Stom Glas S COBISS. SR-ID 8417026 UDC 616.31 ISSN 0039-1743

STOMATOLOŠKI GLASNIK SRBIJE

SERBIAN DENTAL JOURNAL

Vol. 72 • Number 1 • Januar-March 2025

http://www.stomglas.org.rs

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www.stomglas.org.rs

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Časopis izlazi četiri puta godišnje.

The journal is published four times a year.

Finansijsku podršku izdavanju časopisa pružaju Ministarstvo nauke, tehnološkog razvoja i inovacija Republike Srbije i Stomatološka komora Srbije.

The publishing of the Journal is financially supported by The Ministry of Science, Technological Development and Innovation of the Republic of Serbia and Serbian Dental Chamber.

ISSN 0039-1743
ISSN Online 1452-3701
COBISS. SR-ID 8417026
UDC 616.31

www.stomglas.org.rs

Stomatološki glasnik Srbije
Serbian Dental Journal

Izdavač Srpsko lekarsko društvo
Publisher Serbian Medical Society

Osnivač Stomatološka sekcija Srpskog lekarskog društva
Founder Dental Section of the Serbian Medical Society

Contents / Sadržaj

ORIGINAL ARTICLE
ORIGINALNI RAD
DOI: https://doi.org/10.2298/SGS2501003T
UDC: 615.322:582.991; 612.313

Antimicrobial effect of *Sphilantes acmella* on *Streptococcus mutans, Staphylococcus aureus, Enterococcus faecalis* and *Candida albicans* in oral cavity

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SUMMARY

Introduction Due to the increasing tolerance to antibiotics, the treatment of disorders of the microbial community in the oral cavity represents a major challenge. An alternative substance that can partially or completely replace existing antibacterial agents could be products derived from plants. *Spilanthes acmella* has been shown to be effective in the treatment of diseases of the oral cavity. The aim of this study is to investigate the potential antimicrobial efficacy of the plant *Spilanthes acmella* against *Streptococcus mutans*, *Staphylococcus aureus*, *Enterococcus faecalis* and *Candida albicans*, which are frequently associated with diseases of the oral cavity, and to compare this effect with conventional therapies.
Material and methods Three groups of samples were analyzed: the flower heads, the leaves and the remaining aerial parts (the stem and twigs).
Results The results showed that the flower extract showed no inhibitory effect on the bacteria tested. The extract from the stem and twigs showed an inhibitory effect on *Candida albicans*. The leaf extract showed the best inhibitory effect against *Streptococcus mutans*.
Conclusion Considering that chlorhexidine is the only solution with a proven antiplaque effect, we can conclude from these results that the synergistic effect of these two solutions provides the best results in the chemical control of dental plaque and could be part of the protocol in the prevention of both dental caries and periodontal disease in the future.
Keywords: plant extracts; antimicrobial activity; oral cavity; minimum inhibitory concentrations

INTRODUCTION

The human oral microbiome is an extremely complex and extraordinary group of microorganisms that form diverse associations in the mouth and harbor more than 700 species, including harmless symbionts, commensals and opportunistic pathogens [1, 2]. When the oral microbiome is disturbed, dysbiosis occurs in which disease-promoting bacteria gain the upper hand and cause oral diseases [3]. In addition, the role of the oral microbiome in a number of non-oral diseases such as pancreatic cancer, diabetes mellitus and endocarditis has been uncovered [4]. The microorganisms that make up the oral microbiome are usually organized in biofilms, commonly referred to as dental plaque. Oral pathogenic biofilms have been recognized as a predisposing factor for various oral infections, including dental caries, gingivitis, periodontitis and peri-implantitis [5, 6]. Dental caries is considered the most prevalent infectious disease in the world and one of the most frequent oral diseases, affecting 60–90% of schoolchildren and the vast majority of adults [7]. About 5–15% of the general population is affected by severe periodontitis [8]. Disruption of microbial community dynamics plays an important role in the etiology of gingivitis and the development of periodontitis [9].

Streptococcus mutans is considered to be the most important etiological factor in the development of dental caries [10]. In the early stages of caries formation, the combined action of enzymes released by *Strep. mutans* (glucosyltransferase and fructosyltransferase) and the adhesion-promoting substances (glucans) secreted by *Candida albicans* form cariogenic plaque biofilms on tooth surfaces. This provides habitats for the growth of the etiological bacteria [11, 12]. Of particular concern is the observation that there are strains of *Strep. mutans* that are resistant to various antibiotics and also to the presence of fluoride [13, 14].

Staphylococcus aureus is the most pathogenic member of the genus and the causative agent of a variety of diseases ranging from superficial skin abscesses and food poisoning to life-threatening conditions such as bacteremia, necrotic pneumonia in children and endocarditis [15]. *Staph. aureus* is thought to benefit from the presence of *C. albicans* in the oral cavity [16, 17]. The formation of such a specific microbial community associates *Staph. aureus* with several risks, such as the development of oral diseases (e.g. caries,

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halitosis, periodontitis, oral cancer, systemic infections), and may even influence the progression of several systemic diseases such as osteoporosis, atherosclerosis, diabetes, cardiovascular disease and ischemic cardiomyopathy [18]. The widespread use of prophylactic antibiotics in dentistry has been associated with the emergence of antibiotic resistance in several commensal microorganisms, including *Staph. aureus* [19].

Enterococcus faecalis is a facultative anaerobic gram-positive bacterium in the human oral cavity that is mainly responsible for various oral pathologies, in particular dental caries, dental abscesses, periodontal infections, apical periodontitis and persistent endodontic infections [20]. The ability of *E. faecalis* to grow as a biofilm on the walls of root canals and as a monoinfection in treated canals without synergistic support from other bacteria leads to a high resistance to antimicrobial agents [21, 22]. Clinical isolates of *E. faecalis* recovered from root canal and periodontal infections may exhibit antimicrobial resistance to conventional treatments recommended for dental procedures [23].

The opportunistic pathogen *Candida albicans* is the most frequently isolated fungus in oral infections [24]. The results of the meta-analysis by Edit et al. [25] indicate that individuals with the presence of *Candida* spp. have a higher prevalence of dental caries than individuals without these microorganisms in the oral cavity. The presence of *C. albicans* in the oral cavity has been associated with other oral diseases, such as denture stomatitis, oral cancer as well as the failure of endodontic treatments [26, 27, 28]. Over the past two decades, conventional antimicrobials have proven increasingly ineffective in controlling *C. albicans* [4, 29, 30].

Chlorhexidine is the most popular and widely accepted oral antibacterial agent and is considered the gold standard [31]. However, it cannot be used long-term as it has various side effects, such as brown discoloration, taste disturbances, oral mucosal lesions, parotid gland swelling, increased supragingival plaque formation and sometimes an unacceptable taste [32, 33]. Another problem with the use of chlorhexidine is the development of antimicrobial resistance, which is a serious adverse effect [34, 35].

Due to these side effects, it is important to find an alternative substance that can partially or completely replace the existing antibacterial agents. One of the ways to find new promising drugs is to thoroughly investigate herbs and herbal remedies used in the traditional medicine of different countries [36, 37, 38].

One of these herbs is *Spilanthes acmella* L., which is native to Brazil and Peru, but can be introduced as an annual plant in continental climates. This herb is popularly known as a toothache plant as it has an anesthetic effect when the leaves and flowers are chewed [39]. *S. acmella* is an herb with ascending, cylindrical, hairy stems that grows up to 40–60 cm tall and belongs to the *Asteraceae* family. Plant extracts, formulations and bioactive ingredients of *Spilanthes* species have been shown to have a wide range of potential applications in the pharmaceutical industry [40]. *S. acmella* has been shown to be effective in traditional medicine for the treatment of rheumatism, fever and influenza, tuberculosis, rabies, malaria and scurvy [41]. It has antinociceptive, antimicrobial, anti-inflammatory, anesthetic, analgesic, antifungal, antimutagenic, diuretic and immunostimulant effects [42, 43, 44]. It has also been shown to be effective in the treatment of diseases of the oral cavity such as dentalgia, periodontitis and ulcers of the oral mucosa [40, 45]. Alkamides are considered the predominant phytochemicals in the genus *Spilanthes* and the most important alkamide found is spilanthol. Despite numerous studies on the biological significance of this metabolite, there are only a few commercial spilanthol-based products for pharmacological purposes [46].

The aim of this study is to investigate the potential antimicrobial efficacy of the flower heads, the leaves and the stem and twigs of the *S. acmella* plant against typical infectious pathogens in the human oral cavity: *Strep. mutans*, *Staph. aureus*, *E. faecalis* and *C. albicans*. This study will also analyze the comparison with conventional therapies (chlorhexidine). Given the origin of this plant and its limited distribution, such studies have not yet been carried out in European countries as far as we know.

METHODS

Plant material and preparation of the extract

The plant material was obtained in July 2023 from *S. acmella* plants grown from seed (Tuinzaden.eu, Weesperstraat 94d, 1112AP Dieme, The Netherlands). Three different groups of samples were analyzed. The first consisted of the flower heads, the second of the leaves and the third of the remaining aerial parts (the stem and twigs). All parts of the plant material that were torn, crumpled and with dark edges were removed.

The plant parts were thoroughly washed under running tap water. The raw materials were disinfected by immersion in a solution containing 100 ppm (mg/L) of free residual chlorine for 10 minutes [47]. The final rinse was done with distilled water. The fresh samples were dried in an oven at 50°C to remove all water. To obtain a fine and homogeneous powder, the dried mass of flower heads, leaves and remaining aerial parts were macerated separately with liquid nitrogen and a porcelain pestle and mortar. These extracts obtained by maceration were dissolved in methanol (HPLC grade, Merck) (1:20) at room temperature. The *S. acmella* plant material was then left in the bath sonicator for ten minutes. The methanolic extract was then centrifuged for 15 minutes at 5000 rpm in a refrigerated centrifuge (Sigma 4K 15C, Sigma Laborzentrifugen GmbH Osterode am Harz, Germany). The centrifuged aliquot (supernatant) was collected. The residue was centrifuged again in a methanol solution to obtain a larger amount of the extract. The residue was then discarded and the entire methanolic solution was collected and filtered. The solutions were concentrated to dryness under reduced pressure in a rotary evaporator (Buchi Rotavapor, Flawil, Switzerland). The vials containing the extracts were wrapped in aluminum foil and stored in a freezer at -30°C until analysis of potential antimicrobial activity.

Microorganisms used in research

The strains tested were gram-positive facultative anaerobes Strep. mutans ATCC 25175, E. faecalis ATCC 14506, Staph. aureus ATCC 25923 and C. albicans ATCC 10231, which were cultured in the presence of oxygen. All strains were grown overnight at 37 °C in Miller-Hinton broth (HiMedia, Mumbai, Maharashtra, India) with a standard pH of 7.4 for this broth.

Determination of minimum inhibitory concentrations

The method used to evaluate the antimicrobial activity was the minimum inhibitory concentration (MIC) by the tryptic soy agar dilution method (EUCAST, 2024) [48]. During the cooling of the substrate before it hardens, plant extracts are added in the appropriate concentration. Serial dilutions of the plant extracts were prepared in plates with concentrations of 6.25, 12.5, 25, 50, 100, 200 and 400 µg/ml. The MIC was defined as the lowest concentration of the extract that caused no visible bacterial growth compared to the control growth.

There was no intra-observer variation as the investigator inoculating the media for the antimicrobial activity test obtained identical results for three measurements at three time points.

The comparison was made with a standard solution of 0.12% chlorhexidine (Galenika, Zemun, Belgrade, Serbia). Serial dilutions of chlorhexidine were prepared in plates with concentrations of 6.25, 12.5, 25, 50, 100, 200 and 400 µl/ml.

RESULTS

The effect of different concentrations of chlorhexidine was investigated on four types of microorganisms. Chlorhexidine had an inhibitory effect on the tested strains of all three types of bacteria (*Strep. mutans*, *E. faecalis* and *Staph. aureus*) as well as on *C. albicans*. The inhibitory effects were achieved even at the lowest chlorhexidine concentration used (6.25 µg/mL). The extract from the flowerheads of *S. acmella* showed no inhibitory effect on *C. albicans* in our experiment in all tested concentrations (Table 1). We found that the extract from the stem and twigs of *S. acmella* had an inhibitory effect on *C. albicans* at 50 µg/mL as well as at higher concentrations (Table 2).

The leaf extract of *S. acmella* showed a highly effective inhibitory activity against the bacterium *Strep. mutans* (MIC = 6.3 µg/mL) (Table 2).

In our study, we found no significant effect of *S. acmella* extract on *E. faecalis*. The flower of *S. acmella* showed no inhibitory effect on the tested bacteria – MIC > 400 µg/mL (Table 1 and Table 2). Our studies did not confirm any significant effect of *S. acmella* extracts on *S. aureus* (Table 1 and Table 2).

Table 1. Determination of the minimum inhibitory concentrations of chlorhexidine and extracts from flower heads of *S. acmella* plants for *Streptococcus mutans*, *Enterococcus faecalis*, *Staphylococcus aureus* and *Candida albicans*
+ growth of microorganisms;
- inhibition of the growth of microorganisms

Tabela 1. Određivanje minimalnih inhibitornih koncentracija hlorheksidina i ekstrakta iz cvasti biljaka *S. acmella* za *Streptococcus mutans*, *Enterococcus faecalis*, *Staphilococcus aureus* i *Candida albicans*
+ rast mikroorganizama;
- inhibicija rasta mikroorganizama

	Streptococcus mutans	Enterococcus faecalis	Staphylococcus aureus	Candida albicans
Chlorhexidine / Hlorheksidin				
400 µg/mL	-	-	-	-
200 µg/mL	-	-	-	-
100 µg/mL	-	-	-	-
50 µg/mL	-	-	-	-
25 µg/mL	-	-	-	-
12.5 µg/mL	-	-	-	-
6.25 µg/mL	-	-	-	-
S. acmella flowerheads / *S. acmella* cvasti				
400 µg/mL	+	+	+	+
200 µg/mL	+	+	+	+
100 µg/mL	+	+	+	+
50 µg/mL	+	+	+	+
25 µg/mL	+	+	+	+
12.5 µg/mL	+	+	+	+
6.25 µg/mL	+	+	+	+

Table 2. Determination of the minimum inhibitory concentrations of extracts from stems, twigs and leaves of *S. acmella* plants for *Streptococcus mutans*, *Enterococcus faecalis*, *Staphylococcus aureus* and *Candida albicans*. + growth of microorganisms; - inhibition of the growth of microorganisms

Tabela 2. Određivanje minimalnih inhibitornih koncentracija ekstrakata iz stabljika, grančica i listova biljaka *S. acmella* za *Streptococcus mutans*, *Enterococcus faecalis*, *Staphilococcus aureus* i *Candida albicans*
+ rast mikroorganizama;
- inhibicija rasta mikroorganizama

	Streptococcus mutans	Enterococcus faecalis	Staphylococcus aureus	Candida albicans
S. acmella stem and twigs / *S. acmella* stabljike i grančice				
400 µg/mL	+	+	+	-
200 µg/mL	+	+	+	-
100 µg/mL	+	+	+	-
50 µg/mL	+	+	+	-
25 µg/mL	+	+	+	+
12.5 µg/mL	+	+	+	+
6.25 µg/mL	+	+	+	+
S. acmella leaves / *S. acmella* listovi				
400 µg/mL	-	+	+	+
200 µg/mL	-	+	+	+
100 µg/mL	-	+	+	+
50 µg/mL	-	+	+	+
25 µg/mL	-	+	+	+
12.5 µg/mL	-	+	+	+
6.25 µg/mL	-	+	+	+

DISCUSSION

The increasing resistance of pathogens to conventional antibiotics and the undesirable side effects of existing therapies have made traditional medicinal plants an attractive source for screening for antimicrobial agents. In line with these efforts, the present study aimed to investigate the antimicrobial activities of crude methanolic extracts of above ground parts of *S. acmella* against four important dental pathogens: *Strep. mutans*, *E. faecalis*, *Staph. aureus* and *C. albicans*. The aim was also to compare these herbal effects with conventional therapies using chlorhexidine. Numerous studies have already investigated the antibacterial effect of *S. acmella*, but they often lead to contradictory results.

A significant antimicrobial effect of chlorhexidine observed in our study was also reported by Balagopal and Arjunkumar [32], Leyes Borrajo et al. [49] and Jiang et al. [50]. Brookes et al. [35] also cite several studies in their meta-analysis confirming that chlorhexidine is a potent antimicrobial agent. The antifungal effects of chlorhexidine relate to the prevention of biofilm formation [35] and disruption of the structure or cell membrane of *C. albicans* [50]. Although chlorhexidine gluconate is often used to reduce and inhibit biofilm formation, it has some disadvantages. For example, it has some negative effects on the tissues of the oral cavity and also contributes to some negative systemic changes [33, 51]. There is also evidence that some populations of *C. albicans* may persist after the application of chlorhexidine and form a multi-tolerant subpopulation, which may reduce the efficacy of chlorhexidine over time [52]. In these cases, the combined effect of chlorhexidine with some other substances can be of great help. Since the extract from the aerial parts of *S. acmella* has been shown to have an inhibitory effect on *C. albicans* even at low concentrations, we can conclude that it could be a good adjuvant in the treatment of candidiasis, especially when resistant strains are suspected to be present. This is of particular importance as, to our knowledge, no antifungal resistance to spilanthol, the main bioactive metabolite of *S. acmella*, has been demonstrated.

It has been described that *Strep. mutans* communicates closely with *C. albicans* in a complex bidirectional interaction that is involved in biofilm formation [53]. Several reports have shown that the dental microbiome is not only responsible for major disease outbreaks in the oral cavity, but may also play a role in systemic disease [54, 55]. These findings make the control of oral microorganisms an important issue. In this context, the biofilm in dental plaque is a major obstacle to such control as it protects pathogenic bacteria from antibiotics [56, 57]. Since the prevention of biofilm formation is centered on the eradication of *Strep. mutans*, it is important to have effective means to control the presence of this bacterium in the oral cavity. The highly effective bactericidal effect that the extract of *S. acmella* has on *Strep. mutans* offers the possibility of using this plant as an independent or additional medicinal agent that does not have the negative side effects observed with conventional agents [58].

The persistence of *E. faecalis* is problematic for endodontic treatment and new effective antimicrobial agents are clearly needed [59]. Regarding the efficacy of *S. acmella* against this bacteria, different results have been reported. For example, in contrast to our results, Sathyaprasad et al. [60] observed that extracts from the flower heads of *S. acmella* exhibited a statistically broader zone of inhibition compared to Ca(OH)2. Dube et al. [61] investigated the antibacterial efficacy of *Spilanthes calva* De Candolle against *E. faecalis*. From this *in vitro* study, it was concluded that the differences in efficacy between the root extracts and the commonly used root canal irrigants depended on the concentration of the herbal extracts [61]. The differences between the results may be caused by non-standardized conditions for plant cultivation as well as different conditions for the preparation of the plant material or chemical extraction methods.

Staph. aureus is a common gram-positive bacterium in the human mucosal microbiota [62], which is strongly associated with biofilm-related infections [63]. The established biofilms of *Staph. aureus* is highly tolerant to common antimicrobial treatments [64, 65]. Jahan et al. [66] and Thakur et al. [67] found a significant bactericidal effect of the aerial parts of *S. acmella*. Although our results showed no direct effect of *S. acmella* extract on *Staph. aureus*, the possible indirect effect through its action on *C. albicans* could be of importance. When oral immunity is weakened (diabetes mellitus, HIV, cancer, use of corticosteroids, etc.), oropharyngeal candidiasis may develop, overcoming the oral epithelial barrier. If *Staph. aureus* is also present; it can invade together with *C. albicans* and utilize the phagocytes present in the tissue to spread to the draining lymph nodes [68]. Thus, by suppressing the development of candidiasis, *S. acmella* extract may reduce the likelihood of some of the harmful effects of *Staph. aureus* as well as *E. faecalis* and some other bacteria capable for bloodstream infections.

These results justify the use of *S. acmella* for the treatment of various infectious oral diseases caused by the investigated microorganisms. The results of the present work are preliminary and further investigations are required to determine the actual nature of the bioactive compounds which may be present in the different parts of the plant. The *in vitro* observations of the herbal products seem promising, but preclinical and clinical studies are needed to evaluate the biocompatibility and safety factor before they can be conclusively recommended as antimicrobial solutions and drugs. By analyzing the potential mechanism of action and comparing it with conventional therapies, we hope to further explore the potential of *S. acmella* as a valuable addition to the antimicrobial armamentarium.

ACKNOWLEDGMENT

We would like to thank Branislav Šiler for preparing plant material.

CONFLICT OF INTEREST STATEMENT

All authors declare no conflicts of interest.

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Received: 06.12.2024 • Accepted: 09.01.2025

Antimikrobni efekat *Spilanthes acmella* na *Streptococcus mutans, Staphylococcus aureus, Enterococcus faecalis* i *Candida albicans* u usnoj duplji

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SAŽETAK

Uvod Zbog sve veće tolerancije mikroorganizama na antibiotike, lečenje poremećaja mikrobne zajednice u usnoj duplji predstavlja veliki izazov. Alternativne supstance koje mogu delimično ili potpuno zameniti postojeće antibakterijske agense mogu biti proizvodi dobijeni od biljaka. *Spilanthes acmella* pokazala se efikasnom u lečenju bolesti usne duplje.

Cilj ovog istraživanja bio je da se ispita potencijalna antimikrobna efikasnost biljke *Spilanthes acmella* protiv *Streptococcus mutans*, *Staphylococcus aureus*, *Enterococcus faecalis* i *Candida albicans*, mikroorganizama koji se često povezuju sa oboljenjima usne duplje, kao i da se ovaj efekat uporedi sa konvencionalnim terapijama.

Materijal i metode Analizirane su tri grupe uzoraka: cvetne glavice, listovi i preostali nadzemni delovi (stabljika i grančice).

Rezultati Rezultati su pokazali da ekstrakt cveta nije ispoljio inhibitorni efekat na testirane bakterije. Ekstrakt iz stabljike i grančica pokazao je inhibitorni efekat na *Candida albicans*. Ekstrakt lista pokazao je najbolji inhibitorni efekat protiv *Streptococcus mutans*.

Zaključak S obzirom na to da je hlorheksidin jedino sredstvo sa dokazanim antiplak efektom, iz dobijenih rezultata može se zaključiti da sinergistički efekat ova dva rastvora daje najbolje rezultate u hemijskoj kontroli zubnog plaka i može biti deo protokola za prevenciju kako zubnog karijesa, tako i parodontalnih bolesti u budućnosti.

Ključne reči: biljni ekstrakti; antimikrobna aktivnost; usna duplja; minimalna inhibitorna koncentracija

UVOD

Ljudski oralni mikrobiom je izuzetno složena grupa mikroorganizama koji formiraju različite veze u ustima i sadrže više od 700 vrsta, uključujući bezopasne simbionte, komensale i oportunističke patogene [1, 2]. Kada je oralni mikrobiom poremećen, dolazi do disbioze u kojoj patogene bakterije preuzimaju prevlast i izazivaju oralne bolesti [3]. Pored toga, otkrivena je uloga oralnog mikrobioma u brojnim neoralnim bolestima, kao što su rak pankreasa, dijabetes melitus i endokarditis [4]. Mikroorganizmi koji čine oralni mikrobiom obično su organizovani u biofilm, koji se naziva zubni plak. Oralni patogeni biofilma su prepoznati kao predisponirajući faktor za različite oralne infekcije, uključujući karijes, gingivitis, parodontitis i periimplantitis [5, 6]. Zubni karijes se smatra najrasprostranjenijom zaraznom bolešću u svetu i jednom od najčešćih oralnih bolesti, koja pogađa 60–90% školske dece i veliku većinu odraslih osoba [7]. Teškim parodontitisom pogođeno je 5–15% opšte populacije [8]. Poremećaj dinamike mikrobne zajednice igra važnu ulogu u etiologiji gingivitisa i nastanku parodontitisa [9].

Streptococcus mutans se smatra najvažnijim etiološkim faktorom u nastanku karijesa zuba [10]. U ranim fazama formiranja karijesa, kombinovano delovanje enzima koje oslobađa *Strep. mutans* (glukoziltransferaza i fruktoziltransferaza) i supstance koje podstiču adheziju (glukani) koje sintetiše *Candida albicans* formiraju biofilm kariogenog plaka na površini zuba. Time se stvaraju uslovi za rast etioloških bakterija [11, 12]. Posebno je zabrinjavajuće postojanje sojeva *Strep. mutans* koji su otporni na različite antibiotike, kao i na prisustvo fluora [13, 14].

Staphylococcus aureus je najpatogeniji član roda i uzročnik raznih bolesti – od površinskih apscesa kože i trovanja hranom do stanja opasnih po život kao što su bakteremija, nekrotična pneumonija kod dece i endokarditis [15]. *Staph. aureus* ima koristi od prisustva *C. albicans* u usnoj duplji [16, 17]. Formiranje takve specifične mikrobne zajednice povezuje *Staph. aureus* sa nekoliko rizika, kao što je razvoj oralnih bolesti (npr. karijes, halitoza, parodontitis, oralni karcinom, sistemske infekcije), a može uticati i na progresiju nekih sistemskih bolesti kao što su osteoporoza, ateroskleroza, dijabetes, kardiovaskularne bolesti i ishemijska kardiomiopatija [18]. Široka upotreba profilaktičkih antibiotika u stomatologiji povezana je sa pojavom rezistencije na antibiotike kod nekoliko komensalnih mikroorganizama, uključujući *Staph. aureus* [19].

Enterococcus faecalis je fakultativna anaerobna, gram-pozitivna bakterija u usnoj duplji koja je uglavnom odgovorna za različite oralne patologije, posebno zubni karijes, zubne apscese, parodontalne infekcije, apikalni parodontitis i perzistentne endodontske infekcije [20]. Sposobnost *E. faecalis* da formira biofilm na zidovima kanala korena zuba i to kao monoinfekcija u tretiranim kanalima, bez sinergističke podrške drugih bakterija, dovodi do visoke rezistencije na antimikrobne agense [21, 22]. Klinički izolati *E. faecalis* dobijeni iz inficiranih kanala korena zuba kao i parodontalne infekcije mogu pokazati antimikrobnu rezistenciju na konvencionalne tretmane preporučene za stomatološke procedure [23].

Oportunistički patogen *C. albicans* je najčešće izolovana gljiva u oralnim infekcijama [24]. Rezultati metaanalize Edit i saradnika [25] ukazuju da osobe sa prisustvom *Candida* spp. u usnoj duplji imaju veću prevalenciju zubnog karijesa nego osobe bez ovih mikroorganizama. Prisustvo *C. albicans* u usnoj duplji je povezano sa drugim oralnim oboljenjima, kao što su stomatitis proteza, oralni karcinom, kao i neuspešna endodontska lečenja [26, 27, 28]. Tokom poslednje dve decenije, konvencionalni antimikrobni lekovi pokazuju se kao sve neefikasniji u kontroli *C. albicans* [4, 29, 30].

Hlorheksidin je najčešće korišćen i široko prihvaćen oralni antibakterijski agens i smatra se zlatnim standardom [31]. Ipak, njegova dugotrajna upotreba nije preporučljiva zbog brojnih neželjenih efekata: bojenje zuba u smeđu boju, poremećaj čula ukusa, lezije oralne sluzokože, oticanje parotidnih žlezda, povećano formiranje supragingivalnog plaka i ponekad neprijatan ukus [32, 33]. Drugi problem sa upotrebom hlorheksidina je razvoj antimikrobne rezistencije, što predstavlja ozbiljan neželjeni efekat [34, 35].

Zbog ovih neželjenih efekata, važno je pronaći alternativne supstance koje mogu delimično ili potpuno zameniti postojeće antibakterijske agense. Jedan od načina za pronalaženje novih obećavajućih lekova je temeljno istraživanje biljaka i biljnih lekova koji se koriste u tradicionalnoj medicini različitih zemalja [36, 37, 38].

Jedna od ovih biljaka je *Spilanthes acmella* L., poreklom iz Brazila i Perua, koja se može gajiti kao jednogodišnja biljka u kontinentalnoj klimi. Ova biljka je u narodu poznata kao biljka protiv zubobolje jer ima anestetički efekat kada se žvaću listovi i cvetovi [39]. *S. acmella* je biljka sa uzlaznim, cilindričnim, dlakavim stabljikama koja naraste 40–60 cm visine i pripada porodici Asteraceae. Pokazalo se da biljni ekstrakti i bioaktivni sastojci vrsta roda *Spilanthes* imaju širok spektar potencijalnih primena u farmaceutskoj industriji [40]. *S. acmella* se pokazala efikasnom u tradicionalnoj medicini za lečenje reumatizma, groznice i gripa, tuberkuloze, besnila, malarije i skorbuta [41]. Ima antinociceptivna, antimikrobna, antiinflamatorna, anestetička, analgetička, antifungalna, antimutagena, diuretička i imunostimulativna dejstva [42, 43, 44]. Takođe se pokazala efikasnom u lečenju bolesti usne duplje, kao što su dentalne bolesti, parodontitis i čirevi na oralnoj sluzokoži [40, 45]. Alkamidi se smatraju dominantnim fitokemikalijama u rodu *Spilanthes*, a najvažniji pronađeni alkamid je spilantol. Uprkos brojnim studijama o biološkom značaju ovog metabolita, postoji samo nekoliko komercijalnih proizvoda na bazi spilantola za farmakološke svrhe [46].

Cilj ove studije je da se ispita potencijalna antimikrobna efikasnost cvetova, listova, stabljike i grančica biljke *S. acmella* protiv čestih infektivnih patogena u usnoj duplji čoveka: *Strep. mutans*, *Staph. aureus*, *E. faecalis* i *C. albicans*. U ovoj studiji će se takođe porediti efekti biljnog ekstrakta sa efektima konvencionalne terapije hlorheksidinom. S obzirom na poreklo ove biljke i njenu ograničenu rasprostranjenost, ovakva istraživanja, koliko nam je poznato, još uvek nisu sprovedena u evropskim zemljama.

METODE

Biljni materijal i priprema ekstrakta

Biljni materijal je dobijen u julu 2023. od biljaka *S. acmella* uzgojenih iz semena (Tuinzaden.eu, Veesperstraat 94d, 1112AP Dieme, Holandija). Analizirane su tri različite grupe uzoraka. Prvi se sastojao od glavičastih cvasti, drugi od listova, a treći od preostalih nadzemnih delova (stabljika i grančice). Uklonjeni su svi delovi biljnog materijala koji su bili pocepani, zgužvani ili tamnih ivica.

Korišćeni delovi biljaka su temeljno oprani pod tekućom vodom. Materijal je dezinfikovan uranjanjem u rastvor koji sadrži 100 ppm (mg/L) slobodnog hlora tokom deset minuta [47]. Završno ispiranje je obavljeno destilovanom vodom. Sveži uzorci su sušeni u pećnici na 50 °C kako bi se uklonila voda. Da bi se dobio fini i homogeni prah, osušena masa cvasti, listova i preostalih nadzemnih delova odvojeno su usitnjavani korišćenjem tečnog azota u porcelanskom avanu. Ekstrakti dobijeni usitnjavanjem rastvoreni su u metanolu (HPLC kvaliteta, Merck) (1 : 20) na sobnoj temperaturi. Biljni materijal *S. acmella* je zatim tretiran u sonifikatoru deset minuta. Metanolni ekstrakt je zatim centrifugiran 15 minuta na 5000 rpm u hlađenoj centrifugi (Sigma 4K 15C, Sigma Laborzentrifugen GmbH Osterode am Harz, Nemačka). Centrifugirani supernatant je sakupljen, a ostatak je ponovo centrifugiran u rastvoru metanola da bi se dobila veća količina ekstrakta. Preostali deo je zatim odbačen, a ceo metanolni rastvor je sakupljen i filtriran. Rastvori su koncentrovani do suve mase pod sniženim pritiskom u rotacionom isparivaču (Buchi Rotavapor, Flavil, Švajcarska). Bočice sa ekstraktima su umotane u aluminijumsku foliju i čuvane u zamrzivaču na -30 °C do analize potencijalne antimikrobne aktivnosti.

Mikroorganizmi koji se koriste u istraživanju

Testirani sojevi su bili gram-pozitivni fakultativni anaerobi: *Strep. mutans* ATCC 25175, *E. faecalis* ATCC 14506, *Staph. aureus* ATCC 25923 i *C. albicans* ATCC 10231, koji su kultivisani u prisustvu kiseonika. Svi sojevi su uzgajani preko noći na 37 °C u Miller-Hinton medijumu (HiMedia, Mumbai, Indija) sa standardnom pH od 7,4 za ovaj medijum.

Određivanje minimalnih inhibitornih koncentracija (MIC)

Metoda korišćena za procenu antimikrobne aktivnosti bila je minimalna inhibitorna koncentracija (MIC) metodom razblaživanja tripitičnog sojinog agara (EUCAST, 2024) [48]. Prilikom hlađenja, pre nego što očvrsne, u podlogu su dodavani biljni ekstrakti u odgovarajućoj koncentraciji. Serijska razblaženja biljnih ekstrakata pripremana su u koncentracijama od 6,25, 12,5, 25, 50, 100, 200 i 400 µg/ml. MIC je definisan kao najniža koncentracija ekstrakta koja nije izazvala vidljiv rast bakterija u poređenju sa kontrolnim rastom.

Poređenje je vršeno sa standardnim rastvorom 0,12% hlorheksidina (Galenika, Zemun). Serijska razblaženja hlorheksidina su pripremljena, slično biljnim ekstraktima, u koncentracijama od 6,25, 12,5, 25, 50, 100, 200 i 400 µg/ml.

Nije bilo varijabilnosti merenja „unutar posmatrača" pošto je istraživač koji je inokulirao medijume za test antimikrobne aktivnosti dobio identične rezultate za tri merenja u tri vremenska perioda.

REZULTATI

Ispitivano je dejstvo različitih koncentracija hlorheksidina na četiri vrste mikroorganizama. Hlorheksidin je imao inhibitorni efekat na ispitivane sojeve sve tri vrste bakterija (*Strep. mutans*, *E. faecalis* i *Staph. aureus*) kao i na *C. albicans*. Inhibitorni efekti su postignuti čak i pri najnižoj korišćenoj koncentraciji hlorheksidina (6,25 µg/mL). Ekstrakt cvasti *S. acmella* nije pokazao inhibitorni efekat na *C. albicans* u našem eksperimentu u svim ispitivanim koncentracijama (Tabela 1). Potvrđeno je da ekstrakt iz stabljike i grančica *S. acmella* ima inhibitorni efekat na *C. albicans* pri 50 µg/mL, kao i pri svim većim koncentracijama (Tabela 2).

Ekstrakt lista *S. acmella* pokazao je značajnu inhibitornu aktivnost protiv bakterije *Strep. mutans* (MIC = 6,3 µg/mL) (Tabela 2).

U našoj studiji nismo pronašli značajan efekat ekstrakta *S. acmella* na *E. faecalis*. Cvetovi *S. acmella* nisu pokazali inhibitorni efekat na ispitivane bakterije – MIC > 400 µg/mL (Tabela 1 i Tabela 2). Naše studije nisu potvrdile značajan efekat ekstrakta *S. acmella* na *S. aureus* (Tabela 1 i Tabela 2).

DISKUSIJA

Sve veća otpornost patogena na konvencionalne antibiotike i neželjeni efekti postojećih terapija učinili su tradicionalne lekovite biljke privlačnim izvorom za skrining antimikrobnih agenasa. U skladu sa ovim trendovima, ova studija je imala za cilj da istraži antimikrobnu aktivnost metanolnih ekstrakata nadzemnih delova *S. acmella* na četiri važna dentalna patogena: *Strep. mutans*, *E. faecalis*, *Staph. aureus* i *C. albicans*. Cilj je takođe bio da se uporede ovi efekti ekstrakta biljaka sa konvencionalnom terapijom korišćenjem hlorheksidina. Brojne studije su već ispitivale antibakterijski efekat *S. acmella*, ali rezultati nisu bili jednoznačni.

Značajan antimikrobni efekat hlorheksidina dobijen u ovoj studiji takođe je potvrđen u radovima koje su objavili Balagopal i Arjunkumar [32], Leyes Borrajo i saradnici [49] i Jiang i saradnici [50]. Brookes i saradnici [35] takođe navode nekoliko studija u svojoj metaanalizi koje potvrđuju da je hlorheksidin moćan antimikrobni agens. Antifungalni efekti hlorheksidina odnose se na prevenciju formiranja biofilma [35] i narušavanje strukture ćelijske membrane *C. albicans* [50]. Iako se hlorheksidin-glukonat često koristi za smanjenje i inhibiciju formiranja biofilma, on ima izvesne nedostatke. Na primer, može negativno uticati na tkiva usne duplje i doprineti nekim negativnim sistemskim promenama [33, 51]. Takođe postoje dokazi da neke populacije *C. albicans* mogu da opstanu nakon primene hlorheksidina i formiraju multitolerantnu subpopulaciju, što može tokom vremena smanjiti efikasnost hlorheksidina [52]. U ovim slučajevima, kombinovano dejstvo hlorheksidina sa nekim drugim supstancama može biti od velike pomoći. Pošto se pokazalo da ekstrakt nadzemnih delova *S. acmella* čak i u niskim koncentracijama deluje inhibitorno na *C. albicans*, može se zaključiti da bi ekstrakt ove biljke mogao biti dobar adjuvans u lečenju kandidijaze, posebno kada se sumnja na prisustvo rezistentnih sojeva. Ovo je od posebnog značaja jer, prema našim saznanjima, nije pokazana antifungalna otpornost na spilantol, glavni bioaktivni metabolit *S. acmella*.

Dokazano je da *Strep. mutans* blisko komunicira sa *C. albicans* u složenoj dvosmernoj interakciji koja je uključena u formiranje biofilma [53]. Više istraživanja je pokazalo da dentalni mikrobiom nije odgovoran samo za pojavu bolesti u usnoj duplji već može imati važnu ulogu u nastanku sistemskih bolesti [54, 55]. Ovi rezultati ukazuju da je kontrola oralnih mikroorganizama veoma značajna. U tom kontekstu, biofilm u zubnom plaku je glavna prepreka takvoj kontroli jer štiti patogene bakterije od antibiotika [56, 57]. Pošto je prevencija stvaranja biofilma usredsređena na uklanjanje *Strep. mutans*, važno je imati efikasna sredstva za kontrolu prisustva ove bakterije u usnoj duplji. Veoma efikasan baktericidni efekat koji ekstrakt *S. acmella* ima na *Strep. mutans* nudi mogućnost upotrebe ove biljke kao samostalnog ili dodatnog lekovitog sredstva koje nema neželjene efekte uočene kod konvencionalnih agenasa [58].

Perzistentnost *E. faecalis* je problematična za endodontsko lečenje i jasno je da su potrebni novi efikasni antimikrobni agensi [59]. Što se tiče efikasnosti *S. acmella* protiv ove bakterije, zabeleženi su različiti rezultati. Na primer, za razliku od naših rezultata, Sathiaprasad i saradnici [60] primetili su da ekstrakti cvetova *S. acmella* pokazuju širu zonu inhibicije u poređenju sa $Ca(OH)_2$. Dube i saradnici [61] istraživali su antibakterijsku efikasnost *Spilanthes calva* De Candolle protiv *E. faecalis*. Iz ove *in vitro* studije, zaključeno je da razlike efikasnosti između ekstrakata korena ove biljke i uobičajenih sredstava za irigaciju kanala korena zavise od koncentracije biljnih ekstrakata [61]. Razlike između rezultata mogu biti uzrokovane nestandardizovanim uslovima za uzgoj biljaka, kao i različitim uslovima za pripremu biljnog materijala ili hemijskim metodama ekstrakcije.

Staph. aureus je uobičajena gram-pozitivna bakterija u mikrobioti ljudske sluzokože [62] i značajan je faktor infekcija povezanih sa biofilmom [63]. Formirani biofilm *Staph. aureus* je veoma otporan na uobičajene antimikrobne tretmane [64, 65]. Jahan i saradnici [66] i Thakur i saradnici [67] utvrdili su značajan baktericidni efekat nadzemnih delova *S. acmella* protiv ove bakterije. Iako naši rezultati nisu pokazali direktan efekat ekstrakta *S. acmella* na *Staph. aureus*, mogući indirektni efekat preko njegovog delovanja na *C. albicans* mogao bi biti značajan. Kada je oralni imunitet oslabljen (dijabetes melitus, HIV, kancer, upotreba kortikosteroida itd.), može se razviti orofaringealna kandidijaza, koja prolazi kroz oralnu epitelnu barijeru. Ako je pri tome prisutan i *Staph. aureus*, on može zajedno sa *C. albicans* da iskoristi fagocite prisutne u tkivu i proširi se na drenažne limfne čvorove [68]. Dakle, suzbijanjem razvoja kandidijaze, ekstrakt *S. acmella* može smanjiti verovatnoću štetnih efekata *Staph. aureus*, ali i *E. faecalis* i nekih drugih bakterija sposobnih za infekcije putem krvotoka.

Rezultati ovog istraživanja opravdavaju primenu *S. acmella* za lečenje različitih oralnih bolesti izazvanih ispitivanim mikroorganizmima. Rezultati ovog rada su preliminarni i potrebna su dalja istraživanja kako bi se utvrdio sadržaj svih bioaktivnih jedinjenja koja mogu biti prisutna u različitim delovima biljke. *In vitro* zapažanja o ovim biljnim proizvodima su obećavajuća, ali su potrebne pretkliničke i kliničke studije kako bi se procenili faktori biokompatibilnosti i bezbednosti pre nego što se mogu definitivno preporučiti kao antimikrobna rešenja i lekovi. Nadamo se da će analizom potencijalnih mehanizama delovanja i upoređivanjem sa drugim konvencionalnim terapijama biti bolje istražen potencijal *S. acmella* kao korisnog dodatka antimikrobnim tretmanima.

ORIGINAL ARTICLE
ORIGINALNI RAD
DOI: https://doi.org/10.2298/SGS2501014P
UDC: 616.314.163-085

A survey on intentional root canal treatment for crown and bridge among dental practitioners

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SUMMARY
Introduction/Objective Crown and bridge restorations are commonly used by general dental practitioners to replace partially edentulous areas following operative or endodontic procedures. The main goal was to explore the use of intentional root canal treatment (RCT) for crown and bridge procedures among dental practitioners in Tamil Nadu, India.
Methods A total of 124 dental practitioner participated in this questionnaire-based survey.
Results The mean duration of practice was 11.66 years; 68.5% responded that they perform intentional RCT in daily practice; 68.3% stated that they undertake RCT only in attrited or mutilated teeth; 62% reported selecting the option "to avoid postoperative sensitivity or pain and to achieve adequate tooth preparation and clearance"; 54% indicated that this preference is based on previous experience.
Conclusion Based on this survey, many practitioners prefer intentional RCT before crown and bridge procedures.
Keywords: intentional root canal treatment; crown and bridge; tooth preparation; dental practitioners

INTRODUCTION

Crown and bridge restorations are an integral part of comprehensive modern restorative dentistry, commonly employed by general dental practitioners to replace missing teeth or restore damaged ones following operative or endodontic procedures [1, 2]. These restorations not only improve the aesthetic appearance and function of the teeth but also contribute to the overall oral health of patients. Caries and periodontal disease affecting abutment teeth are biological indications for endodontic treatment. Intentional root canal treatment (RCT) is a key procedure often performed in conjunction with crown and bridge procedures, particularly on abutment teeth that serve as anchors for the prosthesis. Patients should be informed of the risks of intentional RCT, and should be given information on alternative treatments, their risks, and prognosis [3, 4]. While intentional RCT is commonly advocated for restorative reasons [5], such as achieving optimal tooth preparation and preventing post-operative complications, the decision to perform such treatments remains a subject of debate among dental professionals. Therefore, the purpose of this study was to explore the prevalence and practices of intentional RCT among dental practitioners in Tamil Nadu, a state in India, with a specific focus on its role in crown and bridge restorations.

METHODS

A total of 124 dental practitioners from Tamil Nadu participated in this questionnaire-based survey conducted from September 2020 to February 2021.

Study design

This was a questionnaire-based survey on knowledge, attitude, and practice. The survey included questions on demographic details as well as practice, recommendation, and opinion on performing intentional or elective RCT as a pretreatment for crown and bridge procedures. The survey included 124 general (BDS) and specialty (MDS) dental practitioners in South India, primarily from Tamil Nadu. No other selection criteria were applied, such as age, sex, and ethnicity. The survey was conducted electronically via Google Forms. It investigated practitioners' knowledge and practice of intentional RCT for crown and bridge. The survey consisted of a total of eight questions, which would take a maximum of three to five minutes to complete. The questionnaire data were entered into Microsoft Excel 2013 by the investigator, and descriptive statistical data were obtained.

RESULTS

The study sample comprised 72 BDS and 52 MDS dentists. Of the 124 participants, seven were MDS in prosthodontics, 72 were BDS, 15 were MDS in other specialties, while the remaining 30 dentists did not mention their specialties (Figure 1).

For the question 'Do you perform intentional RCT?', 85 (68.5%) participants responded affirmatively, of whom 51 were BDS and 34 were MDS. Responses of 39 participants showed they were not performing this procedure; among these, 21 were BDS and 18 were MDS (Figure 2). For the same question, two prosthodontists responded that they are not practicing intentional RCT.

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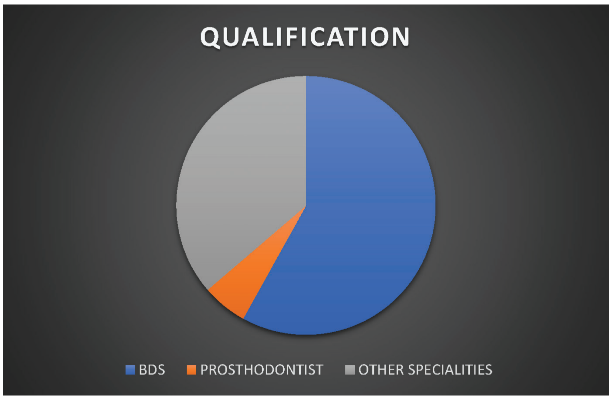

Figure 1. Qualifications of the study participants
Slika 1. Kvalifikacije učesnika studije

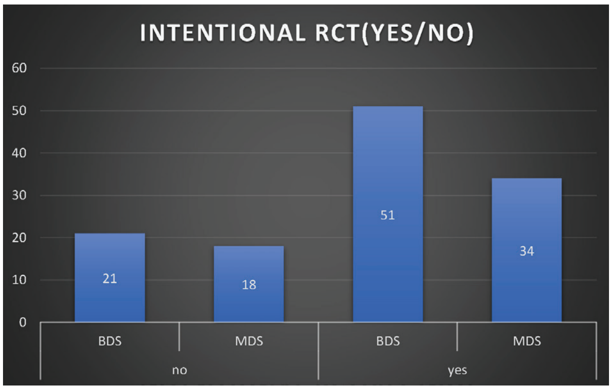

Figure 2. The distribution of answers on performing intentional root canal treatment depending on qualification of study participants
Slika 2. Raspodela odgovora u zavisnosti od kvalifikacija učesnika

Table 1. The distribution of answers on in what clinical situations to recommend the intentional root canal treatment for crown and bridge
Tabela 1. Raspodela odgovora o tome u kojim situacijama se preporučuje namenska endodontska terapija

Question Pitanje	BDS/MDS	No Ne	Yes, in all cases Da, uvek	Only in mutilated or attrited tooth Samo kod destruisanih zuba	Only in anterior teeth Samo kod prednjih zuba	Only in posterior teeth Samo kod bočnih zuba	Other reason Drugi razlozi
Are you recommending root canal treatment in crown and bridge? Da li preporučujete tretman kanala korena kao pripremu za fiksni rad?	BDS	7	16	47	4	0	1
	MDS	11	7	39	2	0	7

BDS – general dental practicioners / opšti stomatolozi; MDS – specialty dental practicioners / specijalisti

Table 2. The distribution of answers on reasons for recommending intentional root canal treatment
Tabela 2. Raspodela odgovora o razlozima za izvođenje namenske terapije kanala korena

Question Pitanje	BDS/MDS	To avoid post op pain or sensitivity Da bi se izbegla postoperativna bol ili osetljivost	To achieve good tooth preparation and good clearance Da bi se postigla bolja preparacija i uklanjanje destruisanog tkiva	Both of the aforementioned Oba prethodno pomenuta razloga	Other reason Drugi razlozi
Why have you recommended intentional root canal treatment? Da bi se postigla bolja preparacija i uklanjanje destruisanog tkiva	BDS	16	10	44	2
	MDS	10	4	32	6

BDS – general dental practicioners / opšti stomatolozi; MDS – specialty dental practicioners / specijalisti

Table 3. The distribution of answers on the source of stated opinion on intentional root canal treatment
Tabela 3. Raspodela odgovora o izvoru iznetog mišljenja

Question Pitanje	BDS/MDS	Learnt from dental schools Naučeno na fakultetu	Previous experience Prethodno iskustvo	Learnt from senior practitioner Naučeno od iskusnijih	Other reason Drugi razlozi
On what is your opinion about intentional root canal treatment based on? Na čemu je zasnovano Vaše mišljenje o namenskoj terapiji kanala korena?	BDS	6	40	22	4
	MDS	8	27	13	4

BDS – general dental practicioners / opšti stomatolozi; MDS – specialty dental practicioners / specijalisti

For 'Do you recommend intentional RCT before crown and bridge procedures?', 68.3% stated that they perform RCT only in attrited or mutilated teeth, followed by 18.3% who perform intentional RCT in all cases (Table 1).

For 'What is the main reason for recommending intentional RCT?', 62% selected both options – to avoid post-operative sensitivity or pain and to achieve adequate tooth preparation and clearance – followed by 23.8% who selected only to avoid post-operative sensitivity or pain (Table 2).

For 'Your opinion on intentional RCT is based on?', 54% reported previous experience, followed by 28.3% who had learnt it from senior practitioners (Table 3).

DISCUSSION

This study explored dental practitioners' attitudes toward intentional RCT as pretreatment for crown and bridge procedures and its implementation in daily practice. Intentional RCT is performed on teeth that have no signs or symptoms of irreversible pulpitis or infection. It follows recognized guidelines and carries the same risks as non-intentional RCT; both entail similar operator-error risks, highlighting the need to consider all possible negative outcomes [6].

Intentional RCT was reported in daily practice by most practitioners, distributed almost equally between BDS and MDS dentists. Most (63.5%) perform it only in mutilated or attrited teeth, aligning with European Society of Endodontology guidelines, which recommend intentional RCT for teeth with presumed infected pulps scheduled for crown and bridge or when the pulp chamber and root canals are needed for retention [7].

Avoiding post-operative sensitivity or pain and achieving optimal tooth preparation were the most common reasons (61%), yet this approach is not evidence-based. De Backer et al. found no significant difference in long-term survival between vital-tooth and root-canal-treated abutments, with higher failure rates in prostheses containing at least one root-canal-treated abutment [8].

Most opinions were based on previous experience, underscoring the need for evidence-based decision-making. Both intentional and non-intentional RCT show similar long-term success; intentional RCT should therefore be limited to attrited or mutilated abutments or when pulp chamber height compromises preparation, and avoided in otherwise healthy teeth.

CONCLUSION

Within the limits of this survey, many practitioners from Tamil Nadu opt for intentional RCT as pretreatment for crown and bridge procedures.

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Received: 09.12.2024 • Accepted: 11.03.2025

Istraživanje o namenskoj terapiji kanala korena kao pripremi za izradu krunica i mostova među stomatolozima

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SAŽETAK

Uvod/Cilj Zubne nadoknade u vidu krunica i mostova stomatolozi obično koriste za popunu delimično bezubog područja i nakon operativnih ili endodontskih zahvata. Glavni cilj studije bio je da se istraži namensko lečenje kanala korena kao priprema za izradu krunica i mostova među stomatolozima u regiji Tamil Nadu u Indiji.

Metode Ukupno 124 stomatologa učestvovala su u ovoj anketi zasnovanoj na upitniku.

Rezultati Prosečno trajanje stomatološke prakse bilo je 11,66 godina. Namensko lečenje korenskih kanala (RCT) u svakodnevnoj stomatološkoj praksi izvodi 68,5% ispitanika; 68,3% ispitanika izjavilo je da radi RCT samo kod abradiranih ili destruisanih zuba; 62% praktičara označilo je opciju da RCT izvodi radi izbegavanja postoperativne osetljivosti ili bola i radi postizanja dobre preparacije, dok je 54% učesnika navelo da postupak izvodi zbog pozitivnog prethodnog iskustva.

Zaključak Na osnovu rezultata ankete, mnogi praktičari su se opredelili za namensko lečenje korenskih kanala pre izrade krunica i mostova.

Ključne reči: namensko lečenje kanala korena; krunica i most; preparacija zuba, stomatologija

UVOD

Krunice i mostovi predstavljaju sastavne komponente savremene restaurativne stomatologije, koje stomatolozi obično koriste za zamenu zuba koji nedostaju ili obnavljanje oštećenih zuba nakon operativnih ili endodontskih procedura [1, 2]. Ove nadoknade ne samo da poboljšavaju estetski izgled i funkciju zuba već doprinose i opštem oralnom zdravlju pacijenata. Oboljenja zubnih tkiva koja utiču na nosače fiksnih nadoknada i biološki su razlozi endodontskog lečenja najčešće su karijes i parodontalna bolest. Značajna procedura koja se često izvodi u okviru restaurativnih postupaka, pa i u kombinaciji sa izradom krunica i mostova, jeste namensko lečenje kanala korena (RCT), posebno na zubima koji služe kao nosači fiksnih protetskih radova. Pacijente treba informisati o rizicima namenskog lečenja kanala korena i treba im dati informacije o alternativnim tretmanima, njihovim rizicima i prognozi [3, 4]. Dok je namenski RCT indikovan u okviru nekih restaurativnih procedura [5], obično radi postizanja optimalne pripreme zuba i sprečavanja postoperativnih komplikacija, odluka o izvođenju ovakvih tretmana ostaje predmet debate među stručnjacima u stomatologiji. Stoga je svrha ove studije bila da se istraže rasprostranjenost i praksa namenskog lečenja korenskih kanala među stomatolozima u Tamil Naduu, sa posebnim fokusom na njegovu ulogu u restauraciji krunica i mostova.

METODE

U ovoj na upitniku zasnovanoj anketi, koja je sprovedena od septembra 2020. do februara 2021. godine, učestvovala su ukupno 124 stomatologa iz Tamil Nadua.

Dizajn studije

Studija je zasnovana na upitniku o znanju, stavovima i praksi stomatologa. Anketa je uključivala pitanja vezana za demografske podatke učesnika, kao i na praksu, preporuke i mišljenje o izvođenju namenske ili elektivne terapije (RCT) kao predtretmana za krunicu i most. Istraživanje je obuhvatilo 124 stomatologa opšte prakse (BDS) i lekare specijaliste (MDS) stomatološke struke u južnoj Indiji, uglavnom iz Tamil Nadua. Nisu postavljeni posebni kriterijumi za isključenje učesnika kao što su starost, pol i etnička pripadnost. Naša studija je sprovedena putem elektronske ankete rađene preko Google formulara. Cilj nam je bio da istražimo znanje i praksu namenskog RCT kao pripremu za izradu krunica i mostova. Anketa se sastojala od ukupno osam pitanja, a za njeno popunjavanje bilo je potrebno najviše tri do pet minuta. Podatke iz upitnika istraživač je uneo u softver Microsoft Excel 2013 i dobijeni su deskriptivni statistički podaci.

REZULTATI

U ovoj studiji učestvovala su 72 doktora stomatologije sa diplomom BDS i 52 sa diplomom MDS. Prosečno trajanje stomatološke prakse bilo je 11,66 godina za obe grupe. Od 124 učesnika, sedmoro su bili doktori stomatologije, a 15 lekari raznih i navedenih specijalnosti. Preostalih 30 stomatologa bili su specijalisti, ali prilikom popunjavanja formulara nisu naveli oblast svoje specijalnosti (Slika 1).

Na pitanje „Da li radite namensko lečenje kanala korena?", 85 (68,5%) učesnika je odgovorilo potvrdno – od kojih je 51 sa BDS diplomom i 34 sa MDS diplomom. Odgovori 39 učesnika pokazali su da ne praktikuju ovu proceduru. Među ovim učesnicima 21 je bio sa diplomom BDS i 18 sa diplomom MDS (Slika 2). Na isto pitanje dva lekara specijalista protetike odgovorila su da ne praktikuju namensko lečenje kanala korena.

Na pitanje „Da li preporučujete namensko lečenje kanala korena kao pripremu za izradu krunica i mostova?", 68,3% učesnika navelo je da radi RCT samo kod istrošenog ili oštećenog zuba, a 18,3% učesnika je izjavilo da rade namensku RCT u svim slučajevima (Tabela 1).

Na pitanje „Koji je razlog za preporuku namenskog tretmana korenskih kanala?", 62% učesnika označilo je dve ponuđene opcije: izbegavanje postoperativne osetljivosti ili bola i postizanje kvalitetne preparacije zuba. Dodatnih 23,8% učesnika izabralo je samo opciju izbegavanja postoperativne osetljivosti ili bola (Tabela 2).

Za poslednje pitanje: „Na čemu se zasniva vaše mišljenje o namenskom tretmanu korenskih kanala?“, 54% učesnika odgovorilo je da se njihovo mišljenje temelji na ličnom prethodnom iskustvu, a 28,3% učesnika je izjavilo da su svoje stavove formirali na osnovu učenja od starijih kolega (Tabela 3).

DISKUSIJA

Glavni cilj ovog istraživanja bio je prikupljanje podataka o stavovima stomatologa o namenskom RCT-u kao predtretmanu za krunice i mostove i primeni ove procedure u svakodnevnoj stomatološkoj praksi. Namenski RCT se, po pravilu, radi na zubu koji nema znakove ili simptome ireverzibilnog pulpitisa ili infekcije. Prati dobro poznate smernice i nosi iste rizike kao i RCT indikovan iz razloga identifikovanih patoloških procesa. I nameski i uobičajni RCT imaju isti nivo rizika od grešaka operatora, što nameće potrebu da se uzmu u obzir svi mogući negativni ishodi ovih procedura [6].

Većina stomatologa uključenih u studiju navela je da u svojoj svakodnevnoj praksi primenjuju namenski RCT, a ta praksa je skoro podjednako zastupljena među praktičarima koji su nivoa BDS i MDS, što znači da podjednako primenjuju namenski RCT. Iz ovoga je moguće zaključiti da su stomatolozi generalno upoznati sa značajem namenskog RCT-a.

Posmatrajući razloge primene RCT-a kao pripreme za izradu krunica i mostova, treba napomenuti da je većina stomatologa (63,5%) odgovorila da ga rade samo na oštećenom ili istrošenom zubu, dok manji broj njih to radi u svim slučajevima. Ovakav pristup je u skladu sa Smernicama Evropskog društva za endodonciju (ESE), u kojima se navodi da namenski RCT treba planirati za zube predviđene za nosače fiksnih radova sa utvrđenom inficiranom pulpom, kao i za zube koji se ne mogu restaurirati bez korišćenja pulpne komore i kanala korena za retenciju nadoknade [7].

Razlog za izbor namenskog RCT-a kako bi se izbegla postoperativna bol ili osetljivost, kao i da bi se postigla dobra preparacija zuba, bio je najzastupljeniji odgovor učesnika ove ankete (61%). Međutim, ovaj stav nije zasnovan na dokazima, jer u studiji koju su uradili De Backer i saradnici nije bilo statistički značajne razlike u dugoročnoj stopi preživljavanja vitalnih zuba i onih sa tretiranim kanalom korena a koji su bili nosači za fiksni protetski rad. Dodatno, propadanje fiksnih protetskih radova je bilo češće kod nadoknada sa najmanje jednim lečenim zubom u odnosu na one koji su imali kao nosače zube sa vitalnom pulpom [8].

Mišljenje o namenskom RCT-u uglavnom je za većinu praktičara zasnovano na prethodnom iskustvu u njihovoj stomatološkoj praksi, praćeno onim naučenim od starijih kolega. Ovo ukazuje na potrebu da se praktičari fokusiraju na razumevanje značaja učenja zasnovanog na dokazima i zauzimanja stavova na osnovu ovoga.

Na osnovu gore navedenih literaturnih podataka, kao preporuka za kliničku praksu može se istaći da namenski i uobičajni RCT koji se rade na nosačima fiksnih radova imaju isti nivo uspeha i dugoročnu stopu preživljavanja i stoga ih treba detaljno razmotriti pre nego što se praktičar odluči za namernsko lečenje kanala korena. Namensko lečenje kanala korena treba da se uradi samo kada je nosač oštećen, a takođe u zavisnosti od visine rogova pulpe na uključenim zubima nosačima. Zbog toga se namenska RCT treba detaljno razmotriti kod inače zdravih zuba.

ZAKLJUČAK

Na osnovu rezultata ovog istraživanja može se zaključiti da su se mnogi praktičari iz Tamil Nadua opredelili za sprovođenje namenskog RCT-a kao predtretmana za izradu krunica i mostova.

REVIEW ARTICLE
REVIJALNI RAD
DOI: https://doi.org/10.2298/SGS2501019T
UDC: 616.31:004.891

Expert systems in dentistry

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SUMMARY

Introduction Artificial intelligence (AI) has become an important factor in social, scientific, and economic development today. It has wide possibilities for application, including dentistry. Its history spans eight decades, and a special area of this research and development is expert systems (ES) related to dentistry. The goal is to analyze the state of development and application of ES in dentistry, and to propose the possibility of their application today.

Methods Using elements of systematic analysis, a representative sample of articles from Web of Science and Scopus references was selected (PubMed/MEDLINE databases), which were analyzed from the point of view of the time dimension of the development of AI and ES.

Results The paper is structured so as to provide answers to the following questions: what is AI and how was it developed, how did ES in dentistry come about and how did it develop, including in Serbia, what are the prospects for the application of AI/ES in dentistry, and what are possible future directions in this area?

Conclusion AI and ES in the field of dentistry are moving from an era of experimental research to the verge of becoming good clinical practice. Digitization and the Industry 4.0 model are current directions, already widespread, which represent strong support for the faster application of these models in dental practice.

Keywords: artificial intelligence; expert systems; dentistry

INTRODUCTION

Artificial intelligence (AI) is a branch of the science of intelligence, which can be natural or artificial. AI is the science and engineering of creating intelligent machines and software systems. These two fields of research are connected and have contributed to each other over the past eight decades. Advances in natural intelligence have laid a solid foundation for AI research: artificial neural networks (ANN), genetic algorithms (GA), etc., while advanced AI tools have helped accelerate new discoveries in natural intelligence [1, 2]. Thus, there is an eight-decade-long history of AI that is more promising today than ever, as it applies to dentistry.

This review paper aims to provide readers with basic facts and knowledge about the development and application of expert systems (ES) in dentistry, to date. The beginnings of application refer, first of all, to AI, which itself has a history of development, also analyzed in detail in this paper. Why? Because ES have been a good basis for the application of AI tools and techniques in dentistry, especially deep learning in the last decade of this century. This work is intended for scientists, researchers and students who want to get concise information about the beginning of the development of a new scientific branch in dentistry, smart dentistry.

This system analysis was performed according to the PRISMA methodology [3], and our queries were the following: Q1 – How ES are used in dentistry, and Q2 – How ES improve decision-making: diagnosis, treatment planning, monitoring treatment progress, and evaluation of therapy success. For these questions, the following were defined: time period of analysis, type of study, ES models, search methodology and assessment of study quality. The sample included 268 papers, and 32 papers met the set criteria.

This paper has several parts: (i) how AI was created and developed, (ii) overview of the development of ES for dentistry, up to today, including Serbia, (iii) challenges and future development of ES for dentistry, (iv) conclusions and future research.

A BRIEF HISTORY OF AI

Before detailing ES in dentistry, it is necessary to briefly analyze the history of AI, which is shown in Table 1 [1, 2, 4]. It covers an interval of eight decades (1940–2020) and has four stages of development, as indicated in the table below.

It can be said that the history of AI starts from the early 1940s. It started with the binary ANN model created by W. McCulloch and W. Pitts of the University of Illinois in

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Table 1. Overview of the development of artificial intelligence (AI) (adapted from Toosi et al. [1], Negnevitsky [2], and Silver et al. [4])
Tabela 1. Pregled razvoja veštačke inteligencije (AI) (prilagođeno prema Toosi et al. [1], Negnevitsky [2] i Silver et al. [4])

Year of appearance Godina pojavljivanja	AI development period Period razvoja AI	Event name Naziv događaja	Characteristic Karakteristika
1943	The Dark Ages of AI Mračno doba AI	Binary ANN model (W. McCullouch, W. Pitts) Binarni ANN model (W. McCullouch, W. Pitts)	Two-state neuron Neuron sa dva stanja
1950		Turing test – can machines think? (A. Turing) Tjuringov test – mogu li mašine da misle? (A. Turing)	Communication: examiner – examinee – computer Komunikacija: ispitivač – ispitivani kompjuter
1951		The first neural computer (M. Minsky, D. Edmonds) Prvi neuronski računar (M. Minski, D. Edmonds)	A network of forty neurons Mreža od četrdeset neurona
1956	The rise of AI Uspon AI	First AI Workshop (J. McCarthy) Prva AI radionica (J. McCarthy)	Artificial intelligence defined Definicija termina „veštačka inteligencija (AI)"
1958		LISP – The First AI Language (J. McCarthy) LISP – Prvi AI jezik (J. McCarthy)	Still in use today – functional language Koristi se i danas – funkcionalni jezik
1961		General Problem Solver (GPS) (A. Newell, H. Simon) Opšti rešavač problema (GPS) (A. Newell, H. Simon)	Uses formal logic to find solutions (does not solve complex cases) Koristi formalnu logiku za traženje rešenja (ne rešava složene slučajeve)
1965		Fazzy sets (L. Zadeh) Neizraziti skupovi (L. Zadeh)	A continuous transition from not belonging to complete belonging Kontinualni prelaz od nepripadanja do potpunog pripadanja
1969		Dendral **(**E. Feigenbaum, B. Buchanan, J. Lederberg, C. Derassi)	The first expert system – spectrogram identification of chemical compounds Prvi ekspertni sistem – spektrogramska identifikacija hemijskih jedinjenja
1970	AI "winter" AI „zima"	ANN Learning (A. Bryson and Y. Ho) ANN učenje (A. Brajson i Y. Ho)	Backpropagation model Model propagacije unazad
1975		GA (J. Holland)	The first genetic algorithm Prvi genetski algoritam
1976		Mysin (E. Shortliffe)	The first expert system for diagnosis Prvi ekspertni sistem za dijagnozu
1982		Hopfield networks (J. Hopfield) Hopfildske mreže (J. Hopfild)	Memory systems with binary boundary nodes, a model for understanding human memory Memorijski sistemi sa binarnim graničnim čvorovima, model za razumevanje ljudskog pamćenja
1986		Backpropagation (BP) (D. Rumelhart, J. McClelland) and DAI (Distributed AI) (A. Bond, L. Gasser) Propagacija unazad (BP) (D. Rumelhart, J. McClelland) i DAI (Distribuirana AI) (A. Bond, L. Gasser)	Neural error (BP) computation and distributed solutions for AI Izračunavanje greške neurona (BP) i distribuirana rešenja za AI
1992	AI becomes a science AI postaje nauka	Genetic programming (GP) (J. Koza) Genetsko programiranje (GP) (J. Koza)	LISP symbolic code LISP simbolički kod
1995		Intelligent agents (M. Wooldridge, R. Jennings) Inteligentni agenti (M. Wooldridge, R. Jennings)	They act on the environment in an intelligent way Deluju na okolinu na inteligentan način
2002		ACO, PSO, AIO, DNA computing ACO, PSO, AIO, DNA računarstvo	AI tools Alati AI
2006		Honda ASIMO robot Robot Honda ASIMO	Moving and climbing stairs Kretanje i penjanje uz stepenice
2016		AlphaGo DeepMind	Man–computer games Igre čovek–kompjuter
2017		IBM Watson	Man–computer games Igre čovek–kompjuter
2022	ChatGPT	Open AI	AI for different fields AI za različite oblasti

1943 [5]. Although their model only considered a binary state (i.e., on/off for each neuron), this model was used as a basis for ANN research in the late 1980s. In 1950, the British mathematician A. Turing proposed the famous Turing test, which is used to determine whether machines can think [6]. The Turing test is performed through computer communication, which includes an examiner, a person (subject), a participant in the experiment, and a computer, which are separated from each other, but communicatively connected. The examiner can ask any question. If the examiner cannot distinguish a machine from a human based on their answers, the computer has passed the test. In 1951, M. Minsky and D. Edmonds, two graduate students from Princeton University, built the first neural computer simulating a network of 40 neurons [7].

An important turning point in the development of AI was the first AI workshop, held in 1956 at Dartmouth College, under the leadership of J. McCarthy [8]. This workshop marked the end of the "Dark Age of AI" and the beginning of the "Rise of AI" in the history of AI. The term "artificial intelligence" was then proposed by J. McCarthy, and it is still in use. He later moved to the Massachusetts Institute of Technology to define the first AI language, LISP, in 1958, which is still in use today. One of the most ambitious projects in this area was the General Problem Solver (GPS), which was created in 1961 by A. Newell and H. Simon from Carnegie Mellon University [9]. GPS is based on formal logic and can generate an infinite number of operators trying to find a solution; however, it is ineffective in solving complicated problems. In 1965, L. Zadeh of UC Berkeley published the famous paper "Fuzzy Sets," which is the basis of the theory of fuzzy sets, or uncertain decision making [10].

The first ES, Dendral [11], was developed at Stanford University in 1969 in a project funded by the National Aeronautics and Space Administration (NASA), led by J. Lederberg, winner of the Nobel Prize for genetics. However, at the time, most AI projects could only solve gaming problems, rather than real-world ones, so many projects in the United States, Great Britain, and several other countries failed, or were useless. That's how AI research entered the so-called "AI Winter."

Despite reduced funding, AI research continued, so in 1970, Bryson and Ho [12] proposed a back-propagation model for neural network learning. Moreover, the first GA was proposed in 1975. Holland [13], from the University of Michigan, used selection, crossover and mutation as genetic operators for optimization and thus developed the GA model. The same team, which was developed by ES Dendral [14], at Stanford University, developed MYCIN in 1976, which is based on IF–THEN rules, as an expert system for the diagnosis of blood diseases using 600 rules, if (IF) – then (THEN). Research has shown that it works better than a junior doctor [15].

After 30 years, the work on ANN has restarted research on them as an important area of AI. A new era has begun in which AI has become a science. It was in 1982 that Hopfield [16] published his Hopfield networks, which are still popular today. In 1986, back propagation became the first implemented learning algorithm in ANN, 16 years after the publication of this model [17]. Also, this year is the beginning of the application of distributed AI (DAI) through parallel distributed knowledge processing. After 22 years, fuzzy set theory or fuzzy logic was successfully incorporated into the operation management of dishwashers and washing machines in 1987 by Japanese companies that produced these household appliances. In 1992, genetic programming was proposed by Koza [18] for manipulation of symbolic code generated in the LISP language. Based on the ideas of DAI and artificial life, intelligent agents gradually took shape in the mid-1990s. In the late 1990s, hybrid systems of fuzzy logic, ANN, and GA became popular tools for solving complex problems. Various new AI approaches have since emerged, including ACO, particle lake optimization (PSO), artificial immunity optimization (AIO), and DNA computing, as well as intelligent agents [19]. The potential of AI in the future – such as dentistry – remains great and currently unpredictable.

The first popular AI tool was AI-based chess software – the computer program Deep Blue, created by International Business Machines Corporation (IBM) [20]. Garry Kasparov, the then world chess champion, played against it in 1997 in an exhibition match, and lost to it by 2.5 to 3.5. Another early example is the Honda ASIMO robot in 2005 that could climb stairs. For a robot to move in an unstructured environment and be commanded by a human, it requires natural language processing capabilities, computer vision, perception, object recognition, machine learning and motion control during operation. Recently, in 2016, AlphaGo DeepMind beat world champion L. Sedol in four out of five games, using cloud computing, supported learning, and a Monte Carlo search algorithm combined with a deep neural network for decision making [21]. Its newer version, AlphaGo Zero, surpassed AlphaGo's ability in just three days through self-learning from scratch [4, 22]. A new breakthrough in this area was IBM Watson, an intelligent platform.

The latest approach is ChatGPT, a general platform for the use of AI in various fields, including dentistry. This is one of the future directions of development of this field in dentistry.

Today, AI techniques and systems can be used in a variety of fields, from chess games to robot control, disease diagnosis, airplane autopilot, smart design, and smart dentistry. In addition to the AI techniques outlined in Table 2, machine learning and deep learning show much promise for smart dentistry. This table classifies typical machine learning models based on whether they are supervised, semi-supervised or unsupervised, discriminative or generative, learning or deep learning. Those used in dentistry are colored red.

Namely, supervised learning finds relations between inputs and outputs over labeled datasets during system training. In unsupervised learning, the model extracts realities, that is, regularities from the data, without mapping inputs to outputs. Semi-supervised learning combines supervised and unsupervised learning by using both labeled and unlabeled data. In addition, a branch of machine learning that particularly stands out in terms of results in recent years is deep machine learning. Generally speaking, it is about the application of ANN with a larger number of layers. Another classification that has been very current in recent years distinguishes between discriminative and generative models. Discriminative models aim to recognize the differences between different types of data, that is, learn what details separate one class of data from another. Generative models try to learn the distribution of data and generate new data [23, 24]

EXPERT SYSTEMS IN DENTISTRY – OVERVIEW OF DEVELOPMENT

ES are intelligent computer programs that solve problems the way experts do, and they represent one of the most important areas of AI research [1, 4]. They have been described as "computerized knowledge," and the British Computer Society has defined ES more fully as "... creating in a computer a component based on knowledge from an expert skill in such a form that the system can

Table 2. Overview of learning models; Toosi et al. [1], Silver et al. [4]
Tabela 2. Pregled modela učenja (primenjenih u stomatologiji); Toosi et al. [1], Silver et al. [4]

<table>
<tr><th>Machine learning model
Model mašinskog učenja</th><th>Supervised/semi-supervised/unsupervised
Nadgledano / polunadgledano / nenadgledano</th><th>Discriminative/generative
Diskriminativno / generativno</th><th>Learning / deep learning
Učenje / duboko učenje</th></tr>
<tr><td>K-means
K srednjih vrednosti</td><td>Unannounced
Nenadgledano</td><td>Generative
Generativno</td><td>Learning
Učenje</td></tr>
<tr><td>K-nearest neighbor
K najbliži sused</td><td rowspan="11">Supervised
Nadgledano</td><td rowspan="10">Discriminative
Diskriminativno</td><td rowspan="9">Deep learning
Duboko učenje</td></tr>
<tr><td>Support vector method*
Metod podržavajućih vektora</td></tr>
<tr><td>Hidden Markov model*
Skriveni Markovljev model</td></tr>
<tr><td>Random forest model*
Model slučajne šume</td></tr>
<tr><td>Extreme Gradient Boosting (XGBoost)
Ekstremno pojačavanje gradijenta (XGBoost)</td></tr>
<tr><td>Ensemble method
Metod ansambla</td></tr>
<tr><td>Convolutional neural networks*
Konvolucijske neuronske mreže</td></tr>
<tr><td>Recurrent neural network*
Rekurentna neuronska mreža</td></tr>
<tr><td>Long short-term neural network
Duga kratkoročna neuronska mreža</td></tr>
<tr><td>Naive Bayes classifiers*
Naivni Bajesovi klasifikatori</td><td rowspan="2">Learning
Učenje</td></tr>
<tr><td>Gaussian mixture model
Gausov mešani model</td><td>Generative
Generativno</td></tr>
<tr><td>A generative adversarial network
Generativna suparnička mreža</td><td>Semi-supervised
Polunadgledano</td><td>Discriminative
Diskriminativno</td><td>Deep learning
Duboko učenje</td></tr>
</table>

*Applied in dentistry

offer intelligent advice or make an intelligent decision about the subject area" [23]. ES solve real problems from different fields, which would otherwise require human expertise. The goal is that the computer program always gives correct answers, in the given field, no worse than an expert, but this is difficult to achieve. That is why a less ambitious goal is set, the system is requested to provide decision-making support.

ES have played a major role in the development and application of AI models (Table 3). However, as the analysis in the table below shows, new generations of ES, based on deep knowledge, are once again entering the scene.

Earlier it was said that Mysin was the first ES used by doctors [15, 25–29], and in this regard everything started with the development of the first ES – Dendral [14, 11], which was used to solve a specific task in science: to help organic chemists in the identification of unknown organic molecules, by analyzing their mass spectra, using knowledge from chemistry. The Dendral software program is considered the first ES, because it automated the decision-making process and defined the problem-solving behavior of organic chemists. The project consisted of two programs – Heuristic Dendral and Meta-Dendral, as well as several subprograms. It is written in the LISP programming language, which is considered the language of AI because of its flexibility. Many ES are derived from Dendral, including MYCIN, Molgen, Prospector, Xcon, and Steamer.

MYCIN was the first AI program to search backwards, which it used to identify bacteria that cause severe infections, such as bacteremia and meningitis, and to recommend antibiotics, with a dose adjusted to the patient's body weight. The very name of this ES comes from the antibiotics themselves, as many antibiotics have the suffix "-mycin." The MYCIN system has also been used to diagnose blood clotting disorders. His knowledge base was defined by rules, and the method of searching and connecting rules for the purpose of reasoning is still an example of a good model of reasoning [from symptom(s) (consequences) to cause(s)].

A detailed analysis of the literature shows that the first ES in dentistry was developed for oral dentistry in 1983 (Table 4) [30]. It was a set of software modules that were used for the diagnosis of clinical conditions and management hypotheses from the knowledge base. These modules were the following: Problem-Knowledge Coupler, Coupler Editor, Knowledge Network, and Problem-Oriented Computerized Medical Record. It contained a section related to oral dentistry.

The next model was developed in 1986 [31]. It is a knowledge-based system, which also works on the basis of rules. Orthodontists have defined a number of characteristic points, or landmarks, on an X-ray image of the human skull that are used to study growth or as a diagnostic aid. The original image was pre-processed with a pre-filtering operator (median filter) followed by an edge detector (Mero-Vassi operator). A knowledge-based line-tracing algorithm is then applied, involving a system with organized rule sets and a simple interpreter. In the inference algorithm, *a priori* knowledge is applied, which takes into account the facts of biological facial shapes,

Table 3. Context of expert systems and artificial intelligence development (amended according to Toosi et al. [1] and Silver et al. [4])
Tabela 3. Kontekst razvoja ES i AI (dopunjeno prema Toosi et al. [1] i Silver et al. [4])

Time period Vremenski period	Period of development of ES Period razvoja ES	Basic characteristic of the period Osnovno obeležje perioda	Detailed characteristics of the period Detaljna karakteristika perioda
1955–1975	First AI jump Prvi skok AI	Search and reasoning (database) Pretraživanje i rezonovanje (baza podataka	New technologies, neural network and perceptron, were applied to search and reasoning. These paradigms made AI capable of performing some intellectual activities, provided it was given rules and goals (solving puzzles, playing chess, and proving mathematical theorems). However, the AI boom entered its first winter in the 1970s, because search and reasoning could not solve more complex problems. Za navedene ključne reči (pretraživanje i rezonovanje) primenjene su nove tehnologije, neuronska mreža i perceptron. Ove paradigme su AI učinile sposobnom da obavlja neke intelektualne aktivnosti, pod uslovom da su joj data pravila i ciljevi (rešavanje zagonetki, igranje šaha i dokazivanje matematičkih teorema). Međutim, AI je ušao u prvi zastoj tokom 1970-ih, jer pretraživanje i zaključivanje nisu mogli da reše složenije probleme.
1975–2000	Second AI jump Drugi skok AI	ES (specially organized knowledge) Ekspertni sistemi (Posebno organizovano znanje)	To break the first AI winter, the new technology of ES was defined. ES were focused on solving complex problems, by transferring expert knowledge into computers. In the early 1970s, the representative expert system MYCIN was developed at Stanford University [13, 24, 25, 26] for the diagnosis of infectious blood diseases, and its accuracy was approximately 60–70%. Thanks to the growth of ES (in number and in the domains to which they were applied), the second leap of artificial intelligence occurred in the 1980s. However, ES had several problems. In particular, they required large amounts of expert knowledge, which were difficult to collect and accurately input into computers at that time (a process known as knowledge engineering). Furthermore, ES were unable to handle exceptional cases because their knowledge was stored mainly as IF–THEN rules. For these reasons, the AI boom entered its second winter in the late 1990s. Da bi se prekinuo prvi „zimski period“ AI, definisana je nova tehnologija – ekspertni sistem (ES). ES su bili fokusirani na rešavanje komplikovanih problema transplantacijom znanja stručnjaka na računar. Početkom 1970-ih na Univerzitetu Stanford razvijen je reprezentativni ekspertni sistem MYCIN [13, 24, 25, 26] za dijagnostiku zaraznih bolesti krvi, čija je tačnost bila 60~70%. Zahvaljujući porastu ES (po broju, a i oblasti na koje su se odnosili), drugi skok veštačke inteligencije je nastao 1980-ih. Međutim, ES su imali nekih problema. Posebno, oni su zahtevali ogromnu količinu znanja stručnjaka, koju je bilo teško prikupiti i tačno uneti u računar u to vreme (inženjerstvo znanja). Štaviše, ES nisu bili u stanju da se izbore sa nekim izuzetnim slučajevima, jer je njihovo znanje bilo uglavnom sačuvano kao pravilo AKO–ONDA. Iz ovih razloga, AI je u[la u svoj drugi „zimski peropd“ krajem 1990-ih.
2000–2015	Third AI jump Treći skok AI	Learning Učenje	The third AI boom emerged due to advances in machine learning and the rise of deep learning. Moreover, this leap was enabled by the advent of smartphones, improvements in computer performance, and the advent of big data analytics (BDA) resulting from the expansion of the Internet. Thanks to these technologies, artificial intelligence that surpasses human abilities has emerged in certain fields, such as IBM Watson (which defeated quiz players in 2017) [27] and AlphaGo (which defeated professional Go players in 2015) [28]. Treći bum veštačke inteligencije je stigao zbog napretka mašinskog učenja i pojave dubokog učenja. Štaviše, ovaj skok je izazvan pojavom pametnih telefona, poboljšanjem performansi računara i dolaskom ere velikih podataka (BDA) zbog ekspanzije interneta. Zahvaljujući ovim tehnologijama, veštačka inteligencija koja prevazilazi ljudsku pojavila se u određenim oblastima kao što su IBM Vatson (koji je 2017. pobedio igrače na kvizu) [27] i AlphaGo (koji je pobedio profesionalne igrače igre Go 2015) [28].
2015–present 2015. do danas	Quadruple jump AI Četvrti skok AI	Deep learning Duboko učenje	The fourth and most recent boom of AI arose as a consequence of the development and rapid implementation of Industry 4.0, based on CPS, the IoT, and BDA. These factors have accelerated the development and application of new deep learning models, paving the way for smart manufacturing and smart systems. Today, IBM Watson is a technology platform that uses NLP and ML to extract knowledge from large volumes of unstructured data, which can then be handed over to experts for analysis and decision-making. This method enables support for experts to generate expert knowledge from vast datasets, which forms a new basis for the development and application of a new generation of ES. Poslednji, četvrti bum veštačke inteligencije nastao je kao posledica razvoja i brze primene Industrije 4.0, zasnovane na CPS, IoT i BDA. Ovi činioci su ubrzali razvoj i primenu novih modela dubokog učenja, na putu izgradnje pametne proizvodnje i pametnih sistema. Danas je IBM Vatson tehnološka platforma koja koristi NLP i mašinsko učenje da bi otkrio činjenice iz velikih količina nestrukturiranih podataka, koji se zatim mogu predati ekspertima na analizu i odlučivanje. Ovaj metod omogućava podršku stručnjacima za generisanje ekspertskih znanja iz ogromne količine podataka, što čini novu osnovu za razvoj i primenu nove generacije ES.

ES – expert systems; AI – artificial intelligence; BDA – big data analytics; CPS – cyber-physical systems, IoT – Internet of Things, NLP – natural language processing; ML – machine learning

Table 4. Overview of developed expert system models and artificial intelligence / machine learning models for dentistry
Tabela 4. Pregled razvijenih modela ES i modela AI/ML učenja za stomatologiju

Year of appearance / reference Godina pojavljivanja / referenca	ES name Naziv ES	Basic characteristics Osnovne karakteristike	Application Primena
1983 [33]	KBS M/D	Based on the rules, it suggests a diagnosis. Na bazi pravila, predlaže dijagnozu.	Diagnosis in oral dentistry Dijagnoza u oralnoj stomatologiji
1986 [34]	Orthodont	A knowledge-based system, which is organized through rules (IF–THEN); four types of operators are used to generate the inference form Sistem na bazi znanja, koji je organizovan preko pravila (AKO–ONDA). Koriste se četiri vrste operatora da generišu oblik zaključivanja.	Orthodontic analysis of X-ray images of the human skull, in order to define and monitor the patient's OP; automatic extraction of OP Ortodontska analiza rendgentskih snimaka ljudske lobanje, radi definisanja i praćenja ortodontskih parametara (OP) pacijenta. Automatsko izdvajanje OP
1987 [35]	KBS M/D	Medical ES with dentistry supplement Medicinski ES sa dodatkom za stomatologiju	Diagnosis and treatment plan in oral dentistry Dijagnoza i plan lečenja u oralnoj stomatologiji
1989 [36]	Orad	By means of Bayes' theorem, the radiograph of patients with intraosseous lesions is evaluated. Pomoću Bajesove teoreme se ocenjuje radiografski snimak pacijenata sa intrakoštanim lezijama.	Support to clinical doctors in formulating a differential diagnosis Podrška kliničkim lekarima u formulisanju diferencijalne dijagnoze
1989 [37]	FRIEL	Using fuzzy logic, the state of the dental arch shape in children is evaluated and a decision is made for further treatment. Pomoću fazi logike se ocenjuje stanje oblika zubnog luka kod dece i donosi odluka za dalje lečenje.	Pediatric dentistry Dečja stomatologija
1991 [38]	Decision-making models Modeli odlučivanja	The following models are used for decision-making in the ES knowledge base: Bayes' theorem, decision tree, ROC curve, sensitivity analysis, impact assessment and others. Za odlučivanje u bazi znanja ES koriste se sledeći modeli: Bajesova teorema, Drvo odlučivanja, ROC kriva, analiza osetljivosti, ocena uticaja i druge.	They are used in different branches of dentistry. Primenjuju se u različitim granama stomatologije.
1991 [39]	Decision model analysis Analiza modela odlučivanja	A detailed overview of different decision models for use in dentistry Detaljan pregled različitih modela odlučivanja za primenu u stomatologiji	Different areas of dentistry Različite oblasti stomatologije
1992 [40]	KBS	Orthodontic analysis of class II occlusion and case 1 Ortodontska analiza zagrižaja klase II i slučaja 1	The knowledge base includes cases with proposed solutions. Baza znanja obuhvata slučajeve sa predlogom rešenja.
1992 [41]	Analysis of ES for medicine and dentistry Analiza ES za medicinu i stomatologiju	The first decade (1980–1992) of development and application of ES Prva dekada (1980–1992) razvoja i primene ES	608 articles in the field of medicine and 8 in the field of dentistry were published. Objavljeno je 608 članaka iz oblasti medicine i osam iz oblasti stomatologije.
1993 [42]	Expert Rule	The knowledge base includes thirteen bite models. Baza znanja obuhvata trinaest modela zagrižaja.	Orthodontics – diagnosis with treatment planning Ortodoncija – dijagnoza sa planiranjem lečenja
1996 [43]	KBS	Orthodontic analysis Ortodotska analiza	Expanding the knowledge base for each new case Proširenje baze znanja za svaki novi slučaj
1996 [44]	KBS	Decision analysis study of doctors and ES Studija analize odluka lekara i ES	Sample of 100 cases, accuracy 88% Uzorak od 100 slučaja, tačnost 88%
1998 [45]	KBS	Application of ANN in ES Primena ANN u ES	Third molar treatment planning Planiranje lečenja trećeg molara
1998 [46]	KBS	ES response validation Validacija odgovora ES	Diagnosis and treatment with orthodontic appliances Dijagnoza i lečenje ortodontskim aparatima
1999 [47]	EIS0-1	Supplementing the knowledge base using the RDR model of knowledge engineering Dopuna baze znanja pomoću RDR modela inženjerstva znanja	It is used for planning orthodontic treatment. Koristi se za planiranje ortodotskog tretmana.
2010 [48]	KBS	Orthodontic treatment of patients (children) Ortodontski tretman pacijenata (dece)	Treatment planning Planiranje lečenja
2015 [49]	eD ES	Oral dentistry (ANN and fuzzy logic) Oralna stomatologija (ANN i fazzy logika)	Diagnosis and treatment plan Dijagnoza i plan lečenja
2020 [50, 51, 52]	Web ES	The certainty factor (CF) between symptoms and diagnosis Faktor izvesnosti (CF) između simptoma i dijagnoze	Oral health diagnosis Dijagnoza oralnog zdravlja
2020 [53]	ES	A CNN with four network depth models CNN sa četiri modela dubine mreže	Diagnosis of radiographic images in oral dentistry Dijagnoza radiografskih snimaka u oralnoj stomatologiji

Year of appearance / reference Godina pojavljivanja / referenca	ES name Naziv ES	Basic characteristics Osnovne karakteristike	Application Primena
2021 [54, 55]	AI/ML	Six models of ML algorithms in use are analyzed. Analizira se šest modela algoritama ML u primeni.	Application in dentistry, especially in orthodontics Primena u stomatologiji, a posebno u ortodonciji
2021 [56]	CNN	ES for automatic identification of 13 points on the patient's face ES za automatsku identifikaciju 13 tačaka na licu pacijenta	Diagnosis of malocclusion with treatment plan Dijagnoza nepravilnog zagrižaja sa planom lečenja
2021 [57]	AI in dentistry AI u stomatologiji	Future trends Budući trendovi	CAD/CAM modeling, implantology, robotic oral surgery CAD/CAM modeliranje, implantologija, robotska oralna hirurgija
2021 [58]	ES based on Bayesian rules ES na bazi Bajesovih pravila	Multiple simultaneous symptoms Više istovremenih simptoma	Diagnosis of the patient's oral health condition Dijagnoza stanja oralnog zdravlja pacijenta
2022 [59]	CNN	700 orthodontic cases, accuracy 97% 700 ortodontskih slučajeva, tačnost 97%	Diagnosis and treatment plan Dijagnoza i plan lečenja
2022 [60]	WebCeph ES (CNN)	Determination of linear and angular cephalometric landmarks Određivanje linearnih i ugaonih cefalometrijskih orijentira	Orthodontic diagnosis and treatment plan Ortodontska dijagnoza i plan lečenja
2023 [61]	AI/ML	Analysis of the application of AI/ML in orthodontics Analiza primene AI/ML u ortodonciji	The best results are achieved by applying deep learning models. Najbolji rezultati se postižu primenom modela dubokog učenja.
2024 [62, 63]	ML	Application in orthodontics Primena u ortdonciji	Dentistry 4.0 Stomatologija 4.0
1993 [65] 1994 [66]	ES	Application in prosthetics Primena u protetici	Rule-based model Model zasnovan na pravilima

ES – expert systems; AI – artificial intelligence; KBS – knowledge-based system; CNN – convolutional neural network; ML – machine learning; CAD – computer-aided design; CAM – computer-aided manufacturing; ANN – artificial neural networks; OP – orthodontic parameters; RDR – Ripple-Down Rules; CF – certainty factor

which can vary significantly from one patient to another. Therefore, the algorithm takes into account objective quality criteria through rules. It is especially noted here that the first positive experiences in the application of this ES were later used, including today, for the development of advanced ES in this area.

The ES example in a study by Abbey [32] was developed for medicine, but was also used in dentistry. This ES is a knowledge-based system (KBS), which generates variable data from the patient and links it to a large fixed knowledge base, which is designed to capture the patient's specific problems. The results in the form of advisory diagnoses and treatment plans are available to the dental clinician, and they relate to oral dentistry.

This ES (Orad) uses Bayesian theorems to evaluate the radiographs of patients with intraosseous lesions, in order to establish a diagnosis [33]. Ninety-eight lesions of the jaw are described in the knowledge base, according to their prevalence and distribution, and according to age, sex, race, presence of pain, number, size and localization of lesions, connection with teeth, etc. The user follows a menu of 16 questions to characterize a specific lesion. ES outputs a list of lesions in order of their estimated probability. Studies show that this ES is useful in assisting clinicians in formulating differential diagnoses.

Using fuzzy logic programming language (FRIL), a consulting ES for orthodontics was developed [34]. It helps dentists in general practice to use ES to assess the shape of the dental arch in children and, based on that, refer them to an orthodontist for detailed diagnosis and further treatment. The goal is for the young patient's permanent teeth to grow properly later on.

Decision-making in clinical dentistry is shaped by various and numerous influences, which is especially true for ES knowledge bases [35]. For these reasons, it is necessary to know the decision models in detail in order to make the correct clinical conclusion using ES. Thus, in a study by McCreery and Truelove [36], a detailed analysis of decision models, 11 in total, with the best application in specific branches of dentistry is presented.

Orthodontic ES for the analysis of Class II and Case 1 occlusions was presented in the study by Brown et al. (1991) [37]. He gives advice to the orthodontist to define the treatment plan. The first decade of ES for medicine are KBS for diagnosis and counseling of physicians regarding treatment plans [38]. It is believed that future research in this area should be directed towards clinical problems. Diagnosis with treatment planning is the ES model presented in a study by Grant and Freer [39], wherein the knowledge base includes 13 different bite models.

A knowledge-based system is presented in a study by Hammond and Freer [40] and is used for orthodontic analysis and synthesis. Its main feature is that for each new case, the existing knowledge base is expanded with it. A comparison of the decisions of ES and dentists is shown that the accuracy of the ES is 88%, which means that it is worse than the expert and can only be assigned a consulting role, not the final decision.

Twelve different models were used as a training tool for NN, on a clinical history sample of 238 mandibular third molars (approximately the same number of male and female patients, aged around 30 years), with output data on oral surgeon treatment plans [41]. Starting from the gold standard for this field (0.8 sensitivity), the ES showed a sensitivity of 0.78 and the oral surgeon 0.88 (not a significant difference), while the difference in specificity is even smaller (0.98 and 0.99 for an oral surgeon), which is also not significant. The conclusion is that it is possible to train the ANN to provide reliable support in defining the treatment plan for the lower third molar. A study by Brickley et al. [42] analyzed the responses of an ES, which is used as an orthodontic consultant for appliance planning. Otherwise, it is a rule-based ES, and the result is that ES answers are satisfactory with 95% accuracy.

EIC0-1 ES constitutes a set of rules (690), with which the orthodontist, using the Ripple-Down-Rules (RDR) knowledge engineering model, designs and supplements the knowledge base, thus increasing the quality of the response of the ES itself [43]. It is suitable for use in the clinic, and students can especially benefit from it when mastering and making decisions for planning orthodontic treatment.

A paper by Xie et al. [44] presented a decision-making model for orthodontic treatment of patients between the ages of 11 and 15, in which it is determined whether tooth extraction is required. ANN is used for training and decision making. Otherwise, it is a rule-based ES, and the result was that the ES answers were satisfactory on a sample of 200 patients (180 for ANN training and 20 for the test). Accuracy was 100% for trained cases and 80% for test cases.

Tinuke and Yetunde [45] demonstrated that ES can effectively automate dental and administrative procedures. They described two AI techniques for reasoning and inference, ANN and fuzzy logic.

Three Web ES are presented by Pasaribu et al. [46], Kurniawan [47], and Sidik et al. [48], which are used to assist the dentist in diagnosing the patient's oral health status. They are based on IF–THEN rules by which symptoms and diseases are related to a certainty factor. The results showed 99% accuracy of his diagnosis compared to the diagnosis of a specialist dentist. A model for the diagnosis of the oral condition of patients who need surgical treatment was based on the diagnosis using radiographic images [49]. The accuracy of this predictive model is achieved by the depth of the convolutional neural network (CNN), which was demonstrated by the experiment. The screening included 960 patients, and the ResNet-18, 34, 50, and 101 models were used, and the accuracy, sensitivity, and specificity of each model were evaluated. ResNet-18 performed best with an area under the curve of 0.979, followed by ResNets-34, 50, and 101 at 0.974, 0.945, and 0.944, respectively.

AI / machine learning (ML) are increasingly applied in the fields of orthodontic diagnosis, treatment planning, growth assessment, and treatment outcome prediction [50, 51]. The following ML algorithms are analyzed: Bayes model (supporting risk assessment in diagnosis), ANN (diagnosis by image analysis), support vector machine is used for skeletal pattern recognition, GA is used for condition prediction trends based on diagnosis, fuzzy logic is used to define the line of reasoning in sets where states are not determined. From these models, deep learning models are being developed today, which will only be applied in the near future, as a support to dentists.

A study by Prasad et al. [52] presented an intelligent model based on CNN for deep learning, for the automatic identification of landmarks on the patient's face (13 in total), by analyzing radiographic images, and in relation to irregular jaw positions and the diagnosis of such a condition. The sample consisted of 950 patients, and excellent results were obtained with a reliability of 95%, which is why this method is recommended for clinical practice.

It can be stated that the application of AI in dentistry is still at an early stage [53, 54]. However, the prospects of this technology are great for diagnosis, treatment planning, recovery monitoring, patient management and administrative tasks. Special breakthroughs are expected in computer-aided design (CAD) and computer-aided manufacturing (CAM), implantology, as well as robotic oral surgery. The analysis in a study by Tam-Nurseman et al. [55] shows that in dentistry a few symptoms are not enough for a diagnosis, and for these reasons, Bayesian rules were applied, which enables linking (ranking and correlation) of several symptoms for a single diagnosis. For these reasons, an improved model of Bayesian rules was developed, which showed good results in defining the diagnosis, with multiple simultaneous symptoms.

Diagnosis and treatment planning are the core of orthodontics, which orthodontists acquire with years of experience [47]. ML has the ability to learn by pattern recognition, and it achieves this in a very short time, ensuring reduced inference error and excluding inter-clinician inference variability, as well as good accuracy. In this study, on a sample of 700 patients, using a four-layer CNN, an accuracy of 97% was achieved [52, 56]. All this was related to the diagnosis and treatment plan in orthodontics. Automated cephalometric analysis is one of the main areas of application of AI in the field of orthodontics. WebCeph ES performs the determination of linear and angular cephalometric landmarks, obtained on a web basis by fully automated measurements of these parameters using this platform. The results of the research show that there was complete agreement between manual measurements and this ES, on a sample of 30 patients.

Systematic reviews analyzed different strategies using AI to improve diagnosis, planning and monitoring of orthodontic treatment [57, 58]. The works were analyzed in an interval of 10 years, and a total of 33 studies were included. The results show that AI is increasingly becoming a part of clinical practice, and in particular the deep learning model. A review paper by Prasad et al. [52] also provides an analysis of the application of AI in orthodontics for diagnostics, cephalometric assessment, tooth age determination, temporomandibular jaw (TMJ) assessment, treatment plan decision making and remote patient monitoring (Dentistry 4.0). However, in clinical application, the validation of the solution must still be done by an expert dentist.

As a conclusion of this analysis, we can state the following: (a) ES in dentistry have been a research direction for four decades, and during that time they have come from individual research ideas to important scientific research practice, with a perspective in clinical dentistry; (b) the application of ES (AI) in dentistry is considered good practice today; (c) deep learning from unstructured databases is the best method of applying ES (AI) in dentistry today.

EXPERT SYSTEMS FOR DENTISTRY IN SERBIA

It is with great pleasure that we can state that at the School of Dental Medicine in Belgrade, at the Clinic for Prosthetics, serious research in this field has been carried out since the beginning of the last decade of the last century, until today [59–62]. All this resulted in the first ES for prosthetist dentists in Serbia. It was a rule-based system (IF–THEN rules), and the knowledge base had 120 rules. The search of the knowledge base was based on the forward chaining model, from symptoms to diagnosis. It was of an experimental-laboratory nature, and later the knowledge from its development served in the wide application of the CAD/CAM system at this clinic, as well as at other clinics of the School of Dental Medicine in Belgrade.

EXPERT SYSTEMS AND ARTIFICIAL INTELLIGENCE IN DENTISTRY – WHAT NEXT

AI-based virtual dental assistants can perform several tasks in a dental practice with greater accuracy, fewer errors, and less manpower compared to humans [51, 52, 53]. They can be used to coordinate appointments, manage insurance and paperwork, and assist in clinical diagnosis or treatment planning. They are very useful in alerting the dentist to medical history, as well as to habits such as alcoholism and smoking. In dental emergencies, the patient has the option of emergency teleassistance, especially when the dentist is unavailable. Thus, a detailed virtual patient database can be created, which will go a long way in providing the ideal treatment for the patient himself.

ARTIFICIAL INTELLIGENCE IN DIAGNOSIS AND TREATMENT

AI can be used as an effective approach in the diagnosis and treatment of lesions of the oral cavity, and it can be used in the screening and classification of suspicious changes in the mucous membrane which go through premalignant and malignant conditions. Even tiny changes at the level of a single pixel are detected, which can go unnoticed by the naked eye. AI can accurately predict genetic predisposition to oral cancer for a large population.

ARTIFICIAL INTELLIGENCE IN ORAL AND MAXILLOFACIAL SURGERY

The biggest application of AI in oral surgery is the development of robotic surgery, wherein the movement of the human hand and human intelligence are simulated. Successful clinical applications in image-guided cranial surgery include oral implant surgery, tumor and foreign body removal, biopsy, and jaw surgery. Comparative studies of oral implant surgery indicate significantly higher accuracy compared to freehand manual surgery, even when performed by experienced surgeons. Shorter operation time, safer manipulation around delicate structures and greater intraoperative precision are obtained. Image-guided robotic surgery allows for more thorough surgical resection, potentially reducing the need for revision procedures.

ARTIFICIAL INTELLIGENCE IN PROSTHETIC DENTISTRY

In order to provide the patient with an ideal aesthetic prosthesis, various factors such as anthropological calculations, facial measurements, ethnicity and patient preferences are integrated by the AI-based virtual prosthetic design assistant. It integrates computational design, knowledge-based systems (ES) and databases, using logic-based representation (AI) as a unifying medium. CAD/CAM application in dentistry is a process by which a finished dental restoration is achieved by a fine milling process of finished ceramic blocks. It is used in the production of inlays, onlays, crowns as well as crowns and bridges. CAD/CAM technique essentially creates two-dimensional and three-dimensional models and their materialization by numerically controlled processing on the machine. This approach replaced the time-consuming and laborious process of conventional casting and reduced the component of human error in the final prosthesis.

ARTIFICIAL INTELLIGENCE IN ORTHODONTICS

Diagnosis and treatment planning can only be determined by analyzing X-rays and photographs with intraoral scanners and cameras. All this is achieved by a virtual dental assistant, which eliminates the need to take impressions of the patient's jaws, as well as several laboratory steps, and the results are much more accurate compared to human perception. Tooth movement and the final treatment outcome can be predicted using AI algorithms and statistical analysis based on ML.

References of the author of this work represent a research contribution to some of the trends mentioned ahead [63–70].

CONCLUSIONS AND FURTHER RESEARCH

ES and AI are research areas in dentistry that are in intensive development, especially in clinical practice. Thanks to the current state of development of machine learning and knowledge engineering techniques, all the conditions have been met to translate clinical procedures of the best diagnostic and treatment practices into virtual dental assistants, as the first stage of development and application of smart dentistry. On the other hand, the aforementioned conditions are created for the development and application of telestomatology or Dentistry 4.0.

The challenges are considerable, but all the previous analyses in this work show that we need multi-disciplinary work, and thus the knowledge of dentists, knowledge engineers, and AI experts.

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Received: 19.11.2024 • Accepted: 30.12.2024

Ekspertni sistemi u stomatologiji

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SAŽETAK

Uvod Veštačka inteligencija (AI) danas predstavlja važan činilac društvenog, naučnog i ekonomskog razvoja. Njene široke mogućnosti primene obuhvataju i stomatologiju. Istorija AI duga je oko osam decenija, a posebna oblast njenog istraživanja i razvoja su i ekspertni sistemi, koji su predmet ovog rada, a odnose se na stomatologiju.

Cilj rada je da se analizira stanje razvoja i primene ekspertnih sistema (ES) u stomatologiji, sa predlogom mogućnosti njihove primene danas.

Metode Korišćenjem elemenata sistemske analize, izabran je reprezentativni uzorak članaka sa SCI, Web of Science i Scopus referenci (PubMed/MEDLINE baze podataka), koji su analizirani iz ugla vremenske dimenzije razvoja AI i ES.

Rezultati Rad je strukturisan tako da daje odgovore na sledeća pitanja: Šta je AI i kako se razvijala, kako su nastali i kako su se razvijali ES u stomatologiji, uključujući i Srbiju, šta su perspektive primene AI/ES u stomatologiji, i koji su mogući pravci budućih istraživanja u ovoj oblasti.

Zaključak AI i ES su u oblasti stomatologije iz ere eksperimentalnih istraživanja na granici da postanu dobra klinička praksa. Digitalizacija i model Industrije 4.0, koji su već široko rasprostranjeni, predstavljaju veliku podršku za bržu primenu ovih modela u stomatološkoj praksi.

Ključne reči: veštačka inteligencija; ekspertni sistemi; stomatologija

UVOD

Veštačka inteligencija (AI) je grana nauke o inteligenciji, koja može biti prirodna i veštačka. AI je nauka i inženjerstvo za stvaranje inteligentnih mašina i softverskih sistema. Ove dve oblasti istraživanja su povezane i doprinosile su jedna drugoj tokom prethodnih osam decenija. Uspesi u prirodnoj inteligenciji postavili su čvrste temelje za istraživanje AI: neuronske mreže (ANN), genetski algoritmi (GA) itd., dok su napredni AI alati pomogli da se ubrzaju nova otkrića u prirodnoj inteligenciji [1, 2]. Dakle, postoji istorija AI, duga osam decenija, koja je danas obećavajuća više nego ikad, što se odnosi i na stomatologiju.

Ovaj pregledni rad ima za cilj da čitaocima stavi na uvid osnovne činjenice i znanja o razvoju i primeni ES u stomatologiji. Počeci primene se odnose, pre svega, na AI, koja sama za sebe ima istoriju razvoja, takođe detaljno analiziranu u ovom radu. Zašto? Zato što su ES bili dobra osnova za primenu alata i tehnika AI u stomatologiji, posebno dubokog učenja u poslednjoj dekadi ovog veka. Ovaj rad je namenjen naučnicima, istraživačima i studentima koji žele da dobiju konciznu informaciju o početku razvoja nove naučne grane u stomatologiji, pametne stomatologije.

Ova sistemska analiza je vršena prema metodologiji PRISMA [3], a naša pitanja su bila: Q1. Kako se ES koriste u stomatologiji? i Q2. Kako ES poboljšavaju donošenje odluka o dijagnozi, planiranju lečenja, praćenju napretka lečenja i ocene uspešnosti terapije? Za ova pitanja bili su definisani: vremenski period analize, tip studije, modeli ES, metodologija pretrage i ocena kvaliteta studije. Uzorak je obuhvatio 268 radova, a postavljene kriterijume su zadovoljila 32 rada.

Ovaj rad ima nekoliko celina: (i) kako je nastala i razvijala se AI, (ii) pregled razvoja ES za stomatologiju do danas, uključujući i Srbiju, (iii) izazovi i budući razvoj ES za stomatologiju, (iv) zaključci i buduća istraživanja.

KRATKA ISTORIJA AI

Pre nego što iznesemo detalje o ES u stomatologiji, neophodno je da ukratko analiziramo istoriju AI, koja je prikazana u Tabeli 1 [1, 2, 4]. Ona obuhvata interval od osam decenija (1940–2020. god.) i ima četiri etape razvoja, kako je to navedeno u donjoj tabeli.

Može se reći da istorija AI počinje od ranih 40-ih godina prošlog veka. Počelo je sa binarnim ANN modelom [5] koji su 1943. godine kreirali V. McCulloch i V. Pitts sa Univerziteta u Ilinoisu. Iako je njihov model samo razmatrao binarno stanje (tj. uključeno/isključeno za svaki neuron), ovaj model je korišćen kao osnova za istraživanje ANN-a kasnih 80-ih godina prošlog veka. Godine 1950. britanski matematičar A. Tjuring je predložio poznati Tjuringov test, pomoću koga se utvrđuje da li mašine mogu da misle [6]. Tjuringov test je izvođen putem kompjuterske komunikacije, koja uključuje ispitivača, čoveka (ispitivani), učesnika u eksperimentu i kompjuter, koji su međusobno razdvojeni, ali komunikaciono povezani. Ispitivač može postaviti bilo kakva pitanja. Ako ispitivač ne može razlikovati mašinu od čoveka na osnovu njihovih odgovora, kompjuter je položio test. Godine 1951. M. Minski i D. Edmonds [7], dva diplomirana studenta sa Univerziteta Prinston, napravili su prvi neuronski računar koji simulira mrežu od 40 neurona.

Važna prekretnica u razvoju AI je bio prva radionica o AI, održana 1956. godine na Dartmut koledžu, pod vođstvom J. Makartija [8]. Ova radionica označila je kraj „mračnog doba" AI i početak uspona AI u istoriji veštačke inteligencije. Termin veštačka inteligencija tada je predložio J. Makarti, i on je još uvek u upotrebi. On se kasnije preselio u Masačusetski institut za tehnologiju (MIT), gde je 1958. definisao prvi jezik veštačke inteligencije, LISP, koji se i danas koristi. Jedan od najambicioznijih projekata u ovoj oblasti bio je General Problem Solver (GPS), koji su 1961. godine stvorili A. Njuel i H. Sajmon sa Univerziteta Karnegi Melon [9]. GPS je zasnovan na formalnoj logici i može da generiše beskonačan broj operatora koji pokušavaju da pronađu rešenje; međutim, neefikasan je u rešavanju komplikovanih problema. Godine 1965, L. Zadeh sa Univerziteta u Berkliju objavio je čuveni rad „Fuzzi skupovi", koji je osnova teorije rasplinutih skupova [10], ili neizvesnog odlučivanja.

Prvi ekspertni sistem, Dendral [11], razvijen je na Univerzitetu Stanford 1969. u okviru projekta koji je finansirala Nacionalna uprava za aeronautiku i svemirska istraživanja (NASA), a vodio ga je Dž. Lederberg, dobitnik Nobelove nagrade za genetiku. Međutim, u to vreme većina projekata AI mogla je da reši samo probleme sa igrama, a ne stvarne probleme, zbog čega su mnogi projekti u Sjedinjenim Američkim Državama, Velikoj Britaniji i nekoliko drugih zemalja propali, odnosno bili beskorisni. Tako su istraživanja AI ušla u tkz. „AI zimu".

Uprkos smanjenom finansiranju, istraživanja AI su se nastavila, tako da su 1970. god., A. Brajson i Y. Ho [12] predložili model propagacije unazad za učenje neuronske mreže. Štaviše, prvi GA je predložio 1975. god. J. Holand sa Univerziteta u Mičigenu, koji je koristio selekciju, ukrštanje i mutaciju kao genetske operatore za optimizaciju [13] i tako razvio model GA. Isti tim koji je razvio ES Dendral [14] na Univerzitetu Stanford, razvio je 1976. godine MYCIN, koji je zasnovan na pravilima IF–THEN, kao ekspertni sistem za dijagnostiku bolesti krvi pomoću 600 pravila, ako (IF) – onda (THEN). Istraživanja su pokazala da on radi bolje od mlađeg lekara [15].

Posle 30 godina, ponovo su započela istraživanja na neuronskim mrežama, kao važnoj oblasti AI. Počeo je novi period, u kome je AI postala nauka. Bilo je to 1982. godine, kada je J. Hopfild objavio svoje Hopfildove mreže, koje su i danas popularne [16]. Godine 1986, propagacija unazad je postala prvi implementirani algoritam učenja u ANN, 16 godina nakon objave ovog modela [17]. Takođe, ova godina je i početak primene distribuirane AI (DAI) kroz paralelno distribuiranu obradu znanja. Posle 22 godine, teorija rasplinutih skupova ili fuzzi logika uspešno je ugrađena u upravljanje radom mašina za pranje sudova i mašina za pranje veša 1987. god., japanskih kompanija koje su proizvodile ove aparate za domaćinstvo. Godine 1992, J. Koza je predložio genetsko programiranje za manipulaciju simboličkim kodom koji je generisan na LISP jeziku [18]. Bazirani na idejama DAI i veštačkog života, inteligentni agenti su postepeno dobili oblik sredinom 1990-ih. Krajem 1990-ih, hibridni sistemi fuzzy logike, ANN i GA postali su popularni alati za rešavanje složenih problema. Posle toga su se pojavili različiti novi pristupi AI, uključujući ACO, optimizaciju jezera čestica (PSO), veštačku optimizaciju imuniteta (AIO) i DNK računarstvo, kao i inteligentni agenti [19]. Potencijal AI u budućnosti – kao što je stomatologija – ostaje veliki i u ovom trenutku nepredvidiv.

Prvi popularni AI alat bio je softver za igranje šaha, kompjuterski program Deep Blue, koji je kreirala korporacija International Business Machines (IBM) [20]. Gari Kasparov, tadašnji svetski šampion u šahu, igrao je protiv njega 1997. god. u egzibicionom meču i izgubio rezultatom 2,5 : 3,5. Još jedan rani primer je robot Honda ASIMO iz 2005. godine, koji je mogao da se penje stepenicama. Da bi se robot kretao u nestrukturisanom okruženju i njime komandovao čovek, potrebne su sposobnosti obrade prirodnog jezika, računarska vizija, percepcija, prepoznavanje objekata, mašinsko učenje i kontrola pokreta tokom rada. Nedavno, 2016. godine, AlphaGo kompanije DeepMind pobedio je svetskog šampiona L. Sedola u četiri od pet igara, koristeći računarstvo u oblaku, podržano učenjem i Monte Karlo algoritmom za pretragu u kombinaciji sa dubokom neuronskom mrežom za donošenje odluka [21]. Njegova novija verzija, AlphaGo Zero [4, 22], nadmašila je sposobnost AlphaGo-a za samo tri dana kroz samoučenje od nule. Novi iskorak u ovoj oblasti predstavlja inteligentna platforma IBM Watson.

Najnoviji pristup predstavlja ChatGTP, opšta platforma za korišćenje AI u različitim oblastima, uključujući i stomatologiju. Ovo je jedan od budućih pravaca razvoja ove oblasti u stomatologiji.

Danas se tehnike i sistemi AI mogu koristiti u različitim oblastima – od šahovskih partija i upravljanja robotima, preko dijagnoze bolesti, autopilota u avionima, pametnog projektovanja, pa sve do pametne stomatologije. Pored AI tehnika prikazanih u Tabeli 2, mašinsko učenje i duboko učenje pokazuju mnogo toga obećavajućeg za pametnu stomatologiju. Ova tabela klasifikuje tipične modele mašinskog učenja na osnovu toga da li su nadgledani, polunadgledani ili nenadgledani, diskriminativni ili generativni, kao i prema tome da li se odnose na standardno učenje ili duboko učenje. Modeli koji se primenjuju u stomatologiji obojeni su crvenom bojom.

Naime, nadgledano učenje pronalazi relacije između ulaza i izlaza nad označenim skupovima podataka u toku obučavanja sistema. Kod nenadgledanog učenja, model izdvaja realacije, odnosno zakonitosti iz podataka, bez mapiranja ulaza na izlaze. Polunadgledano učenje kombinuje nadgledano i nenadgledano učenje tako što koristi i označene i neoznačene podatke. Pored toga, grana mašinskog učenja koja se naročito ističe po rezultatima poslednjih godina je duboko mašinsko učenje. Uopšteno rečeno, radi se o primeni neuronskih mreža sa većim brojem slojeva. Još jedna klasifikacija koja je vrlo aktuelna poslednjih godina razlikuje diskriminativne i generativne modele. Diskriminativni modeli imaju za cilj da prepoznaju razlike između različitih tipova podataka, odnosno uče koje pojedinosti odvajaju jednu klasu podataka od druge. Generativni modeli pak nastoje da nauče distribuciju podataka i generišu nove podatke [23, 24].

EKSPERTNI SISTEMI U STOMATOLOGIJI – PREGLED RAZVOJA

Ekspertni sistemi (ES) su inteligentni računarski programi koji rešavaju probleme na način na koji to čine eksperti, i predstavljaju jednu od najznačajnijih oblasti istraživanja veštačke inteligencije [1, 4]. Opisani su kao „kompjuterizovano znanje", a Britansko kompjutersko društvo je definisalo ES potpunije kao: ... stvaranje u računaru komponente zasnovane na znanju iz ekspertske veštine u takvom obliku da sistem može ponuditi inteligentne savete ili doneti inteligentnu odluku o predmetnoj oblasti [23]. ES rešavaju realne probleme iz različitih oblasti, koji bi inače zahtevali ljudsku ekspertizu. Cilj je da računarski program uvek daje korektne odgovore u datoj oblasti, ne lošije od eksperta, ali je to teško dostižno. Zato se postavlja manje ambiciozan cilj, traži se da sistem pruži pomoć u odlučivanju.

ES su odigrali veliku ulogu u razvoju i primeni modela AI (Tabela 3). Međutim, kako pokazuje analiza u donjoj tabeli, na scenu ponovo stupaju nove generacije ES zasnovanih na dubokom znanju.

Ranije je rečeno da je Mysin bio prvi ES koji su koristili lekari [15, 25–29], a u vezi sa tim sve je počelo razvojem prvog

ES – Dendral [14, 11], koji se koristio za rešavanje specifičnog zadatka u nauci: pomoći organskim hemičarima u identifikaciji nepoznatih organskih molekula analizom njihovih masenih spektara, uz korišćenje znanja iz hemije. Softverski program Dendral smatra se prvim ES, jer je automatizovao proces donošenja odluka i definisao ponašanje organskih hemičara u rešavanju problema. Projekat se sastojao od dva programa: Heuristic Dendral i Meta-Dendral i nekoliko podprograma. Napisani su u programskom jeziku Lisp, koji se smatra jezikom AI zbog svoje fleksibilnosti. Mnogi ES su izvedeni iz Dendrala, uključujući MYCIN, Molgen, Prospector, Kscon i Steamer.

MYCIN je bio prvi AI program za pretraživanje unazad, kojim je identifikovao bakterije koje izazivaju teške infekcije, kao što su bakteremija i meningitis i preporučivao antibiotike sa dozom prilagođenom telesnoj težini pacijenta. Sam naziv ovog ES potiče od samih antibiotika, jer mnogi antibiotici imaju sufiks "-mycin". Sistem MYCIN je takođe korišćen za dijagnozu bolesti zgrušavanja krvi. Njegova baza znanja bila je definisana pravilima, a način pretraživanja i povezivanja pravila radi zaključivanja i danas predstavlja primer dobrog modela rezonovanja (od simtoma (posledica) ka uzroku(cima).

Detaljna analiza literature pokazuje da je prvi ES u stomatologiji razvijen za oralnu stomatologiju 1983. god. (Tabela 4) [30]. Bio je to skup softverskih modula koji su se koristili za dijagnozu kliničkih stanja i upravljačkih hipoteza iz baze znanja, koja je razvijena na osnovu relevantnih informacija iz medicinske literature. Ovi moduli su bili: Problem-Knowledge Coupler, Coupler Editor, Mreža znanja i kompjuterizovani medicinski karton orijentisan na probleme. On je sadržavao jedan deo koji se odnosio na oralnu stomatologiju.

Sledeći model je razvijen 1986. god. [31]. Radi se o sistemu zasnovanom na znanju, koji takođe funkcioniše na bazi pravila. Ortodonti su definisali određeni broj karakterističnih tačaka, ili orijentira, na rendgenskom snimku ljudske lobanje koje se koriste za proučavanje rasta ili kao dijagnostička pomoć. Originalna slika je prethodno obrađena operatorom predfiltriranja (medijanski filter), a zatim detektorom ivica (Mero-Vassi operator). Zatim se primenjuje algoritam za praćenje linija zasnovan na znanju, koji uključuje sistem sa organizovanim skupovima pravila i jednostavnim tumačem. U algoritmu zaključivanja primenjuje se apriorno znanje, koje uzima u obzir činjenice bioloških oblika lica, koji mogu značajno da variraju od jednog do drugog pacijenta. Zbog toga algoritam putem pravila uzima u obzir objektivne kriterijume kvaliteta. Ovde se posebno napominje da su prva pozitivna iskustva u primeni ovog ES kasnije iskorišćena, uključujući i današnje vreme, za razvoj naprednih ES u ovoj oblasti.

Primer ES u studiji koju je sproveo Abbey [32] razvijen je za medicinu, ali je imao primenu i u stomatologiji. Ovaj ES je sistem zasnovan na znanju, koji generiše promenljive podatke od pacijenta i povezuje ih sa velikom fiksnom bazom znanja, koja je projektovana tako da obuhvata specifične probleme pacijenta. Rezultati u vidu savetodavnih dijagnoza i planova lečenja na raspolaganju su stomatologu kliničaru i odnose se na oralnu stomatologiju.

Ovaj ES (Orad) koristi Bajesove teoreme za ocenu radiografskog snimka pacijenata sa intrakoštanim lezijama, radi postavljanja dijagnoze [33]. U bazi znanja opisano je 98 lezija vilice, prema njihovoj prevalenci i distribuciji, kao i prema starosti, polu, rasi, prisustvu bola, broju, veličini i lokalizaciji lezija, povezanosti sa zubima itd. Korisnik prati meni od 16 pitanja kako bi se okarakterisala konkretna lezija. ES kao izlaz daje listu lezija poređanih prema procenjenoj verovatnoći. Ispitivanja pokazuju da je ovaj ES koristan kao pomoć kliničarima u formulisanju diferencijalnih dijagnoza.

Korišćenjem programskog jezika za fazzy logiku (FRIL), razvijen je konsultanski ES za ortodonciju [34]. On pomaže stomatolozima opšte prakse da korišćenjem ES ocene stanje oblika zubnog luka kod dece i na osnovu toga ga upute ortodontu za detaljnu dijagnozu i dalje lečenje. Cilj je da mladom pacijentu kasnije pravilno izrastu i budu raspoređeni stalni zubi.

Donošenje odluka u kliničkoj stomatologiji je skopčano sa različitim i velikim brojem uticaja, što posebno važi i za baze znanja kod ES [35]. Iz tih razloga, potrebno je detaljno poznavati modele odlučivanja da bi se doneo pravilni klinički zaključak pomoću ES. Tako je u studiji koju su sproveli McCreery i Truelove [36] prikazana detaljna analiza 11 modela odlučivanja sa najboljom primenom u specifičnim granama stomatologije.

Ortodontski ES za analizu zagrižaja klase II i slučaja 1 prikazan je u studiji koju su sproveli Brown i sar. (1991) [37]. On daje savete ortodontu za definisanje plana lečenja. Prva dekada ES za medicinu su sistemi zasnovani na znanju za dijagnozu i savetovanje lekara u vezi sa planovima lečenja [38]. Smatra se da bi buduća istraživanja u ovoj oblasti trebalo da budu usmerena ka kliničkim problemima. Dijagnoza sa planiranjem lečenja je model ES prikazan u studiji koju su sproveli Grant i Freer [39], u kojoj baza znanja obuhvata 13 različitih modela zagrižaja.

Sistem na bazi znanja prikazan je u studiji koju su sproveli Hammond i Freer [40] i koristi se za ortodontsku analizu i sintezu. Njegova osnovna karakteristika je da se za svaki novi slučaj postojeća baza znanja njime proširi. Poređenjem odluka ES i stomatologa pokazano je da je tačnost ES 88%, što znači da je lošiji od eksperta i njemu se može dodeliti samo konsultantska uloga, ne i konačna odluka.

Kao alat za obučavanje neuronske mreže (NN) korišćeno je 12 različitih modela, na uzorku kliničke istorije od 238 donjih trećih molara (približno istog broja muških i ženskih pacijenta, uzrasta oko 30 god.), sa izlaznim podacima o planovima tretmana oralnog hirurga [41]. Polazeći od zlatnog standarda za ovu oblast (osetljivost 0,8), ES je pokazao osetljivost od 0,78, a oralni hirurg od 0,88 (razlika nije značajna), dok je razlika u specifičnosti još manja (0,98 za ES i 0,99 za oralnog hirurga), što takođe nije značajno. Zaključak je da je moguće obučiti NN da pruža pouzdanu podršku pri definisanju plana lečenja za donji treći molar. Studija koju su sproveli Brickley i saradnici [42] analizirala je odgovore ES, koji se koristi kao konsultant u ortodonciji za planiranje aparata. Inače, radi se o ES na bazi pravila, a rezultati pokazuju da su odgovori ES zadovoljavajući, sa 95% tačnosti.

EIC0-1 ES čini skup pravila (690) pomoću kojih stomatolog ortodont, koristeći model inženjerstva znanja Ripple-Dovn-Rules (RDR), dizajnira i dopunjuje bazu znanja, čime povećava kvalitet odgovora samog ES [43]. Pogodan je za upotrebu na klinici, a posebne koristi od njega mogu da imaju studenti pri usavršavanju i donošenju odluka u planiranju ortodontskog tretmana.

U radu čiji su autori Xie i saradnici [44] prikazan je model za donošenje odluka za ortodontski tretman pacijenata između 11. i 15. godina, kod kojih se utvrđuje da li je potrebna ekstrakcija zuba. Za obuku i donošenje odluka koristi se veštačka neuronska mreža (ANN). Inače, radi se o ES na bazi pravila, a rezultati su pokazali da su odgovori ES zadovoljavajući na uzorku od 200 pacijenata (180 za obuku ANN, a 20 za testiranje). Tačnost je iznosila 100% za obučene slučajeve, a 80% za test primer.

Sledeći primer je pokazao da ES može efikasno da automatizuje stomatološke i administrativne procedure [45]. On koristi dve tehnike AI za rezonovanje i zaključivanje – ANN i fazzy logiku.

Tri veb ES predstavili su Pasaribu i saradnici [46], Kurniawan [47] i Sadik i saradnici [48]. Oni se koriste za pomoć stomatologu pri dijagnozi oralnog zdravlja pacijenta. Zasnovani su na pravilima (AKO –ONDA) u kojima su simptomi i bolesti povezani sa faktorom izvesnosti (CF). Rezultati su pokazali 99% tačnosti njegove dijagnoze u poređenju sa dijagnozom stomatologa specijaliste. Model za dijagnozu oralnog stanja pacijenata kojima je potrebno hirurško lečenje [49] zasnovan je dijagnostici pomoću radiografskih snimaka. Tačnost ovog prediktivnog modela postiže se dubinom CNN, što je eksperimentom i pokazano. Skrining je obuhvatio 960 pacijenata, a korišćeni su modeli ResNet-18, 34, 50 i 101, pri čemu su ocenjivani tačnost, osetljivost i specifičnost svakog modela. ResNet-18 je imao najbolje performanse sa površinom ispod krive od 0,979, zatim ResNets-34, 50 i 101 sa vrednostima 0,974, 0,945 i 0,944, respektivno.

AI i mašinsko učenje (ML) sve se više primenjuju u oblastima ortodontske dijagnoze, planiranja lečenja, procene rasta i predviđanja ishoda lečenja [50, 51]. Analiziraju se sledeći algoritmi ML: Bejsov model (podrška oceni rizika u dijagnozi), NN (dijagnoza analizom snimaka), mašina vektora podrške (MVP) (koristi se za prepoznavanje skeletnih uzoraka), genetski algoritam (GA)(koristi se za trendove predviđanja stanja na osnovu dijagnoze), fazzy logika (FL) (koristi se za definisanje linije rezonovanja u skupovima gde nisu determinisana stanja). Iz ovih modela se danas razvijaju modeli dubokog učenja (Deep ML), koji će se u bliskoj budućnosti i jedino primenjivati, kao podrška stomatolozima.

Studija Prasada i saradnika [52] prikazala je inteligentni model zasnovan na CNN za duboko učenje, za automatsku identifikaciju orijentira na licu pacijenta (ukupno 13), analizom radiografskih snimaka, a u vezi sa nepravilnim položajima vilica i dijagnozom takvog stanja. Uzorak je obuhvatao 950 pacijenata, a uz pouzdanost od 95% dobijeni su odlični rezultati, zbog čega se ovaj metod preporučuje i za kliničku praksu.

Može se konstatovati da je primena AI u stomatologiji još uvek u ranoj fazi razvoja [53, 54]. Međutim, perspektive ove tehnologije su velike za dijagnozu, planiranje lečenja, praćenje oporavka, upravljanje pacijentima i administrativne poslove. Posebni pomaci se očekuju u CAD/CAM modeliranju, implantologiji, kao i u robotskoj oralnoj hirurgiji. Analiza u studiji koju su sproveli Tam-Nurseman i saradnici [55] pokazuje da u stomatologiji nekoliko simptoma nije dovoljno za dijagnozu, pa su iz tih razloga primenjena Bajesova pravila, koja omogućuju povezivanje (rangiranje i korelaciju) više simptoma za jednu dijagnozu. Iz ovih razloga je razvijen unapređeni model Bajesovih pravila, koja su pokazala dobre rezultate u definisanju dijagnoze, sa više istovremenih simptoma.

Dijagnoza i planiranje lečenja su srž ortodoncije, koju ortodonti dobijaju višegodišnjim iskustvom [47]. Mašinsko učenje (ML) ima sposobnost učenja prepoznavanjem obrazaca, a to postiže u veoma kratkom roku, smanjujući verovatnoću greške u zaključivanju i isključujući varijabilnost zaključivanja među kliničarima, kao i dobru tačnost. U ovoj studiji je na uzorku od 700 pacijenata, korišćenjem četvoroslojne CNN, postignuta tačnost od 97% [52, 56]. Sve ovo se odnosilo na dijagnozu i plan lečenja u ortodonciji. Automatizovana cefalometrijska analiza je jedna od glavnih oblasti primene AI u oblasti ortodoncije. WebCeph ES vrši određivanje linearnih i ugaonih cefalometrijskih orijentira, dobijenih na veb bazi potpuno automatizovanim merenjima ovih parametara pomoću ove platforme. Rezultati istraživanja pokazuju da je dobijena potpuna saglasnost između merenja ručnim putem i pomoću ovog ES, na uzorku od 30 pacijenata.

Sistematski pregled [57, 58] analizira različite strategije koje koriste AI u poboljšanju dijagnoze, planiranja i praćenja lečenja u ortodonciji. Analizirani su radovi u intervalu od 10 godina, a ukupno su obuhvaćene 33 studije. Rezultati pokazuju da AI sve više postaje deo kliničke prakse, a posebno model dubokog učenja. Pregledni rad Prasada i saradnika [52] takođe daje analizu primene AI u ortodonciji u oblastima dijagnostike, cefalometrijske ocene, određivanja starosti zuba, temporomandibularne ocene vilica (TMJ), donošenja odluka o planu lečenja i daljinskog praćenja pacijenata (Stomatologija 4.0). Međutim, u kliničkoj primeni, još uvek, validaciju rešenja mora da uradi ekspert stomatolog.

Kao zaključak ove analize možemo da konstatujemo sledeće: (a) ES u stomatologiji su istraživački pravac već četiri decenije, i za to vreme su od pojedinih istraživačkih ideja došli do važne naučnoistraživačke prakse, sa perspektivom u kliničkoj stomatologiji, (b) ES se danas smatraju dobrom praksom primene AI u stomatologiji, i (c) duboko učenje iz nestrukturisanih baza podataka je najbolji metod današnje primene ES (AI) u stomatologiji.

EKSPERTNI SISTEMI ZA STOMATOLOGIJU U SRBIJI

Sa velikim zadovoljstvom možemo istaći da se na Stomatološkom fakultetu u Beogradu, na Klinici za protetiku, ozbiljna istraživanja u ovoj oblasti rade od početka poslednje decenije prošlog veka, pa sve do danas [59–62]. Sve to je rezultiralo i prvim ES za stomatologa protetičara u Srbiji. On je bio sistem zasnovan na pravilima (pravila AKO–ONDA), a baza znanja je imala 120 pravila. Pretraživanje baze znanja je bilo po modelu pretraživanja unapred, od simptoma ka dijagnozi. On je bio eksperimentalno-laboratorijskog karaktera, a kasnije su ta znanja iz njegovog razvoja poslužila u širokoj primeni CAD/CAM sistema na ovoj klinici, kao i drugim klinikama Stomatološkog fakulteta u Beogradu.

EKSPERTNI SISTEMI I VEŠTAČKA INTELIGENCIJA U STOMATOLOGIJI – ŠTA DALJE

Virtuelni stomatološki asistenti zasnovani na AI mogu da obavljaju nekoliko zadataka u stomatološkoj praksi sa većom preciznošću, manje grešaka i manje radne snage u poređenju sa ljudima [51, 52, 53]. Mogu da se koristiti za koordinaciju zakazivanja termina, upravljanje osiguranjem i papirologijom, kao pomoć u kliničkoj dijagnozi ili planiranju lečenja. Veoma su korisni da upozoravaju stomatologa o istoriji bolesti, kao i navikama poput alkoholizma i pušenja. U hitnim stomatološkim slučajevima, pacijent ima mogućnost hitne teleasistencije, posebno kada je stomatolog nedostupan. Tako se može kreirati detaljna virtuelna baza podataka o pacijentu, koja će mnogo pomoći u pružanju idealnog tretmana za samog pacijenta.

VEŠTAČKA INTELIGENCIJA U DIJAGNOZI I LEČENJU

AI se može koristiti kao efikasan pristup u dijagnostici i lečenju lezija usne duplje, kao i u skriningu i klasifikaciji sumnjivih promena sluzokože, koja prolazi kroz premaligna i maligna stanja. Detektuju se čak i sitne promene na nivou jednog piksela koje mogu ostati neprimećene golim okom. AI može tačno predvideti genetsku predispoziciju za oralni karcinom na nivou velike populacije.

VEŠTAČKA INTELIGENCIJA U ORALNOJ I MAKSILOFACIJALNOJ HIRURGIJI

Najveća primena veštačke inteligencije u oralnoj hirurgiji jeste razvoj robotske hirurgije, u kojoj se simulira kretanje ljudske ruke i ljudska inteligencija. Uspešna klinička primena u hirurgiji vođenom slikom u predelu lobanje obuhvata hirurgiju oralnih implantata, uklanjanje tumora i stranih tela, biopsiju i operaciju vilica. Uporedne studije oralne implantološke hirurgije ukazuju na znatno veću tačnost u poređenju sa ručnim zahvatom slobodnom rukom, čak i ako ga izvode iskusni hirurzi. Dobija se kraće trajanje operacije, sigurnija manipulacija oko delikatnih struktura i veća intraoperativna preciznost. Robotska operacija vođena slikom omogućava temeljniju hiruršku resekciju, što potencijalno smanjuje potrebu za revizionim procedurama.

VEŠTAČKA INTELIGENCIJA U PROTETSKOJ STOMATOLOGIJI

Da bi se pacijentu pružila idealna estetska proteza, virtuelni asistent dizajna za upotrebu u protetici na bazi AI integrisao je različite faktore poput antropoloških proračuna, merenja lica, etničke pripadnosti i preferencija pacijenata. On integriše kompjuterski dizajn, sisteme zasnovane na znanju (ES) i baze podataka, koristeći logički zasnovanu reprezentaciju (AI) kao objedinjujući medijum. Primena CAD/CAM tehnologije u stomatologiji je proces kojim se postiže gotova dentalna restauracija finim procesom glodanja gotovih keramičkih blokova. Koristi se u proizvodnji inleja, onleja, krunica i mostova. CAD/CAM tehnika u suštini stvara dvodimenzionalne i trodimenzionalne modele i njihovu materijalizaciju numerički kontrolisanom obradom na mašini. Ovaj pristup je zamenio dugotrajan i naporan proces konvencionalnog livenja i smanjio komponentu ljudske greške u finalnoj protezi.

VEŠTAČKA INTELIGENCIJA U ORTODONCIJI

Dijagnoza i planiranje lečenja mogu se utvrditi isključivo analizom rendgenskih snimaka i fotografija intraoralnim skenerima i kamerama. Sve ovo se postiže virtuelnim stomatološkim asistentom, čime se eliminiše potreba za uzimanjem otisaka vilica pacijenta, kao i za nekoliko laboratorijskih koraka, a rezultati su mnogo tačniji u poređenju sa ljudskom percepcijom. Pomeranje zuba i konačni ishod lečenja mogu se predvideti korišćenjem algoritama AI i statističke analize na bazi učenja (ML).

Ovde svakako treba dodati i neke reference autora ovog rada koje predstavljaju istraživački doprinos nekim od trendova opisanih u prethodnim delovima teksta [63–70].

ZAKLJUČCI I DALJA ISTRAŽIVANJA

ES i AI su istraživačke oblasti u stomatologiji koje se intenzivno razvijaju, posebno u kliničkoj praksi. Zahvaljujući današnjem stanju razvoja mašinskog učenja i tehnika inženjerstva znanja, stekli su se svi uslovi da se kliničke procedure najbolje prakse dijagnostike i lečenja prevedu u virtuelne stomatološke asistente, kao prvu fazu razvoja i primene pametne stomatologije. Sa druge strane, time se stvaraju uslovi za razvoj i primenu telestomatologije ili Stomatologije 4.0.

Izazovi su veliki, ali sve prethodne analize u ovom radu pokazuju da nam je potreban multidisciplinaran rad, a time i znanja stomatologa, inženjera znanja i eksperata za AI, što ovaj rad i pokazuje.

CASE REPORT
PRIKAZ PACIJENTA

DOI: https://doi.org/10.2298/SGS2501035K
UDC: 616.31-77; 616.31-089

Application of piezosurgery for transcrestal sinus lift during simultaneous implant placement – case report

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SUMMARY

Introduction Implant placement is often complicated in the posterior maxilla by post-extraction bone resorption, pneumatization of maxillary sinuses, and poor quality of alveolar bone. In these situations, elevation of the maxillary sinus floor is one possible solution, which requires surgical maxillary sinus augmentation techniques that can convert part of the sinus cavity into bone suitable for implant placement.

Case outline A 34-year-old female patient was referred for implant treatment of the posterior left maxilla. A radiographic assessment revealed an atrophied posterior maxilla in the region of 25, 26, and 27, with a residual alveolar ridge height of 6 mm. At site 26, a transcrestal sinus lift was performed using a piezoelectric-surgery technique. A xenograft mixed with hyaluronic acid was used as the graft material. After graft application, a two-stage endosseous implant (Bio3, Pforzheim, Germany) with dimensions 8 × 4.2 mm was placed in the prepared site.

Conclusion Piezosurgery is an optimal option in all cases where sinus membrane elevation via the transcrestal approach is required, with the possibility of simultaneous implant placement when the residual alveolar ridge height is > 5 mm.

Keywords: sinus lift; transcrestal approach; piezoelectric surgery; endosseous dental implants

INTRODUCTION

The maxillary sinus is the largest of the paranasal sinuses and in adults contains roughly 12–15 mL of air [1]. It is a pyramidal structure with its base close to the nasal cavity, the superior portion forming the floor of the orbit, and the apex directed toward the zygomatic bone [2]. The floor of the sinus extends anteriorly to the premolar or canine region and posteriorly to the maxillary tuberosity, with its lowest part in many cases being close to the area of the first molar. The floor of the maxillary sinus is the thickest wall in dentate adults and is at about the same level as the nasal floor. In ø edentulous patients it is 1 cm below the nasal floor [3].

The rising demand for implant treatment corresponds with a growing need for their placement in various anatomical sites. Implant placement is often complicated in the posterior maxilla by post-extraction bone resorption, pneumatization of maxillary sinuses, and poor alveolar-bone quality, leading to a faster rate of bone loss compared with other areas of the mouth [4]. In these situations, elevation of the maxillary sinus floor is one possible solution, which requires surgical maxillary-sinus-augmentation techniques that can convert part of the sinus cavity into bone suitable for implant placement [5].

The most widely used technique for maxillary-sinus-floor elevation is the classic lateral antrostomy introduced by Tatum in 1976 and later published by Boyne and James in 1980. This technique is based on the lateral-window method, a modification of the well-known Caldwell–Luc sinus-revision procedure, in which grafted bone may be added in excess of 10–16 mm through a lateral-wall quadrilateral osteotomy [6]. According to traditional protocols, in cases of good-quality bone and subantral bone height of 5–6 mm the implant is placed simultaneously with the sinus-floor elevation, with or without adding bone-graft material [7]. In contrast, in situations of poor-quality bone or of subantral bone height < 5 mm, lateral antrostomy is performed and the space under the elevated Schneiderian membrane is filled with bone-graft material [6].

The most common intraoperative complication with these surgical approaches is perforation of the Schneiderian membrane [8]. Although no evidence suggests that perforation of the Schneiderian membrane reduces the survival rate of the implants, perforation may cause the grafting materials to enter the sinus cavity, leading to inflammation [9].

A crestal approach for sinus-floor elevation was initially suggested by Tatum, while Summers later proposed the osteotome technique to place implants in a simpler, more conservative, and less invasive manner than the lateral approach [10]. In Summers' technique, an osteotome is inserted through the edentulous alveolar crest at the

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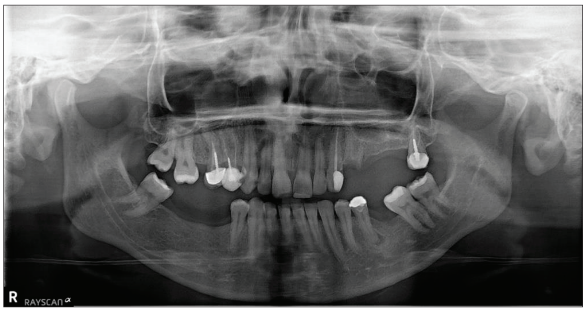

Figure 1. Panoramic X-ray of the initial situation
Slika 1. Ortopantomografski snimak početne situacije

Figure 2. Placed implant at site 24 and preparation of implant site 26
Slika 2. Postavljeni implantat u regiji 24 i priprema implantnog ležišta 26

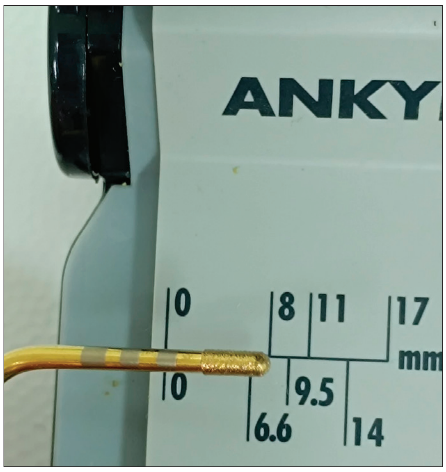

Figure 3. Piezoelectric extension with a rounded tip
Slika 3. Piezoelektrični nastavak sa zaobljenim vrhom

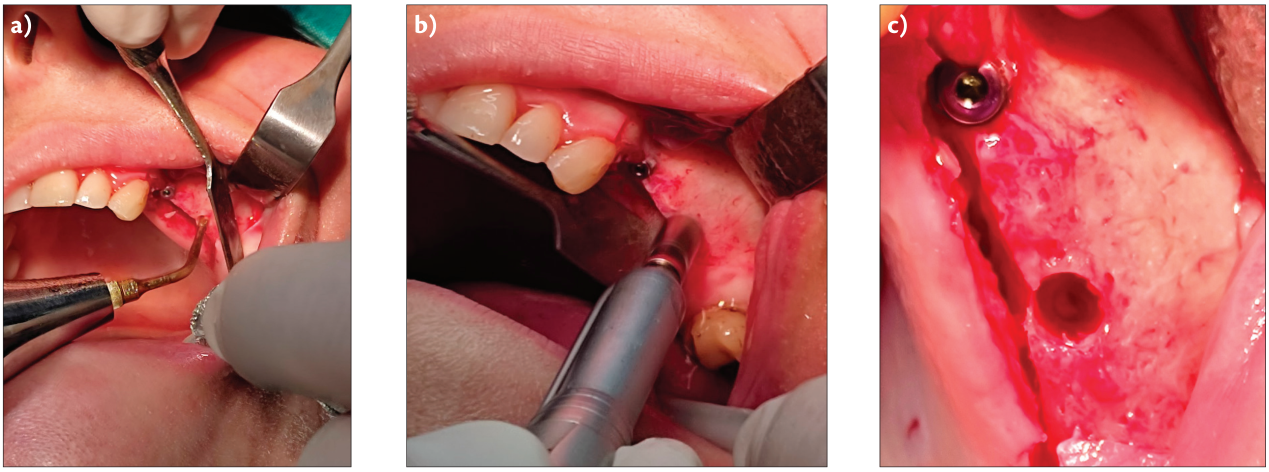

Figura 4. a) Maxillary-sinus-floor elevation using piezoelectric surgery; b) Expansion of implant site 26; c) Prepared implant site 26
Slika 4. a) Podizanje dna maksilarnog sinusa pomoću piezohirurgije; b) Proširenje implantnog ležišta 26; c) Pripremljeno implantno ležište 26

inferior border of the maxillary-sinus floor. This intrusion procedure produces a fracture in the least traumatic way possible and the sinus floor is moved upward, creating a space for bone graft placement and simultaneous implant insertion [11].

Over the past decade, various modifications of the osteotome technique for sinus lifting have been introduced, including hydraulic, crestal-core, and infracture methods. These techniques fall under osteotome-mediated sinus-floor elevation, which allows for localized sinus-floor elevation via a crestal approach, the placement of grafting materials beneath it, and the subsequent insertion of implants. One of the many described techniques uses piezoelectric ultrasonic vibration (25–30 kHz). The piezosurgery device precisely cuts only mineralized structures (bone) without cutting soft tissues, which remain undamaged even in case of accidental contact. The typical cavitation effect induces hydropneumatic pressure in the physiological saline solution that contributes to atraumatic sinus membrane elevation [12].

The aim of this article is to present a case report on the transcrestal sinus-lift technique using piezosurgery, with simultaneous placement of a dental implant in the posterior maxilla.

CASE REPORT

A 34-year-old female patient, a non-smoker, denied the presence of systemic diseases or the use of chronic therapy. Clinical examination and radiographic assessment revealed an atrophied posterior maxilla in the region of teeth 25, 26, and 27, with a residual alveolar-ridge height of 6 mm (Figure 1). After discussing the current condition and the necessity of a surgical approach for sinus-membrane elevation, the patient agreed to undergo the procedure.

Following the administration of local infiltrative anesthesia at the surgical site and elevation of a full-thickness flap, the first implant site was prepared at the level of tooth 24, and a two-stage implant (Bio3, Pforzheim, Germany) with dimensions 11.5 × 3.3 mm was placed. Once the first implant was positioned, preparation of the implant site for the second implant in the region of tooth 26 continued

Figure 5. Mixing graft material with hyaluronic acid
Slika 5. Mešanje graft materijala sa hijaluronskom kiselinom

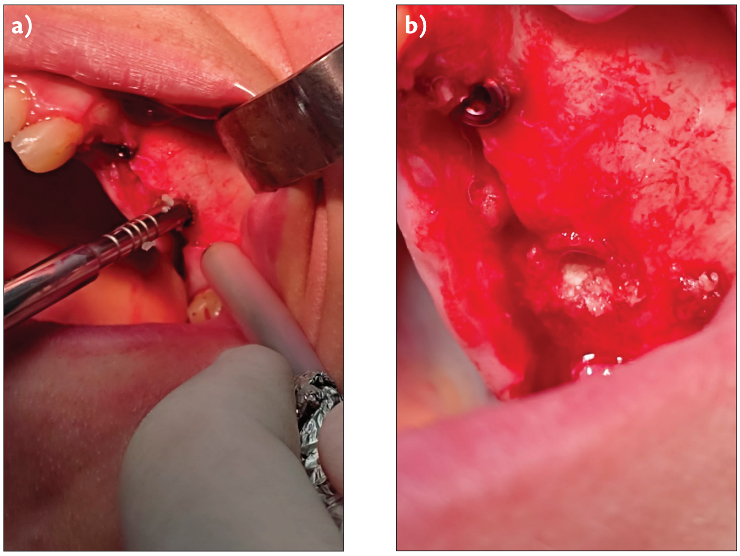

Figure 6. Filling the prepared site with graft material (a and b)
Slika 6. Popunjavanje pripremljenog ležišta graft materijalom **(**a i b**)**

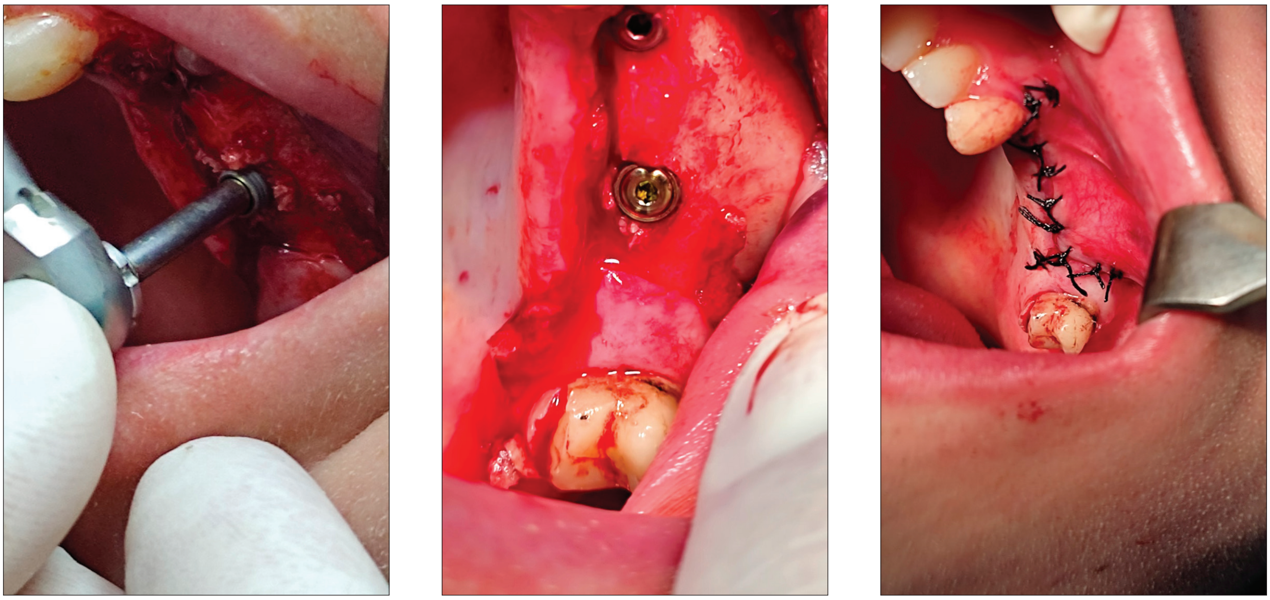

Figure 7. a) Implant placement at prepared site 26; b) Both implants at sites 24 and 26; c) Closed surgical site with simple interrupted sutures
Slika 7. a) Postavljanje implantata u pripremljeno ležište 26; b) Postavljeni implantati u regijama 24 i 26; c) Zatvorena hirurška regija pojedinačnim šavovima

using standard drills from the surgical set, where the residual alveolar-ridge height was limited (Figure 2).

In such cases of atrophied posterior maxilla, characterized by low supportive capacity, the implant site is prepared with reduced dimensions to enhance primary implant stability. The preparation was carried out up to 1 mm from the bony floor of the maxillary sinus. Upon reaching the appropriate depth, piezoelectric extensions with a rounded (ball-shaped) tip were used to perforate the bony floor, allowing contact with the sinus membrane (Figure 3). The ultrasonic vibrations facilitated elevation of the sinus membrane. This was followed by expansion of the implant site using a stopper sleeve with smaller dimensions than the planned implant size and by filling the created subantral space with graft material (Figure 4).

A xenograft from the same manufacturer (Bio3), combined with hyaluronic acid, was used (Figure 5). The graft was applied into the sinus cavity with a specialized applicator until the prepared site was completely filled (Figure 6). After graft application, a two-stage endosseous implant (Bio3) with dimensions 8 × 4.2 mm was placed in the prepared site. The surgical site was then closed with simple interrupted sutures (Figure 7). Antibiotics (amoxicillin 875 mg + clavulanic acid 125 mg, twice a day) were prescribed for seven days and analgesics as required.

A follow-up radiographic examination at six months showed successfully osseointegrated implants, with no changes in the sinus cavity and no clinical signs of postoperative complications (Figure 8). After successful implant therapy, the patient proceeded with prosthetic rehabilitation involving fabrication of a fixed prosthetic restoration.

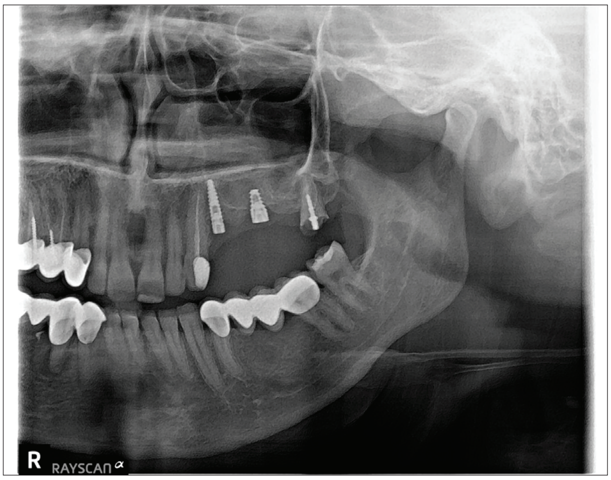

Figure 8. Follow-up panoramic X-ray after six months
Slika 8. Kontrolni ortopantomografski snimak nakon šest meseci

DISCUSSION

According to the literature, if implants are installed at the time of a sinus-lifting procedure, many investigators agree that there should be a minimum of 5 mm or more of initial subantral bone height and bone of sufficient density to provide good initial dental implant stability [13, 14].

Patients presenting < 5 mm of residual subantral bone are usually treated using the lateral antrostomy technique and two-stage surgery, with sinus lifting performed in one stage and implant placement later in the second stage [15].

According to Toffler [16], the primary determinant of implant survival with osteotome-mediated sinus-floor elevation procedures is the height of the residual alveolar ridge.

In a multicenter retrospective study, Rosen et al. evaluated the outcome of the Summers' technique in the placement of implants below the maxillary sinus floor: the success rate was 96% when the residual bone height was 5 mm or more, but dropped to 85% when crestal bone height was 4 mm or less.

Existing literature suggests that residual bone height has a significant influence on the outcome of crestal procedures. Specifically, the success rate decreases with reduced residual bone height [17].

In general, studies comparing the lateral and transcrestal approaches for sinus lift show that the transcrestal technique allows for a maximum bone-height increase of 3–4 mm, whereas the lateral technique permits an increase of 10–12 mm [18].

In a study conducted by Baldi et al. [19], two transcrestal techniques – piezoelectric and osteotome-mediated sinus-floor elevation – were evaluated. The mean sinus-floor elevation (6.78 mm) was equal to or greater than the augmentation reported in previous studies using osteotome-mediated sinus-floor elevation [19].

In the retrospective study by Bernardello et al. [20], a one-stage crestal approach for sinus lift was performed using a specific sequence of drills (Cosci's technique). The shape of the drill tip prevents perforation of the sinus membrane and permits gentle abrasive removal of the cortical bone without fracture.

Out of 134 implants immediately inserted into sites with a residual bone height of less than 5 mm (average height 3.46 ± 0.91 mm), an excellent survival rate (96.3%) was observed over a 48-month follow-up. The average bone-height gain was 6.48 ± 2.38 mm, greater than the increase typically achieved using the osteotome technique (3–4 mm) [20].

Marchetti et al. [21] concluded that the average volume augmentation after the piezoelectric transcrestal approach was 4.2 mm, as assessed at the 12-month X-ray check-up.

Many authors suggest that in cases of low supportive capacity (e.g. an atrophic posterior maxilla), the diameter of the implant-site preparation should be reduced compared with standard protocols to optimize primary stability [19].

One of the most frequent causes of failure during maxillary-sinus-floor augmentation by the crestal approach is rupture of the Schneiderian membrane. Although the crestal approach is less invasive, the lack of a direct view of the membrane prevents assessment of a possible perforation, with subsequent dispersion of graft material in the maxillary sinus and failure of the regenerative treatment [21].

Wallace et al. [22] reported that the membrane-perforation rate fell from 30% with rotary instrumentation to 7% using the piezoelectric technique.

Apart from reducing the risk of membrane perforation, piezoelectric surgery offers several advantages over other techniques used for the transcrestal approach. Some of these advantages include the following: minimal movement of the piezosurgery extensions, which increases cutting precision and reduces patient discomfort; the absence of macrovibrations, making the instrument more manageable and allowing greater intra-operative control, resulting in a safer approach in anatomically challenging regions; and the ability to maintain a clear surgical site by keeping a blood-free field during bone cutting, due to the air–water cavitation effect of the ultrasonic instrument [23].

Different types of biomaterials have been used for sinus augmentation, including autograft, allograft, xenograft, alloplast, and growth factors, and the selection of the ideal graft material is controversial.

Autogenous grafts, harvested from intra- or extra-oral sources, are the gold standard owing to their osteogenic capacity, but increased morbidity, limited availability, and a high resorption rate (up to 40%) make them less desirable.

Allogenic bone grafts, or allografts, are obtained from cadavers of the same species as the recipient of the graft. They are osteoconductive space-maintaining scaffolds for bone regeneration.

Their osteoinductive capability can be enhanced by demineralization, although processing reduces growth-factor content.

Xenografts are obtained from different animal species and act as semi-permanent, slowly resorbing, osteoconductive grafts.

Alloplastic grafting materials are either synthetic (polymers, calcium sulphates, hydroxyapatite, calcium phosphates) or natural (coral- or algae-derived hydroxyapatite). Alloplastic grafting materials are generally osteoconductive only [24].

In the present study, a xenograft mixed with hyaluronic acid was used as graft material. According to numerous studies, the crucial factors for successful implant treatment after a sinus-lift procedure include thorough evaluation of the patient's systemic and oral health and precise radiographic measurement of the residual bone height. These factors directly influence the choice of sinus-lift approach and technique.

The ability to work in direct proximity to the sinus membrane without causing perforation makes piezosurgery an optimal option in all cases where sinus membrane elevation via the transcrestal approach is required, with the possibility of simultaneous implant placement when the height of the residual alveolar ridge is more than 5 mm.

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Received: 18.02.2024 • Accepted: 12.03.2025

Primena piezohirurgije za transkrestalni pristup sinus liftu uz istovremeno postavljanje implantata – prikaz slučaja

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SAŽETAK

Uvod Postavljanje implantata u posteriornoj maksili često je otežano zbog postekstrakcione resorpcije kosti, pneumatizacije maksilarnih sinusa i lošeg kvaliteta alveolarne kosti. U takvim situacijama, podizanje dna maksilarnog sinusa predstavlja jedno od mogućih rešenja, koje zahteva hirurške tehnike augmentacije sinusa kako bi se deo sinusne šupljine pretvorio u kost pogodnu za postavljanje implantata.

Prikaz slučaja Pacijentkinja stara 34 godine upućena je na implantološki tretman posteriorne leve maksile. Radiografska procena pokazala je atrofičnu posteriornu maksilu u regiji zuba 25, 26 i 27, sa preostalom visinom alveolarnog grebena od 6 mm. Na mestu zuba 26 izvršeno je podizanje membrane sinusa transkrestalnim pristupom primenom piezoelektrične hirurške tehnike. Kao graft materijal korišćen je ksenograft pomešan sa hijaluronskom kiselinom. Nakon aplikacije grafta, u pripremljeno ležište postavljen je dvofazni endoosealni implantat (Bio3, Pforzheim, Nemačka) dimenzija 8,0 × 4,2 mm.

Zaključak Piezohirurgija predstavlja optimalno rešenje u slučajevima kada je potrebno transkrestalno podizanje membrane sinusa, uz mogućnost istovremene ugradnje implantata kada je visina preostalog alveolarnog grebena veća od 5 mm.

Ključne reči: sinus lift; transkrestalni pristup; piezoelektrična hirurgija; endoosealni dentalni implantati

UVOD

Maksilarni sinus je najveći paranazalni sinus i kod odraslih sadrži približno 12–15 ml vazduha [1]. To je piramidalna struktura sa bazom blizu nosne šupljine, gornjim delom koji formira dno orbite i vrhom usmerenim ka zigomatičnoj kosti [2]. Dno sinusa se proteže anteriorno do regije premolara ili očnjaka i posteriorno do maksilarnog tubera, pri čemu je njegov najniži deo u mnogim slučajevima blizu područja prvog molara. Dno maksilarnog sinusa je najdeblji zid kod pacijenata sa očuvanim zubima i nalazi se otprilike na istom nivou kao i dno nosne šupljine. Kod bezubih pacijenata ono se nalazi 1 cm ispod dna nosne šupljine [3].

Povećani interes za terapiju implantatima dovodi do povećane potrebe za njihovim postavljanjem na različitim anatomskim lokacijama. Postavljanje implantata u posteriornoj maksili često je otežano postekstrakcionom resorpcijom kosti, pneumatizacijom maksilarnih sinusa i lošim kvalitetom alveolarne kosti, što dovodi do brže resorpcije kosti u poređenju sa drugim regijama usne duplje [4]. U ovim situacijama, podizanje dna maksilarnog sinusa predstavlja jedno od mogućih rešenja, koje zahteva hirurške tehnike augmentacije sinusa kako bi se deo sinusne šupljine pretvorio u kost pogodnu za postavljanje implantata [5].

Najčešće korišćena tehnika za podizanje dna maksilarnog sinusa je klasična lateralna antrostomija, koju je uveo Tatum 1976. godine, a kasnije objavili Boyne i James 1980. godine. Ova tehnika se zasniva na metodi lateralnog prozora, koja predstavlja modifikaciju dobro poznate Caldwell-Luc revizije sinusa, pri čemu se graftovana kost može dodati u količini većoj od 10 do 16 mm putem lateralnim zidom kvadrilateralne osteotomije [6]. Prema tradicionalnim protokolima, u slučajevima kada je kvalitet kosti dobar, a subantralna visina kosti 5–6 mm, implantat se postavlja istovremeno sa podizanjem dna sinusa, sa dodavanjem graft materijala ili bez njegovog dodavanja [7]. Nasuprot tome, u situacijama kada je kvalitet kosti loš ili kada je subantralna visina kosti manja od 5 mm, vrši se lateralna antrostomija i prostor ispod podignute Šnajderove membrane popunjava se graft materijalom [6]. Najčešća intraoperativna komplikacija ovih hirurških pristupa je perforacija Šnajderove membrane [8]. Iako ne postoje dovoljni dokazi da perforacija Šnajderove membrane smanjuje stopu preživljavanja implantata, može doći do ulaska graft materijala u sinusnu šupljinu, što dovodi do njene upale [9].

Krestalni pristup za podizanje dna sinusa prvobitno je predložio Tatum, dok je Summers kasnije razvio osteotomsku tehniku za postavljanje implantata na jednostavniji, konzervativniji i manje invazivan način u odnosu na lateralni pristup [10]. U Samersovoj tehnici, osteotom se uvodi kroz bezubi alveolarni greben na donjoj granici dna maksilarnog sinusa. Ova intruziona procedura izaziva frakturu na najmanje traumatičan način i omogućava pomeranje dna sinusa naviše. Time se stvara prostor za koštani graft i istovremeno postavljanje implantata [11].

Tokom poslednje decenije, uvedene su različite modifikacije osteotomske tehnike za podizanje sinusa, uključujući hidrauličnu metodu, krestalnu jezgro-tehniku i infrakturne metode. Ove tehnike spadaju u osteotomski posredovanu elevaciju dna sinusa (osteotome-mediated sinus floor elevation – OMSFE), koja omogućava lokalizovano podizanje dna sinusa krestalnim pristupom, postavljanje graft materijala ispod podignute membrane sinusa i naknadnu ugradnju implantata. Jedna od mnogih opisanih tehnika koristi piezoelektrične ultrazvučne vibracije (25–30 kHz). Piezohirurški aparat precizno seče samo mineralizovane strukture (kost) bez oštećenja mekih tkiva, koja ostaju netaknuta čak i u slučaju kontakta. Tipični efekat kavitacije stvara hidropneumatski pritisak u fiziološkom rastvoru, što doprinosi atraumatskom podizanju membrane sinusa [12].

Cilj ovog rada je prikaz slučaja transkrestalne tehnike podizanja sinusa pomoću piezohirurgije, sa istovremenim postavljanjem dentalnog implantata u posteriornoj maksili.

PRIKAZ SLUČAJA

Pacijentkinja stara 34 godine, nepušač, na osnovu dobijenih anamnestičkih podataka, negirala je prisustvo sistemskih bolesti ili upotrebu hronične terapije. Kliničkim pregledom i radiografskom procenom utvrđena je atrofija posteriorne maksile u regiji zuba 25, 26 i 27, sa preostalom visinom alveolarnog grebena od 6 mm (Slika 1). Nakon razgovora i objašnjenja trenutnog stanja i potrebe za hirurškim pristupom radi podizanja membrane sinusa, pacijentkinja je pristala na hirurški zahvat.

Nakon primene lokalne infiltracione anestezije u hirurškoj regiji i podizanja mukoperiostalnog režnja, pripremljeno je prvo implantno ležište u nivou zuba 24, gde je postavljen dvofazni implantat (Bio3, Pforzheim, Nemačka) dimenzija 11,5 mm × 3,3 mm. Nakon postavljanja prvog implantata, nastavilo se sa pripremom implantnog ležišta za drugi implantat u regiji zuba 26 korišćenjem standardnih drilova iz hirurškog seta, gde je preostala visina alveolarnog grebena bila ograničena (Slika 2).

Kod ovakvih slučajeva atrofične posteriorne maksile, karakterisane smanjenim kapacitetom potpore, implantno ležište se priprema sa smanjenim dimenzijama kako bi se poboljšala primarna stabilnost implantata. Preparacija implantnog ležišta drilovima završila se na 1 mm od koštanog dna maksilarnog sinusa. Po dostizanju odgovarajuće dubine, piezoelektrični nastavci sa zaobljenim (okruglim) vrhom korišćeni su za perforaciju koštanog dna, omogućavajući kontakt sa sinusnom membranom (Slika 3). Ultrazvučne vibracije olakšale su podizanje membrane sinusa. Nakon toga je usledilo proširenje implantnog ležišta pomoću upotrebe stopera (stopper sleeve) smanjene dimenzije u odnosu na planirani implantat, kao i popunjavanje formiranog subantralnog prostora graft materijalom (Slika 4).

Korišćen je ksenograft istog proizvođača (Bio3, Pforzheim, Nemačka), u kombinaciji sa hijaluronskom kiselinom (Slika 5). Graft materijal je apliciran u sinusnu šupljinu specijalnim aplikatorom sve dok pripremljeno ležište nije bilo potpuno ispunjeno (Slika 6). Nakon aplikacije grafta, u pripremljeno ležište postavljen je dvofazni endoosealni implantat (Bio3, Pforzheim, Nemačka) dimenzija 8,0 × 4,2 mm. Hirurška regija je zatvorena pojedinačnim šavovima (Slika 7). Prepisana je antibiotska terapija (amoksicilin 875 mg + klavulonska kiselina 125 mg, dva puta dnevno) u trajanju od sedam dana, uz analgetike po potrebi.

Kontrolnim radiografskim pregledom nakon šest meseci utvrđeni su uspešno oseointegrisani implantati, bez promena u sinusnoj šupljini i bez kliničkih znakova postoperativnih komplikacija (Slika 8). Nakon uspešne implantološke terapije, pacijentkinja je nastavila sa protetskom rehabilitacijom, koja je obuhvatala izradu fiksno-protetskog rada.

DISKUSIJA

Prema podacima iz literature, ukoliko se implantati postavljaju istovremeno sa procedurom podizanja sinusa, mnogi istraživači se slažu da bi minimalna visina preostale subantralne kosti trebalo da bude 5 mm ili više, uz dovoljnu gustinu kosti, kako bi se obezbedila dobra primarna stabilnost implantata [13, 14]. Kod pacijenata sa manje od 5 mm preostale subantralne kosti obično se preporučuje tehnika lateralne antrostomije i dvofazna hirurgija, gde se podizanje sinusa izvodi u prvoj fazi, dok se implantati postavljaju kasnije, u drugoj fazi [15]. Toffleru [16] navodi da je primarni faktor za uspeh implantata pri transkrestalnom osteotomski posredovanom podizanju dna maksilarnog sinusa visina preostalog alveolarnog grebena.

U multicentričnoj retrospektivnoj studiji, Rosen i saradnici analizirali su ishod Samersove tehnike prilikom postavljanja implantata ispod dna maksilarnog sinusa: stopa uspešnosti bila je 96% kada je preostala visina kosti bila 5 mm ili više, ali je drastično opala na 85% kada je visina krestalne kosti bila 4 mm ili manje. Postojeća literatura sugeriše da preostala visina kosti ima značajan uticaj na ishod sinus lifta transkrestalnim pristupom, pri čemu se stopa uspeha smanjuje sa smanjenjem preostale visine kosti [17]. Generalno, studije koje porede lateralni i transkrestalni pristup podizanja sinusa pokazuju da transkrestalna tehnika omogućava povećanje visine kosti za 3 do 4 mm, dok lateralna tehnika omogućava povećanje od 10 do 12 mm [18].

S druge strane, u studiji koju su sproveli Baldi i saradnici analizirane su dve transkrestalne tehnike — piezoelektrično i osteotomski posredovano podizanje dna maksilarnog sinusa. Utvrđeno je da prosečna visina podizanja sinusa (6,78 mm) odgovara ili premašuje povećanje zabeleženo u prethodnim studijama koje su koristile osteotomski posredovano podizanje dna sinusa [19].

U retrospektivnoj studiji koju su sproveli Bernardello i saradnici, jednofazni krestalni pristup za podizanje sinusa sproveden je korišćenjem specifičnog niza drilova (Cosci tehnika). Oblik vrha drilova sprečava perforaciju membrane sinusa i omogućava blago abrazivno uklanjanje kortikalne kosti dna sinusa bez frakture. Od 134 implantata imedijatno postavljenih u mesta sa preostalom visinom kosti manjom od 5 mm (prosečna visina: 3,46 ± 0,91 mm), zabeležena je visoka stopa preživljavanja (96,3%) tokom perioda praćenja od 48 meseci. Prosečno povećanje visine kosti u ovoj studiji iznosilo je 6,48 ± 2,38 mm, što je više od povećanja koje se obično postiže osteotomskom tehnikom (3–4 mm) [20]. Marchetti i saradnici [21] u svojoj studiji su zaključili da je prosečno povećanje zapremine kosti nakon piezoelektrične tehnike za transkrestalni pristup bilo 4,2 mm, što je potvrđeno rendgenskim snimkom nakon 12 meseci.

Mnogi autori predlažu da se u slučaju niske potpore kosti vilice, kao što je atrofična posteriorna maksila, prečnik implantnog ležišta smanji u odnosu na standardne protokole kako bi se optimizovala primarna stabilnost implantata [19]. Jedan od najčešćih uzroka neuspeha pri augmentaciji poda maksilarnog sinusa krestalnim pristupom jeste ruptura Šnajderove membrane. Iako je krestalni pristup manje invazivan, nedostatak direktne vizuelizacije membrane sprečava procenu moguće perforacije, što može dovesti do disperzije graft materijala u maksilarni sinus i neuspeha regenerativnog tretmana [21]. Wallace i saradnici navode da je stopa perforacije membrane smanjena sa prosečnih 30%, koliko se beležilo pri korišćenju rotacionih instrumenata, na 7%, kada se koristi piezoelektrična tehnika [22].

Osim što smanjuje rizik od perforacije membrane, piezoelektrična hirurgija pruža brojne prednosti u odnosu na druge tehnike transkrestalnog pristupa. Neke od ovih prednosti uključuju minimalno pomeranje piezohirurških nastavaka, što povećava preciznost sečenja i smanjuje nelagodnost pacijenta; odsustvo makrovibracija, što čini instrument lakšim za rukovanje i omogućava bolju intraoperativnu kontrolu, rezultirajući sigurnijim pristupom u anatomski izazovnim regijama; sposobnost održavanja jasnog hirurškog polja bez prisustva krvi tokom osteotomije, zahvaljujući efektu kavitacije vazdušno-vodenog mlaza ultrazvučnog instrumenta [23].

Za augmentaciju sinusa korišćeni su različiti biomaterijali, uključujući autograft, alograft, ksenograft, aloplast i faktore rasta. Izbor idealnog graft materijala je i dalje predmet rasprave. Autogeni graftovi, koji se mogu uzeti iz intraoralnih ili ekstraoralnih izvora, smatraju se zlatnim standardom za augmentaciju sinusa zbog svoje osteogene sposobnosti, ali su manje poželjni zbog povećane morbidnosti, ograničene dostupnosti i visoke stope resorpcije grafta (do 40%). Alogeni graftovi (alografti) dobijaju se od kadavera iste vrste kao i recipijent grafta i deluju kao osteokonduktivni materijali koji omogućavaju regeneraciju kosti. Njihova osteoinduktivna sposobnost može biti povećana uklanjanjem mineralizovanog dela grafta kako bi se dobio materijal sa većom koncentracijom koštanih morfogenetskih proteina (BMP) i drugih proteina specifičnih za kost. Treba imati na umu da eliminacija patogena i antigena tokom obrade graft materijala dovodi do značajnog smanjenja količine faktora rasta. Ksenografti, dobijeni od različitih vrsta životinja, deluju kao polutrajni ili sporo resorbujući osteokonduktivni graftovi. Aloplastični graft materijali su sintetskog porekla, kao što su polimeri, kalcijum-sulfati, hidroksiapatit i kalcijum-fosfati, ili prirodnog porekla, kao što je hidroksiapatit dobijen iz korala i algi. Aloplastični graft materijali se generalno smatraju isključivo osteokonduktivnim, bez osteoinduktivnih svojstava [24]. U ovoj studiji kao graft materijal korišćen je ksenograft pomešan sa hijaluronskom kiselinom. Prema brojnim istraživanjima sprovedenim na ovu temu, ključni faktori za uspešan tretman implantatima nakon podizanja sinusa uključuju adekvatnu procenu sistemskog i oralnog zdravlja pacijenta, kao i odgovarajuću radiografsku dijagnostiku sa preciznim merenjem preostale visine kosti. Ovi faktori direktno utiču na izbor pristupa i tehnike podizanja dna maksilarnog sinusa.

Mogućnost rada u neposrednoj blizini membrane sinusa bez izazivanja njene perforacije čini piezohirurgiju optimalnom opcijom u svim slučajevima gde je potrebno podizanje membrane sinusa transkrestalnim pristupom, uz mogućnost istovremene implantacije kada je visina preostalog alveolarnog grebena veća od 5 mm.

BOOK REVIEW
PRIKAZ KNJIGE
UDC: 616.3174(075.8)

Oral pathophysiology

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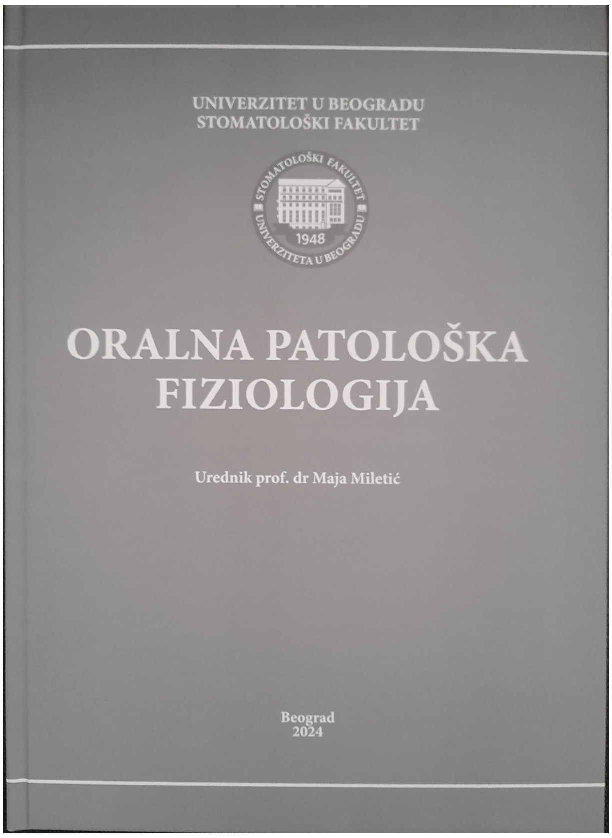
SUMMARY
A book from the field of basic dental sciences is described, published in mid-2024. Its content is briefly presented, as well as its essential importance for students on integrated dental studies as well as anyone interested in the mechanisms of pathological changes in oral structures.

Knowledge of the processes underlying the disease is of essential importance for a high-quality and successful therapeutic procedure – from diagnosis, through therapeutic procedures to monitoring the success of the treatment. Furthermore, atypical clinical presentations are common in practice and can lead to unforeseen problems during disease recognition, as well as during therapeutic procedures. Overcoming these challenges also depends on the knowledge of the basics of pathological processes. Until now, no book in Serbian exclusively focused on the pathophysiological basis of oral diseases has been available to professionals. In 2024, a textbook on this topic was published, edited by Prof. Dr. Maja Miletić and issued by the School of Dental Medicine, University of Belgrade.

This is the first book in our country that combines knowledge from oral pathophysiology and is intended primarily for students of integrated and doctoral studies in dentistry, and it can also be used by specialists who want to refresh and enrich their knowledge in this area. They can certainly benefit significantly from understanding and clarifying clinical situations, especially in atypical cases. Therefore, it can be useful for doctors in everyday dental practice. The editor is Maja Miletić, a professor at the School of Dental Medicine, University of Belgrade. As the editor herself states, the book integrates existing knowledge of the functioning of the immune system and immunoregulation, inflammation, disorders of immune-response regulation and autoimmune processes to provide a precise understanding of pathophysiological mechanisms and the role of inflammatory mediators in the inflammatory processes that occur in the dental pulp, periapical lesions and the periodontal ligament. In separate chapters, facts about oral manifestations in autoimmune diseases and immunodeficiencies are presented in detail.

The textbook consists of seven chapters written by authors in their respective fields of expertise. It contains numerous summary tables and diagrams that significantly facilitate understanding of the complex molecular mechanisms in this field. A detailed approach allows readers to follow and understand the presented data with ease. This makes the text easy to read and accessible to readers of various interests and backgrounds in the field, both students and scholars. All authors are faculty members of the School of Dental Medicine in Belgrade, except Dr. Slavko Mojsilović, a senior research associate at the Institute for Medical Research of the University of Belgrade, who wrote the introductory chapter, which contains a description of the basics of the immune system.



The special quality of the book is that it points to the clinical implications of the described pathophysiological processes, which is enhanced by the fact that the authors include clinicians from various fields – oral surgery, periodontology, endodontics and restorative dentistry.

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As mentioned, the first chapter is a kind of introduction to this complex field and deals with the structure and function of the immune system. Cells and signaling pathways and mechanisms in the body's immune system are described, which is essential for understanding specific mechanisms in oral structures.

The second chapter, authored by Dr. M. Miletić, deals with processes and biologically active molecules involved in inflammation.

The third chapter was written by Dr. K. Beljić Ivanović and Dr. J. Ilić. In it, the pathophysiological mechanisms of the inflammatory response of the dental pulp are presented. This is preceded by a description of these structures in non-pathological conditions.

The fourth chapter, by M. Andrić, deals with pathophysiological mechanisms and the role of inflammatory mediators in periapical lesions. In the fifth chapter, written by Dr. N. Nikolić Jakoba, pathophysiological mechanisms and the role of inflammatory mediators in periodontitis are described and analyzed in detail.

The sixth chapter, authored by Assistant Professor A. Jakovljević, describes and analyzes oral manifestations of immunodeficiencies.

Chapter seven, signed jointly by the editor-in-chief and Dr. Jakovljević, deals with oral manifestations in the clinically most significant autoimmune diseases. Oral changes in rheumatoid arthritis, systemic lupus, and those characteristic of autoimmune dermatoses and intestinal diseases have been described.

The textbook is a thoroughly contemporary reading in this field. Thanks to the detailed descriptions, as well as the comprehensible and receptive writing style, it will help students in integrated studies acquire foundational knowledge and will also benefit readers who already possess certain insight in this field. It will help practitioners improve diagnostic work and better understand the basics of oral pathological processes. For those involved in scientific research, it will point to some new possible directions of investigation in this area.

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Received: 19.03.2025 • Accepted: 22.03.2025

Oralna patološka fiziologija

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SAŽETAK
Ovaj tekst daje opis knjige iz oblasti bazičnih stomatoloških nauka, koja je izašla iz štampe sredinom 2024. godine. Ukratko su prikazani njen sadržaj i suštinski značaj za studente na integrisanim studijama, kao i za sve koje zanimaju mehanizmi patoloških promena u oralnim strukturama.

Poznavanje procesa koji leže u osnovi oboljenja od suštinskog je značaja za kvalitetan i uspešan terapijski postupak – od dijagnostike, preko terapijskih procedura do praćenja uspeha sprovedenog lečenja. Pored toga, atipične kliničke slike i manifestacije česte su u praksi i mogu dovesti do nepredviđenih problema tokom prepoznavanja oboljenja, ali i tokom izvođenja terapijskih postupaka. Prevazilaženje ovih izazova takođe je uslovljeno dobrim poznavanjem osnova patoloških procesa. Stručnoj javnosti do sada nije bila dostupna knjiga na srpskom jeziku čija je tema isključivo patofiziološka osnova oralnih oboljenja. Tokom 2024. godine pojavio se udžbenik sa ovom tematikom, uređen od strane prof. dr Maje Miletić, a u izdanju Stomatološkog fakulteta Univerziteta u Beogradu.

Ovo je prva knjiga u Srbiji koja objedinjava saznanja iz oralne patološke fiziologije. Namenjena je prvenstveno studentima integrisanih i doktorskih studija stomatologije, ali je mogu koristiti i specijalisti koji žele da osveže i obogate svoje znanje iz ove oblasti. Može im biti od značajne pomoći u razumevanju i pojašnjavanju kliničkih situacija, naročito u atipičnim slučajevima. Stoga može biti korisna i lekarima u svakodnevnoj stomatološkoj praksi. Urednik knjige je profesorka Stomatološkog fakulteta Univerziteta u Beogradu Maja Miletić. Kako sama urednica navodi, knjiga integriše dosadašnja saznanja o funkcionisanju imunskog sistema i imunoregulacije, inflamacije, poremećaja regulacije imunskog odgovora i autoimunskih procesa u cilju preciznog sagledavanja patofizioloških mehanizama i uloge inflamatornih medijatora u zapaljenjskim procesima u pulpi zuba, periapikalnim lezijama i parodoncijumu. U odvojenim poglavljima detaljno se iznose saznanja o oralnim manifestacijama u autoimunskim bolestima i imunodeficijencijama.

Udžbenik se sastoji od sedam poglavlja koja su napisali različiti autori iz domena svoje kompetentnosti. Sadrži brojne sumarne tabele i šeme koje značajno olakšavaju razumevanje složenih molekularnih mehanizama ove kompleksne oblasti. Detaljan pristup omogućava čitaocima da sa lakoćom prate i razumeju prezentovane podatke; samim tim, štivo je lako čitljivo i prijemčivo čitaocima različitih interesovanja i predznanja iz ove oblasti, kako studentima tako i naučnicima. Svi autori su nastavnici Stomatološkog fakulteta u Beogradu, osim dr Slavka Mojsilovića, višeg naučnog saradnika Instituta za medicinska istraživanja Univerziteta u Beogradu, koji je napisao uvodno poglavlje sa opisom osnova imunskog sistema. Poseban kvalitet knjige ogleda se u tome što ukazuje na kliničke implikacije opisanih patofizioloških procesa, a što dodatno dobija na značaju činjenicom da su među autorima i kliničari iz raznih oblasti – oralne hirurgije, parodontologije, endodoncije i restaurativne stomatologije.

Kao što je pomenuto, prvo poglavlje predstavlja vrstu uvoda u ovu kompleksnu oblast i bavi se opisom strukture i funkcije imunskog sistema. Opisane su ćelije i signalni putevi i mehanizmi u odbrambenom sistemu organizma, što je od suštinskog značaja za razumevanje specifičnih mehanizama u oralnim strukturama. Drugo poglavlje, autora dr M. Miletić, bavi se procesima zapaljenja i biološki aktivnim molekulima. U trećem poglavlju, koje su napisali dr K. Beljić Ivanović i dr J. Ilić, izneti su patofiziološki mehanizmi u zapaljenskom odgovoru pulpe zuba, a prethodi im opis ovih struktura u stanjima koja nisu patološka.

Četvrto poglavlje, autora M. Andrića, bavi se patofiziološkim mehanizmima i ulogom inflamatornih medijatora u periapikalnim lezijama. U petom poglavlju, koje je napisala dr N. Nikolić Jakoba, detaljno se opisuju i analiziraju patofiziološki mehanizmi i uloga inflamatornih medijatora u parodontitisu. Šesto poglavlje, autora docenta A. Jakovljevića, detaljno opisuje i analizira oralne manifestacije imunodeficijencija. Sedmo poglavlje, koje zajedno potpisuju glavna urednica i dr Jakovljević, bavi se oralnim manifestacijama kod klinički najznačajnijih autoimunskih oboljenja. Opisane su oralne promene kod reumatoidnog artritisa, sistemskog lupusa, kao i promene karakteristične za autoimunske dermatoze i crevne bolesti.

Udžbenik predstavlja savremeno štivo iz ove oblasti. Zahvaljujući detaljnim opisima i razumljivom i prijemčivom stilu pisanja, pomoći će u usvajanju osnovnih znanja studentima integrisanih studija, ali i onima koji znanja iz ove oblasti već imaju. Pomoći će praktičarima da unaprede dijagnostiku i bolje razumeju osnove oralnih patoloških procesa. Onima koji se bave naukom, ukazaće na moguće nove pravce istraživanja u ovoj oblasti.

Da li ste pažljivo čitali radove?

1. Veštačka inteligencija je grana nauke o:
   a) inteligenciji
   b) razmišljanju
   c) zaključivanju

2. Razvoj veštačke inteligencije traje:
   a) osam godina
   b) osam decenija
   c) osam vekova

3. Tjuringovim testom se utvrđuje:
   a) da li mašine mogu da misle
   b) da li mogu mašinski da se formiraju površine zadatih oblika
   c) količina minerala u stenama

4. Prvi neuronski računar simulira mrežu od:
   a) 30 neurona
   b) 40 neurona
   c) 100 neurona

5. Prvi jezik veštačke inteligencije zove se:
   a) LISP
   b) MISP
   c) DISP

6. GPS, zasnovan na formalnoj logici:
   a) neefikasan je u rešavanju komplikovanih problema
   b) veoma je efikasan u rešavanju komplikovanih problema
   c) najefikasniji je u rešavanju komplikovanih problema

7. Čuveni rad koji je osnova teorije rasplinutih skupova [8], ili neizvesnog odlučivanja, poznat je pod imenom:
   a) Fuzzi skupovi
   b) Busy skupovi
   c) Ludi skupovi

8. Novi period u kome je AI postala nauka počeo je:
   a) 1982. godine
   b) 1992. godine
   c) 2002. godine

9. Prvi popularni AI alat je:
   a) softver za igranje fudbala
   b) softver za igranje kriketa
   c) softver za igranje šaha

10. ChatGPT je:
    a) opšta platforma za korišćenje AI u različitim oblastima
    b) platforma za korišćenje AI u mašinstvu
    c) platforma za korišćenje AI u stomatologiji

11. Pronalaženje relacije između ulaza i izlaza nad označenim skupovima podataka u toku obučavanja sistema naziva se:
    a) nadgledano učenje
    b) nenadgledano učenje
    c) standardno učenje

12. Diskriminativni modeli mašinskog učenja imaju za cilj da:
    a) prepoznaju razlike između različitih tipova podataka
    b) usaglase razlike između različitih tipova podataka
    c) nauče distribuciju podataka i generišu nove podatke

13. Generativni modeli mašinskog učenja imaju za cilj da:
    a) nauče distribuciju podataka i generišu nove podatke
    b) usaglase razlike između različitih tipova podataka
    c) prepoznaju razlike između različitih tipova podataka

14. Ekspertni sistemi su:
    a) standardni računarski sistemi
    b) inteligentni računarski programi koji rešavaju probleme na način na koji to čine eksperti
    c) računarski sistemi koji iznalaze najbrža rešenja

15. Ekspertni sistemi su opisani kao:
    a) kompjuterizovano znanje
    b) sveopšte znanje
    c) upotpunjeno znanje

16. Ekspertni sistemi su odigrali veliku ulogu u razvoju i primeni:
    a) veštačke inteligencije
    b) softverskih rešenja uopšteno
    c) hardvera

17. Prvi ekspertni sistem koji su koristili lekari je:
    a) Mysin
    b) Dendral
    c) Prospector

18. Mycin, Molgen, Prospector su ekspertni sistemi izvedeni iz:
    a) Dendrala
    b) Kscona
    c) Steamera

19. Prvi AI program za pretraživanje unazad, koji se koristio za identifikaciju bakterija koje izazivaju teške infekcije, kao što su bakteremija i meningitis, i da preporuči antibiotike bio je:
    a) Mycin
    b) Dendral
    c) Protector

20. Prvi ekspertni sistem u stomatologiji razvijen je:
    a) 1993. godine
    b) 1983. godine
    c) 2003. godine

21. Ekspertni sistem Orad za postavljanje dijagnoze koristi Bajesove teoreme za:
    a) analizu modela za studije
    b) analizu radiografskih snimaka pacijenata sa intrakoštanim lezijama
    c) analizu anamnestičkih podataka

22. EIC0-1 ES čini skup pravila pomoću kojih stomatolog ortodont, koristeći model inženjerstva znanja Ripple-Down Rules (RDR):
    a) dizajnira i dopunjuje bazu znanja
    b) povećava kvalitet odgovora samog ekspertnog sistema
    c) Oba odgovora su tačna

23. Model za donošenje odluka za ortodontski tretman pacijenata između 11 i 15 godina, kod kojih se utvrđuje da li je potrebna ekstrakcija zuba:
    a) koristi veštačku neuronsku mrežu (ANN)
    b) ima tačnost 100% za obučene slučajeve
    c) Oba odgovora su tačna

24. Najveća primena veštačke inteligencije u oralnoj hirurgiji je:
    a) razvoj robotske hirurgije gde se simulira kretanje ljudske ruke i ljudska inteligencija
    b) u vođenju dokumentacije
    c) analiza primene antibiotika

25. Virtuelni asistent dizajna za upotrebu u protetici na bazi AI:
    a) integriše kompjuterski dizajn
    b) koristi logički zasnovanu reprezentaciju kao objedinjujući medijum
    c) Oba odgovora su tačna

26. Virtuelnim stomatološkim asistentom u ortodonciji:
    a) eliminiše se potreba za uzimanjem otisaka
    b) pomeranje zuba i konačni ishod lečenja mogu se predvideti korišćenjem algoritama AI
    c) Oba odgovora su tačna

27. Mikroorganizmi koji čine oralni mikrobiom obično su organizovani u:
    a) biofilm
    b) planktonski oblik ekosistema
    c) druge oblike organizacije

28. *Streptococcus mutans* se smatra najvažnijim etiološkim faktorom u nastanku:
    a) karijesa
    b) parodontopatije
    c) nekarijesnih lezija

29. Najpatogeniji član roda *Staphylococcus* i uzročnik raznih bolesti, od površinskih apscesa kože i trovanja hranom do stanja opasnih po život je:
    a) *Staphylococcus aureus*
    b) *Staphylococcus epidermidis*
    c) *Staphylococcus hominis*

30. Najčešće izolovana gljiva u oralnim infekcijama je:
    a) *Pithomyces chartarum*
    b) *Candida albicans*
    c) *Trichophyton mariatii*

31. Hlorheksidin se ne može koristiti dugotrajno jer:
    a) ima različite neželjene efekte, kao što su bojenje zuba u smeđu boju, poremećaj ukusa
    b) smanjuje svoju aktivnost na svetlosti
    c) ne utiče na stvaranje plaka

32. Na hlorheksidin:
    a) ne stvara se mikrobna rezistencija
    b) stvara se mikrobna rezistencija
    c) bakterije ne reaguju

33. Biljka *Spilanthes acmella L.* poznata je u narodu kao lek protiv:
    a) glavobolje
    b) zubobolje
    c) kostobolje

34. Biljka iz prethodnog pitanja ima anestetički efekat:
    a) kada se žvaću listovi i cvetovi
    b) kada se guta ekstrakt korena
    c) nema anestetički efekat

35. *S. acmella* se pokazala efikasnom u tradicionalnoj medicini za lečenje:
    a) reumatizma
    b) pulpitisa
    c) malih boginja

36. Dominantnim fitohemikalijama u rodu *Spilanthes* smatraju se:
    a) flavonoidi
    b) alkamidi
    c) piruvati

37. Da bi se dobio fini i homogeni prah biljnog porekla u studiji o biljkama objavljenoj u ovom broju, osušena masa cvasti, listova i preostalih nadzemnih delova:
    a) usitnjena je u avanu nakon delovanja tečnog azota
    b) mlevena je u aparatu – homogenizatoru
    c) usitnjena je u avanu nakon sušenja na suncu

38. Metoda korišćena za procenu antimikrobne aktivnosti bila je:
    a) minimalna inhibitorna koncentracija (MIC)
    b) PCR
    c) CFU

39. U ovoj studiji poređenje je vršeno sa:
    a) standardnim rastvorom 0,12% hlorheksidina
    b) rastvorom 3% vodonik-peroksida
    c) rastvorom 1% NaOCl

40. Inhibitorni efekat na *C. albicans* nije pokazao:
    a) ekstrakt cvasti *S. acmella*
    b) ekstrakt grančice
    c) ekstrakt stabla

41. U ovoj studiji:
    a) nije pronađen značajan efekat ekstrakta *S. acmella* na *E. faecalis*
    b) pronađen je značajan efekat ekstrakta *S. acmella* na *E. faecalis*
    c) ovo nije ispitivano

42. U ovoj studiji:
    a) nije pronađen značajan efekat ekstrakta *S. acmella* na *S. aureus*
    b) pronađen je značajan efekat ekstrakta *S. acmella* na *S. aureus*
    c) ovo nije ispitivano

43. Tradicionalne lekovite biljke postale su privlačan izvor za skrining antimikrobnih agenasa zbog:
    a) sve veće otpornosti patogena na konvencionalne antibiotike
    b) neželjenih efekata postojećih terapija
    c) Oba odgovora su tačna

44. U ovoj studiji utvrđen je:
    a) značajan antimikrobni efekat hlorheksidina
    b) slab antimikrobni efekat hlorheksidina
    c) Ovo nije ispitivano

45. Ova studija je imala za cilj da istraži antimikrobnu aktivnost:
    a) metanolnih ekstrakata nadzemnih delova *S. acmella*
    b) etanolnih ekstrakata nadzemnih delova *S. acmella*
    c) acetonskih ekstrakata nadzemnih delova *S. acmella*

46. Antifungalni efekti hlorheksidina odnose se na:
    a) prevenciju formiranja biofilma
    b) narušavanje strukture ćelijske membrane *C. albicans*
    c) Oba odgovora su tačna

47. U slučaju smanjene efikasnosti hlorheksidina:
    a) on se ne sme koristiti
    b) on se ipak mora koristiti
    c) preporučuje se kombinacija sa drugim antimikrobnim agensima

48. Najčešće korišćena tehnika za podizanje dna maksilarnog sinusa je:
    a) lateralna antrostomija, koju je uveo Tatum, a kasnije su je objavili Boyne i James
    b) Caldwell–Luc revizija sinusa
    c) Obe metode se podjednako često koriste

49. Rezultati ovog rada su:
    a) preliminarni
    b) definitivni
    c) ne zahtevaju dalja istraživanja

50. Rezultati ovog istraživanja u lečenju različitih oralnih bolesti izazvanih ispitivanim mikroorganizmima:
    a) opravdavaju primenu *S. acmella*
    b) ne opravdavaju primenu *S. acmella*
    c) Ovo se ne može precizirati

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JEDINICE MERA. Dužinu, visinu, težinu i zapreminu izražavati u metričkim jedinicama (metar – m, kilogram (gram) – kg (g), litar – l) ili njihovim delovima. Temperaturu izražavati u stepenima Celzijusa (°C), količinu supstance u molima (mol), a pritisak krvi u milimetrima živinog stuba (mm Hg). Sve rezultate hematoloških, kliničkih i biohemijskih merenja navoditi u metričkom sistemu prema Međunarodnom sistemu jedinica (SI).

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ISSN Online 1452-3701
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Dental Journal / glavni i odgovorni urednik
Slavoljub Živković. - God. 1, br. 1 (1955)-
. - Beograd (Džordža Vašingtona 19) :
Srpsko lekarsko društvo, 1955- (Beograd :
Službeni glasnik). - 29,5 cm

Dostupno i na: http://www.stomglas.org.rs - Tromesečno

ISSN 0039-1743 = Stomatološki glasnik Srbije
(Štampano izd.)
COBISS.SR-ID 8417026