic bacteria and carious dentin by ablation using different modes of Er: YAG lasers. *Brazilian Journal of Medical and Biological Research* 2018; 51.

[39] Valério RA, Borsatto MC, Serra MC, Polizeli SAF, Nemezio MA, Galo R, Aires CP, dos Santos AC, Corona SAM. Caries removal in deciduous teeth using an Er: YAG laser: a randomized split-mouth clinical trial. *Clinical oral investigations* 2016; 20: 65-73.

[40] Tao S, Li L, Yuan H, Tao S, Cheng Y, He L, Li J. Erbium laser technology vs traditional drilling for caries removal: a systematic review with meta-analysis. *Journal of Evidence Based Dental Practice* 2017; 17: 324-334.

[41] Montedori A, Abraha I, Orso M, D’Errico PG, Pagano S, Lombardo G. Lasers for caries removal in deciduous and permanent teeth. *Cochrane Database of Systematic Reviews* 2016.

[42] Berk N, Başaran G, Özer T. Comparison of sandblasting, laser irradiation, and conventional acid etching for orthodontic bonding of molar tubes. *The European Journal of Orthodontics* 2008; 30: 183-189.

[43] Castellan CS, Luiz AC, Bezinelli LM, Lopes RM, Mendes FM, Eduardo CDP, Freitas PMD. In vitro evaluation of enamel demineralization after Er: YAG and Nd: YAG laser irradiation on primary teeth. *Photomedicine and laser surgery* 2007; 25: 85-90.

[44] Correa-Afonso AM, Ciconne-Nogueira JC, Pécora JD, Palma-Dibb RG. In vitro assessment of laser efficiency for caries prevention in pits and fissures. *Microscopy research and technique* 2012; 75: 245-252.

[45] Apsari R, Pratomo D, Hikmawati D, Bidin N: Microstructure and mechanical changes induced by Q-Switched pulse laser on human enamel with aim of caries prevention. In: AIP Conference Proceedings: 2016. *AIP Publishing*: 020001.

[46] Fumes AC, Longo DL, De Rossi A, Fidalgo TKdS, de Paula e Silva FWG, Borsatto MC, Küchler EC. Microleakage of sealants after phosphoric acid, Er: YAG laser and air abrasion enamel conditioning: systematic review and meta-analysis. *Journal of Clinical Pediatric Dentistry* 2017; 41: 167-172.

[47] Kumar G, Dhillon JK, Rehman F. A comparative evaluation of retention of pit and fissure sealants placed with conventional acid etching and Er, Cr: YSGG laser etching: A randomised controlled trial. *Laser therapy* 2016; 25: 291-298.

[48] Karaman E, Yazici A, Baseren M, Gorucu J. Comparison of acid versus laser etching on the clinical performance of a fissure sealant: 24-month results. *Operative dentistry* 2013; 38: 151-158.

[49] Durmus B, Giray F, Peker S, Kargul B. Clinical evaluation of a fissure sealant placed by acid etching or Er: YAG laser combined with acid etching. *Oral Health Prev Dent* 2017; 15: 157-162.

[50] Brugnera Jr A, Rosso N, Duarte D, Pinto AG, Genovese W. The use of carbon dioxide laser in pit and fissure caries prevention: clinical evaluation. *Journal of clinical laser medicine & surgery* 1997; 15: 79-82.

[51] Ortega-Concepcion D, Cano-Duran JA, Pena-Cardelles JF, Paredes-Rodriguez VM, Gonzalez-Serrano J, Lopez-Quiles J. The application of diode laser in the treatment of oral soft tissues lesions. A literature review. *Journal of clinical and experimental dentistry* 2017; 9: e925-e928.

[52] Navarro R, Marquezan M, Cerqueira DF, Silveira BL, Correa MS. Low-level-laser therapy as an alternative treatment for primary herpes simplex infection: a case report. *The Journal of clinical pediatric dentistry* 2007; 31: 225-228.

[53] Roeykens H, De Moor R. The use of laser Doppler flowmetry in paediatric dentistry. *European Archives of Paediatric Dentistry* 2011; 12: 85-89.

[54] Sabuncuoglu FA, Ersahan S. Comparative evaluation of pulpal blood flow during incisor intrusion. *Australian orthodontic journal* 2015; 31: 171.

[55] Emshoff R, Moschen I, Strobl H. Use of laser Doppler flowmetry to predict vitality of luxated or avulsed permanent teeth. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2004; 98: 750-755.

[56] Ajcharanukul O, Matthews B. Effects of bleaching on laser Doppler blood-flow signals recorded from human teeth in vitro. *Archives of oral biology* 2015; 60: 1471-1473.

[57] Roeykens HJ, Deschepper E, De Moor RJ. Laser Doppler flowmetry: reproducibility, reliability, and diurnal blood flow variations. *Lasers in medical science* 2016; 31: 1083-1092.

[58] Banthitkhunanon P, Chintakanan S, Wanachantararak S, Vongsavan N, Matthews B. Effects of enamel and dentine thickness on laser doppler blood-flow signals recorded from the underlying pulp cavity in human teeth in vitro. *Archives of oral biology* 2013; 58: 1692-1695.

[59] Setzer F, Challagulla P, Kataoka S, Trope M. Effect of tooth isolation on laser Doppler readings. *International endodontic journal* 2013; 46: 517-522.

[60] Ghouth N, Duggal MS, BaniHani A, Nazzal H. The diagnostic accuracy of laser Doppler flowmetry in assessing pulp blood flow in permanent teeth: A systematic review. *Dental Traumatology* 2018; 34: 311-319.

[61] Ansari G, Safi Aghdam H, Taheri P, Ghazizadeh Ahsaie M. Laser pulpotomy-an effective alternative to conventional techniques-a systematic review of literature and meta-analysis. *Lasers Med Sci* 2018; 33: 1621-1629.

[62] Nematollahi H, Sarraf Shirazi A, Mehrabkhani M, Sabbagh S. Clinical and radiographic outcomes of laser pulpotomy in vital primary teeth: a systematic review and meta-analysis. *European archives of paediatric dentistry : official journal of the European Academy of Paediatric Dentistry* 2018; 19: 205-220.

[63] Ansari G, Morovati SP, Asgary S. Evaluation of Four Pulpotomy Techniques in Primary Molars: A Randomized Controlled Trial. *Iranian endodontic journal* 2018; 13: 7-12.

[64] Bahrololoomi Z, Fekrazad R, Zamaninejad S. Antibacterial Effect of Diode Laser in Pulpectomy of Primary Teeth. *J Lasers Med Sci* 2017; 8: 197-200.

[65] Bahrololoomi Z, Poursina F, Birang R, Foroughi E, Yousefshahi H. The Effect of Er:YAG Laser on Entroccocus faecalis Bacterium in the Pulpectomy of Anterior Primary Teeth. *J Lasers Med Sci* 2017; 8: 166-171.

[66] Garcia-Sanz V, Paredes-Gallardo V, Bellot-Arcis C, Mendoza-Yero O, Donate-Buendia C, Montero J, Albaladejo A. Effects of femtosecond laser and other surface treatments on the bond strength of metallic and ceramic orthodontic brackets to zirconia. *PloS one* 2017; 12: e0186796.

[67] Usumez S, Orhan M, Usumez A. Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics* 2002; 122: 649-656.

[68] Han RQ, Yang K, Ji LF, Ling C. Analysis of Shear Bond Strength and Morphology of Er:YAG Laser-Recycled Ceramic Orthodontic Brackets. *BioMed research international* 2016; 2016: 7276287.

[69] Fujita S, Yamaguchi M, Utsunomiya T, Yamamoto H, Kasai K. Low-energy laser stimulates tooth movement

velocity via expression of RANK and RANKL. *Orthodontics & craniofacial research* 2008; 11: 143-155.

[70] Limpanichkul W, Godfrey K, Srisuk N, Rattanayatikul C. Effects of low-level laser therapy on the rate of orthodontic tooth movement. *Orthodontics & craniofacial research* 2006; 9: 38-43.

[71] Qamruddin I, Alam MK, Mahroof V, Fida M, Khamis MF, Husein A. Effects of low-level laser irradiation on the rate of orthodontic tooth movement and associated pain with self-ligating brackets. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics* 2017; 152: 622-630.

[72] Deana NF, Zaror C, Sandoval P, Alves N. Effectiveness of Low-Level Laser Therapy in Reducing Orthodontic Pain: A Systematic Review and Meta-Analysis. *Pain research & management* 2017; 2017: 8560652.