International Journal of Research and Review
Vol. 9; Issue: 5; May 2022
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Review Article

Dental LASERs - Introduction and Implications in Dentistry: A Review Article

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DOI: https://doi.org/10.52403/ijrr.20220533

ABSTRACT

Advancements in equipment technology has been one of the biggest revolutions of modern dentistry. One such equipment technology introduced in modern dentistry is LASER or "Light Amplification by Stimulated Emission of Radiation." LASERs were introduced in dentistry way back in 1960 by Miaman. He also explained both hard and soft tissue applications of LASERs. Some of the hard tissue applications include caries prevention, bleaching, cavity preparation etc. Soft tissue applications include wound healing, removal of hyperplastic tissue etc. Dental LASERs might cost a fortune but it's an effective tool to increase the efficiency, ease and comfort of the dental treatment.

Keywords: LASERs, Dentistry, Dental Caries, Diagnosis, Management.

Despite colossal developments in oral health, dental caries yet remains a community health issue globally. Dental caries is prevalent worldwide amongst adults and school children; nearly 100% of the population is affected in most of the countries. Caries harms the outer dental structures, eventually reaching the dental pulp, making the teeth undermined and ultimately compromise functional abilities. It accounts as the major reason for loss of tooth. The key aspect which defines the outcome and forthcoming functioning of the restoration is the remaining part of the tooth.[1]

Management of carious lesions require its removal, followed by placement of suitable dental restoration. Removal of carious lesions is traditionally done with the help of tungsten carbide and diamond rotating burs followed by restoration. While the treatment can be carried out under local anesthetics in most of the cases to minimise pain and discomfort, a challenge is faced when the patient is anxious or not at ease. Anxiety may worsen dental pain or alter the course of treatment, similarly due to the inability to control the speed of rotating drills there is an increased risk of accidental pulp exposure. In an order to overcome these shortcomings, modern dentistry focuses on minimally invasive procedures.

Laser technology being a minimally invasive procedure has substituted the use of high and low rotating speed drills, thus is considered conservative and less traumatic caries removal procedure. Various studies proved the usage of lasers in prevention of caries on the enamel surface.[2] The wavelengths of CO_2 lasers are attuned by absorbing peak of carbonated hydroxyapatite (HAP) because they demonstrate noteworthy inhibition of enamel demineralization (50-98 %).[3-5] The energy of laser is absorbed which is then transformed to heat, leading to microstructural and chemical alterations in the surface of enamel which is irradiated thereby improving enamel acid resistance.[3,4] Laser also helps to maintain a dry surrounding that improves the dentists vision of the working field thereby resulting in an improved outcome.

HISTORY AND TYPES OF LASERS

Laser is an abbreviation for light amplification by stimulated emission of radiation. Laser may be defined as a device that emits light through a process of optical amplification based on stimulated emission of electromagnetic radiation. The earliest laser was introduced by Theodore H. Maiman in the year 1960 by means of a synthetic ruby crystal as a lasing medium which was triggered by the use of increased flashes of energy of the intense light.[6] The first clinical application was for the analysis and management of dermal lesions. Subsequently, was found useful in surgeries and then in ophthalmology.[7] Oral soft tissue surgery was the first dental application of laser.[7]

Lasers used in dentistry can be classified according to the casing medium used such as, gas laser and solid laser. It may also be classified according to the type of tissue it is applicable upon, such as, hard tissue and soft tissue lasers.

TYPES OF LASERS

Carbon dioxide Lasers

These lasers can be used for removing soft tissues. Since, they allow minimal tissue penetration the procedure is relatively quicker. These however, cannot be used in cases of hard tissues as they tend to be bulky. Thus, may result in tissue damage.

Diode lasers

These are a type of soft tissue laser and are relatively smaller in size. They are commonly used in dentistry as they tend to be affordable and compact. These lasers are majorly used in gingivectomy, impression roughing, teeth whitening procedures and more.

Erbium lasers

The erbium 'family 'of lasers has two distinct wavelengths, Er, Cr: YSGG (yttrium scandium gallium garnet) lasers and Er: YAG (yttrium aluminium garnet) lasers. The erbium wavelengths have a high affinity for hydroxyapatite and the highest absorption of water in any dental laser wavelengths. Consequently, it is the laser of choice for treatment of dental hard tissues.[8] In addition to hard tissue procedures, erbium lasers can also be used for soft tissue ablation, because the dental soft tissue also contains a high percentage of water.[9]

Neodymium Yttrium Aluminium Garnet Laser

The Nd: YAG wavelength is highly absorbed by the pigmented tissue, making it a very effective surgical laser for cutting and coagulating dental soft tissues, with good hemostasis. In addition to its surgical applications.[10] There has been research on using the Nd: YAG laser for nonsurgical sulcular debridement in periodontal disease control[11] and the Laser Assisted New Attachment Procedure (LANAP).[12]

CLASSIFICATION OF LASERS

Based on its hardness, spectrum of light and material used.[13] they are classified as soft tissue lasers and hard tissue lasers.[13]

Soft Tissue Lasers

They commonly use diodes. Clinical indications include - Healing of localised osteitis, healing of aphthous ulcers, reduction of pain and treatment of gingivitis. Soft tissue lasers used in clinical practice include

1. **Helium-Neon (He-N)** at 632.8 nm (red, visible).
2. **Gallium-Arsenide (Ga-As)** at 830 nm (infra-red,
   invisible).

Hard Tissue Lasers

Surgically they can be used to cut both soft and hard tissues. Commonly used hard tissue lasers are:

1. **Argon lasers (Ar)** at 488 to 514 nm
2. **Carbon dioxide lasers (CO2)** at 10.6 micrometers
3. **Neodymium-doped yttrium aluminium garnet (Nd: YAG)** at 1.064 micrometer.

4. **Neodymium yttrium–aluminium-perovskite (Nd:YAP)** at 1,340 nm.[6]

Based on wavelength

Lasers are classified in 4 categories based on their wavelengths, as follows [14]

1. **Ultraviolet:** It has a spectrum of 300-400 nm, these are not applicable in dentistry
2. **Visible light:** It has a spectrum of 400-700 nm.
3. **Near Infrared (NIR):** It has a spectrum of 700-1200 nm.
4. **Far Infrared (FIR):** It has a spectrum of more than 1200 nm.

Based on the Material Used

1. **Gas:** examples of these are Ar and CO2 lasers.
2. **Liquid:** Examples of these are Dyes.
3. **Solid:** Examples of these are Nd: YAG, Er:YAG and diode lasers
4. **Semiconductor:** Examples of these are: hybrid silicon laser
5. **Excimers:** Examples of these are argon-fluoride, krypton-fluoride and xenon-fluoride lasers. [13]

CHARACTERISTICS OF LASERS

The beam is monochromatic, bright, unidirectional and coherent.

A. Monochromaticity

The luminous waves emitted come out with the same wavelength and energy. A single wavelength or a narrow band of wavelengths emitted allows precise targeting within tissue, while sparing adjacent structures.

B. Brilliancy

The light beam emitted is extremely intense and angularly well centred. The brightness or intensity is one of the important properties and can be enhanced by techniques like pulsing and Q-switching where extremely high peak power can be delivered in nanoseconds.

C. Coherency

All the photons emitted vibrate in phase agreement both in space and time. Coherence is a measure of precision of the waveform. Highly coherent laser beam can be more precisely focused.

D. Directionality

All the photons travel in one direction. Directionality of the laser correlates with the emission of an extremely narrow beam of light that spreads slowly.[15]

MECHANISM OF ACTION OF LASERS

The laser consists of an energy source, an active lasing medium, and two or more mirrors. In the dental laser, the light reaches the target tissue via the fiberoptic cable, hollow wave guide, focusing lenses, and cooling system. The Amdt–Schutz principle is the basis for the action. This means that the increase or decrease of the stimulus beyond the optimal dose will lead to weakening or absence of the effect. The optimal effect is created with the optimal dose.[16]

Laser beams used in dentistry are of two types, namely the visible beam such as the argon laser and the invisible beam such as the carbon dioxide laser. It is the wavelength and optical features of the target tissue, which are the deciding factors for the type and extent of interaction that might occur. The laser converts electromagnetic energy and the wavelength depends on both design and clinical applications.[17]

Dose Calculation is an important aspect so as to maintain an important optimum power density to trigger biological effects so that the low output will not be fully compensated by long exposure; and the depth of treatment target site is in consideration. Laser transmission through mucous and fat cells is more as compared to muscle cells. Moreover, Hemoglobin and other bodily pigments are strong absorbers of lasers. Advanced penetration can be achieved by getting the laser source closer to the target.[16, 18]

Laser- Tissue interaction:

Therapeutic laser light is a kind of light that stimulates the biological process and affects mostly the cells in an oxidation reduction reaction. The cell will be acidic in this stage but after the laser is done, the cell will become more alkaline and less acidic and will be able to perform its normal functions. The most important thing is to increase the adenosine triphosphate and it is mainly produced at the end of the Krebs cycle where the photon acceptor enzyme cytochrome is inhibited by nitric oxide. The laser light will initiate the binding between the nitric oxide and cytochrome-c oxidase, which will allow it to resume the action and production of the adenosine triphosphate enzyme. The principle is to supply the direct bio-stimulative energy to the body cells, and cellular photoreceptors will also absorb the low-level laser light which will produce ATP. The photochemical theory is the most accepted theory that is shown to explain the effects and the mechanisms of lasers, by which the light is absorbed by specific molecules and then some biological events will happen. Photoreceptors are some kinds of endogenous proteins and molecules in the respiratory chain such as cytochrome c-oxidase that will lead to increased ATP.[19]

When the laser energy comes in contact with the concerned site, it can be:

1. **Reflected** - When there is reflection of laser light beam from a surface in a direct or diffuse fashion.
2. **Absorbed** - There is a reaction which takes place when energy of the laser comes in contact with the atoms of the tissue it is directed at, eventually transforming into heat.
3. **Transmitted** - The energy of laser traverses through the tissue directly, not instigating any effect, eventually reaching the underlying tissue.
4. **Scattered** - The energy of the laser fans out to a broader area. If the light gets scattered, it is no more considered to be a coherent beam and therefore does not reach where its required.[15]

APPLICATION OF LASERS

Lasers are an innovative tool in modern dental practice. Since, lasers are minimally invasive in nature, they are commonly used in various dental procedures. They have the following applications,

Soft tissue applications:

- Wound healing
- Photoactivated dye disinfection using lasers
- Pain relief and accelerated healing of post herpetic neuralgia and apthous ulcer
- Frenectomies
- Aesthetic gingival re-contouring and crown lengthening
- Exposure of unerupted and partially erupted teeth
- Removal of inflamed and hypertrophic tissue

Hard tissue applications:

- Cavity preparation, caries, and restorative removal
- Laser fluorescence
- Treatment of dentinal hypersensitivity
- Etching of tooth surface

Miscellaneous applications:

- Analgesic effect on nerves following an oral surgery
- Post-surgical pain relief
- Nerve repair and regeneration

DENTAL CARIES

Definition

Dental caries involves interactions between the tooth structure, the microbial biofilm formed on the tooth surface and sugars, as well as salivary and genetic influences. The dynamic caries process consists of rapidly alternating periods of tooth demineralization and demineralization which, if net demineralization occurs over sufficient time, results in the initiation of specific caries lesions at certain anatomical predilection sites on the teeth.[20] Dental caries is a chronic disease that progresses slowly in most people. The disease can be seen in both the crown (coronal caries) and root (root caries) portions of primary and permanent teeth, and on smooth as well as pitted and fissured surfaces. It can affect enamel, the outer covering of the crown; cementum, the outermost layer of the root; and dentine, the tissue beneath both enamel and cementum. Caries in primary teeth of preschool children is commonly referred to as early childhood caries.[21]

Risk factors

A person's risk of caries can vary with time since many risk factors are changeable. Physical and biological risk factors for enamel or root caries include inadequate salivary flow and composition, high numbers of cariogenic bacteria, insufficient fluoride exposure, gingival recession, immunological components, need for special health care, and genetic factors.[22-26] Caries is related to one's lifestyle, and behavioral factors under a person's control are clearly implicated. These factors include poor oral hygiene; poor dietary habits - i.e., frequent consumption of refined carbohydrates; frequent use of oral medications that contain sugar; and inappropriate methods of feeding infants.[22,23,27,28]

Colonisation by mutans streptococci, and other cariogenic bacteria at a young age could be a key risk factor for caries development.[29,30] However, the role of mutans streptococci as the main cause of caries has not been proven. Because of the complexity of the oral microflora, which contains several hundred species of bacteria and millions of cells growing on a single tooth surface, no single bacterial species can predict caries development in a particular person.

Pathogenesis

Dental caries results from interactions over time between bacteria that produce acid, a substrate that the bacteria can metabolise, and many host factors that include teeth and saliva. Dental caries results from an ecological imbalance in the physiological equilibrium between tooth minerals and oral microbial biofilms. Bacteria live on teeth in microcolonies that are encapsulated in an organic matrix of polysaccharides, proteins, and DNA secreted by the cells, which provides protection from desiccation, host defences and predators and provides enhanced resistance to antimicrobial agents. Teeth offer non-shedding surfaces for microbial colonisation and large numbers of bacteria and their by-products accumulate in a biofilm on tooth surfaces in health and disease.[21,31]

The mechanisms of the caries process are similar for all types of caries. Endogenous bacteria (largely mutans streptococci [Streptococcus mutans and Streptococcus sobrinus] and Lactobacillus spp) in the biofilm produce weak organic acids as a by-product of metabolism of fermentable carbohydrates. This acid causes local pH values to fall below a critical value resulting in demineralisation of tooth tissues.[32] If the diffusion of calcium, phosphate, and carbonate out of the tooth is allowed to continue, cavitation will eventually take place. Demineralisation can be reversed in its early stages through uptake of calcium, phosphate, and fluoride. Fluoride acts as a catalyst for the diffusion of calcium and phosphate into the tooth, which remineralises the crystalline structures in the lesion. The rebuilt crystalline surfaces, composed of fluoridated hydroxyapatite and fluorapatite, are much more resistant to acid attack than is the original structure. Bacterial enzymes can also be involved in the development of caries.[21]

Caries lesions develop where oral biofilms are allowed to mature and remain on teeth for long periods. If a cavity is allowed to develop, the site provides an ecological niche in which plaque organisms gradually adapt to a reduced pH.[33] Formation of a cavitated lesion protects the biofilm, and unless the patient is able to cleanse this area, the carious process will continue.[34]

LASERS IN DIAGNOSIS AND TREATMENT OF DENTAL CARIES

- **LASERS AS A DIAGNOSTIC TOOL FOR DENTAL CARIES:**

Conventionally, diagnosis of a carious lesion is carried out using visual examination, instruments such as explorers and radiographs. However, various factors may restrain the visibility such as, complex tooth structure, bacterial plaque, saliva, therefore many carious lesion remain undetected. To overcome these shortcomings, laser devices such as DIAGNOdent and DIAGNO-cam have been introduced. DIAGNOdent is the most widely used laser-fluorescence caries detection device. It uses a red laser (wavelength ∼688 nm) based on the principle that healthy (non-pathological mineralized) and carious enamel and dentin tooth tissues have different fluorescent properties that are detected by the device. As such, it has demonstrated acceptable levels of reproducibility of diagnosis of caries and is recommended as an adjunct diagnostic tool along with conventional radiography.[35] Various other technologies have been introduced, namely VistaProof which is efficient in detecting early and incipient lesions. These devices are capable of producing a visual diagnosis which could be shown to the patients as well.

- **TREATMENT OF DENTAL CARIES:**

Removal of carious tooth structure:

Following the detection of a carious lesion, its removal is required. Traditionally, this is carried out using high and low-speed air turbine hand pieces in addition to manual excavators followed by adequate restoration. However, heat produced by these may cause pulpal damage. Rotary instruments produce sound and vibrations which can be causes of discomfort for patients. To overcome these drawbacks, lasers capable of ablating mineralized tissues, such as CO2 and erbium lasers, are used for tooth tissue ablation without noise and vibrations. However, laser ablation can cause production of excessive heat which can be deleterious to pulpal tissues. It has been observed that uncooled laser ablation of enamel can lead to a temperature rise as high as 300–800°C that may lead to permanent damage to the dental pulp.[36] However, this can be managed by means of a high-flow water spray.

Cavity preparation

Lasers have successfully replaced the traditional method of using high and low-speed air turbine hand pieces for cavity preparation. They also provide analgesic effect on the involved tooth.

Lasers confer to the modern approach of minimally invasive dentistry (MID) since they act by cutting only at their tip, thus preventing the loss of healthy tooth structures. Lasers tend to be relatively safer in case of unanticipated movement of the patient. Additional benefit includes the elimination of smear layer.

In cases of carious lesions which are limited proximally having intact occlusal surface, lasers could be used to preparing a box only preparation on the proximal surface without destructing the sound occlusal surface. In cases where the carious lesion extends deep within the tooth, lasers can be used to prepare the cavity, by restricting its initial depth of preparation and selective removal of the superficial layer of dentin without injuring the underlying pulp.[15] The cases which require direct pulp capping treatment due to accidental pinpoint non-carious exposure, Er: YAG lasers can be used in a defocussed mode for partly necrotising the superficial tissue in order to create a defensive barrier surrounding the exposed pulp tissue.[37]

CONCLUSIONS

Lasers confer to the modern approach of Minimally Invasive Dentistry (MID), despite its various benefits these are not routinely used for various dental procedures. This is majorly due to factors like high cost, lack of training, technique sensitivity and inability to have manual control. However, as a result of development in terms of research and awareness among dental professionals, application of lasers in dentistry is expected to grow in near future. It's essential for dental clinicians to provide their patients with desirable treatment that has favourable outcomes, which can be achieved with enhanced techniques and equipments.

Acknowledgement: None
Conflict of Interest: None
Source of Funding: None

REFERENCES

1. Prithwish M, Patel A, Chandak M, et al. Minimally invasive endodontics a promising future concept: a review article. International Journal of Scientific Study 2017;5(1):245- 51
2. Anauate-Netto C, Neto BL, Amore R, et al. Caries progression in non-cavitated fissures after infiltrant application: a 3-year follow-up of a randomized controlled clinical trial. J Appl Oral Sci 2017;25(4):442- 54.
3. Kim JW, Lee R, Chan KH, et al. Influence of a pulsed CO2 laser operating at 9.4 μm on the surface morphology, reflectivity, and acid resistance of dental enamel below the threshold for melting. J Biomed Opt 2017;22(2):28001.
4. Correa-Afonso AM, Ciconne-Nogueira JC, Pécora JD, et al. In vitro assessment of laser efficiency for caries prevention in pits and fissures. Microsc Res Tech 2012;75(2):245-52.
5. Correa-Afonso AM, Bachmann L, de Almeida CG, et al. FTIR and SEM analysis of CO2 laser irradiated human enamel. Arch Oral Biol 2012;57(9):1153-8.
6. Alster TS. Manual of cutaneous laser techniques. Lippincott Williams and Wilkins 2000: p. 11.
7. Koci E, Almas A. Laser application in dentistry: an evidance-based clinical decision-making update. Pak Oral Dent J 2009;29(2):409-23.
8. Harashima T, Kinoshita J, Kimura Y, Brugnera A, Zanin F, Pecora JD, et al. Morphological comparative study on ablation of dental hard tissue at cavity preparation by Er: YAG and Er, CR: YSGG lasers. *Photomed Laser Surg.* 2005;23:52–5.
9. Ishikawa I, Aoki A, Takasaki AA. Clinical application of erbium: YAG Laser in periodontology. *J Int Acad Periodontol.* 2008;10:22–30
10. Fornaini C, Rocca JP, Bertrand MF, Merigo E, Nammour S, Vescovi P. Nd: YAG and diode lasers in the surgical management of soft tissues related to orthodontic treatment. *Photomed Laser Surg.* 2007;25:381–92.
11. Aoki A, Mizutani K, Takasaki AA, Sasaki KM, Nagai S, Schwarz F, et al. Current status of clinical laser applications in periodontal therapy. *Gen Dent.* 2008; 56:674–87.
12. Slot DE, Kranendonk AA, Paraskevas S, Van der Weijden F. The effect of a pulsed Nd: YAG laser in non-surgical perdiodontal therapy. *J Periodont.* 2009;80:1041–56.
13. Singh H, Bhaskar DJ, Agali RC. Lasers: an emerging trend in dentistry. International Journal of Advanced Health Sciences 2014;1:4:5-13.
 changes from here
14. Asnaashari M, Safavi N. Application of Low level Lasers in Dentistry (Endodontic). J Lasers Med Sci 2013; 4(2):57-66
15. Chaudhari PS, Chandak MG, Relan KN, et al. Lasers in diagnosis, interception and management of white spot lesions and dental caries - a review. J Evolution Med Dent Sci 2021 ;10(09):624-631, DOI: 10.14260/jemds/2021/134
16. Luke AM, Mathew S, Altawash MM, Madan BM. Lasers: a review with their applications in oral medicine. J Lasers Med Sci. 2019;10(4):324-329. doi:10.15171/jlms.2019.52.
17. Asnaashari M, Zadsirjan S. Application of Laser in Oral Surgery. *J Laser Med Sci.* 2014;5(3):97–107. doi: 10.22037/jlms.v5i3.5853.
18. Tunér J, Ribeiro MS, Simões A. Dosimetry. In: Freitas PM, Simões A, eds. Lasers in Dentistry: A Guide to Clinical Practice. USA: Wiley Blackwell; 2015. p. 148-152.
19. Sun G, Tuner J. Low level laser therapy in dentistry. *Dent Clin North Am.* 2004;48(4):1061–1076. doi: 10.1016/j.cden.2004.05.004.
20. Pitts NB, Zero DT, Marsh PD, Ekstrand K, Weintraub JA, Ramos-Gomez F, Tagami J,

Twetman S, Tsakos G, Ismail A. Dental caries. Nat Rev Dis Primers. 2017 May 25; 3:17030. doi: 10.1038/nrdp.2017.30. PMID: 28540937.
21. Selwitz, R.H., Ismail, A.I. and Pitts, N.B., 2007. Dental caries. *The Lancet*, *369*(9555), pp.51-59.
22. Featherstone JD, Adair SM, Anderson MH, et al. Caries management by risk assessment: consensus statement, April 2002. J Calif Dent Assoc 2003; 31: 257–69.
23. Krol DM. Dental caries, oral health, and pediatricians. Curr Probl Pediatr Adolesc Health Care 2003; 33: 253–70.
24. Hassell TM, Harris EL. Genetic infl uences in caries and periodontal diseases. Crit Rev Oral Biol Med 1995; 6: 319–42.
25. Anderson M. Risk assessment and epidemiology of dental caries: review of the literature. Pediatr Dent 2002; 24: 377–85.
26. Thomson WM. Dental caries experience in older people over time: what can the larger cohort studies tell us? Br Dent J 2004; 196: 89–92.
27. Winn DM. Tobacco use and oral disease. J Dent Educ 2001; 65: 306–12.
28. Touger-Decker R, van Loveren C. Sugars and dental caries. Am J Clin Nutr 2003; 78: S881–92.
29. Berkowitz RJ. Acquisition and transmission of mutans streptococci. J Calif Dent Assoc 2003; 31: 135–38.
30. Seow WK. Biological mechanisms of early childhood caries. Community Dent Oral Epidemiol 1998; 26 (suppl 1): 8–27.
31. Scheie A, Peterson F. The biofilm concept: consequences for future prophylaxis of oral diseases? Crit Rev Oral Biol Med 2004; 15: 4–12.
32. Caufield PW, Griffen AL. Dental caries. An infectious and transmissible disease. Pediatr Clin North Am 2000; 47: 1001–19.
33. Fejerskov O. Changing paradigms in concepts on dental caries: consequences for oral health care. Caries Res 2004; 38: 182–91.
34. Kidd EA, Fejerskov O. What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res 2004; 83: C35–38.
35. Lussi A, Imwinkelried S, Pitts N, et al: Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. Caries Res 1999; 33:261–266
36. Fried D, Visuri SR, Featherstone JD, et al: In- frared radiometry of dental enamel during Er:YAG and Er:YSGG laser irradiation. J Biomed Opt 1996;1:455–465.
37. Attrill DC, Farrar SR, King TA, et al. Er:YAG laser etching of dental enamel as an alternative to acid etching. Lasers Med Sci 2000; 15:154-61.

How to cite this article: Shweta Chaudhary. Dental LASERs - Introduction and Implications in dentistry: a review article. *International Journal of Research and Review*. 2022; 9(5):259-266.
DOI: *https://doi.org/10.52403/ijrr.20220533*

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