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PREGLEDNI RAD
REVIEW

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Doze zračenja kod uobičajenih stomatoloških radioloških pretraga: pregled

Radiation Doses of Common Dental Radiographic Examinations: A Review

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Sažetak
Čak i male doze zračenja mogu biti biološki štetne zbog stohastičkih učinaka, kao što je, na primjer, nastanak karcinoma koji može potaknuti primljena količina radijacije. Efektivne doze radijacije variraju između 4 i16 µSv kod ortopanskih snimki, pa od 33 do 150 µSv kada se pojedinačno snima svaki zub u usnoj šupljini, naravno ovisno o primijenjenoj tehnici. Efektivne doze primljene kod CT-a s cone-beamom znatno su različite, a ovise o opremi koja se koristi, no općenito su veće nego kod ortopanskih snimki, a manje nego kod multidetektorskih CT-a. Načini na koje se smanjuje doza tijekom stomatoloških rendgenskih pretraga jesu ponajprije kriteriji je li uopće potrebna rtg snimka, zatim primjena receptora koji brzo reagiraju i bolja izoštrenost suženoga snopa, posebice kod djece.

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Uvod

Ubrzo nakon što su otkrivene rentgenske zrake postalo je jasno da zračenje može biti opasno. No, u tim ranim danima radiologije nisu se dovoljno shvaćali efekti ionizirajuće radijacije, a napori da se izlaganje zračenju prati i drži pod nadzorom temeljili su se na analizi učinaka razmjerno velikih doza na kožu tijela.

Danas je neshvatljivo da bi se nekoga izlagalo velikim dozama zračenja, osim ako je riječ o jakim lokalnim dozama u radioterapiji karcinoma ili pak neželjenoj izvrgnutosti u slučaju nuklearnog incidenta. Danas je pozornost usmjerena na uobičajene razine doza u dijagnostičkoj radiografiji, što uključuje i rtg. snimke u stomatologiji.

Introduction

Shortly after x rays were discovered, it became evident that radiation has the potential to cause harm. However, understanding of the biological effects of ionizing radiation was limited in the early days and attempts to monitor and control radiation exposure were based on observation of the effects of relatively large doses to the skin.

Today it is unlikely that anyone would be exposed to large doses of radiation other than to localized high doses used in radiotherapy for cancer or in case of a nuclear accident. Attention now is focused on doses of the level used in diagnostic imaging, including dental x-rays.

Radi boljeg razumijevanja, slijedi kratak pregled vrsta efekata radijacije. Deterministički učinci su oni kod kojih je ozbiljnost razmjerna primljenoj dozi. Pritom može, ali i ne mora, postojati prag ispod kojega nema nikakvih efekata. Posljedice takvih determinističkih, a možemo ih nazvati i ne-stohastičkih efekata, jesu crvenilo kože, gubitak kose i smanjeno lučenje sline. Čest je i gubitak stanične funkcije ili stanična smrt, ovisno o primljenoj dozi. Kod malih količina koje se koriste u dijagnostici, vjerojatno nema determinističkih učinaka.

Ipak, male doze radijacije mogu uzrokovati promjene unutar DNK stanice, no one ne moraju biti smrtonosne, ali mogu potaknuti mutacije koje, pak, mogu završiti karcinomom. Najveći dio promjena u DNK-u obično se otkrije i popravi i prije nego što počnu problemi, no taj korektivni mehanizam nije savršen, pa neke promjene mogu ostati i dalje se akumulirati. Nepopravljiva šteta vjerojatno će se dogoditi kod velikih pojedinačnih ili akumuliranih doza, ali i mali pojedinačni udari radijacije mogu stvoriti mutaciju koja može uzrokovati karcinom. Što je neka osoba izloženija jačoj radijaciji, to će joj prije biti oštećen DNK. Takva vrsta efekta – kada je mogućnost učinka proporcionalna primljenoj dozi - zove se stohastički efekt, a najčešće su posljedice karcinom ili genetske promjene u budućim naraštajima.

Zbog tih stohastičkih efekata sve je veće zanimanje za mjerenje količina zračenja korištenih u rtg-dijagnostici, kako bi se smanjile koliko god je to moguće.

Kako tehnologija napreduje, sve su savršeniji rtg-uređaji i nove vrste filmova. Sada se vrlo često snima i digitalno, pa su doze potrebne za dijagnostičke slike znatno manje. No, u većini zemalja godišnji se broj pojedinačnih rtg-snimki kod svakog pacijenta povećava, tako da ukupno primljena doza zračenja zapravo ostaje ista, ili čak raste. Vjerojatno je to na svjetskoj razini još izraženije zbog sve češće uporabe kompjutorske tomografije (CT-a) - tu posebice mislimo na CT s konusnim beamom (CBCT)) za zubne implantate i ortodontske zahvate. Sve to, ali i razumijevanje efekata zračenja na molekularnoj razini, upućuje na vrijedno staro pravilo – koliko god je razumno manje moguće, poznato pod engleskim akronimom ALARA (As Low as Reasonably Achievable).

Svrha je ovoga rada općenito opisati tehnike mjerenja radijacije te doze zračenja za uobičajene pretrage u stomatologiji, zatim usporediti razine koje se mogu postići optimalnim postupcima s onima

To aid in understanding the reason for this, a brief review of the types of radiation effects will be provided. *Deterministic* effects are those in which the *severity* of the effect is proportional to the dose. There may or may not be a threshold, a dose below which no effect is seen at all. Examples of deterministic (or non-stochastic) effects include skin reddening, hair loss, and decreased salivary function. With this type of effect there is frequently loss of cell function or cell death, depending on the dose. The low doses used in diagnostic imaging are unlikely to cause deterministic effects.

On the other hand, low doses of radiation can cause changes in the DNA of the cell that may not be lethal but that could cause the mutations that could lead to cancer. Most of these DNA changes are discovered and repaired before they cause problems, but the repair mechanism is not perfect and some of the changes may persist and accumulate. Non-repairable damage is more likely to occur with higher doses or dose rates but there is a chance that even a single small "hit" of radiation could produce a mutation that could cause cancer. The more radiation a person is exposed to, the more chances he has of receiving a non-repaired DNA injury. This type of effect in which the *probability* of an effect is proportional to the dose is described as a *stochastic* effect, with the most common examples being carcinogenesis and genetic effects seen in future generations.

It is because of stochastic effects that there is an interest in quantifying radiation doses used in diagnostic imaging and reducing them whenever possible.

As technology has improved, with new x-ray machines, films, and digital imaging, the doses required to produce diagnostic images in dentistry have significantly declined. However, the number of radiographs made each year has been increasing in most countries, such that the total radiation dose to the public is stable or even increasing. This is expected to be even more so with the increased use of computed tomography (CT), especially cone-beam CT (CBCT), throughout the world for dental implant and orthodontic imaging. This, coupled with our increasing knowledge of the effects of radiation on a molecular level, suggests that the radiation safety principle of ALARA (As Low as Reasonably Achievable) is as important today as it has ever been in the past.

The objective of this paper is to review the techniques of radiation measurement in general and then to present radiation doses for commonly used examinations in dentistry, contrasting the dose levels that koje se doista primaju u stomatološkoj praksi te na kraju istaknuti tehnike kojima možemo postići željeni cilj ALARA-e, a to je – koliko god je razumno manje moguće.

Mjerenje radijacije

Mnogo je različitih razina zračenja koje se mogu mjeriti, a dvije najčešće vrste kod dijagnostičke radiologije su ulazna površinska izloženost (ESE) i efektivna doza. Kao što samo ime kaže, ulazna površinska izloženost (ESE) je količina zračenja koja pogađa neko tkivo. Može se jednostavno izmjeriti tako da se mjerač - obično neka ionizirajuća komorica - izloži rentgenskim zrakama. Tu dozu obično određuje ovlaštena institucija kao osnovu za preporuke o razini izloženosti, kad je riječ o pojedinim vrstama rtg-pretraga. Tako je, na primjer, prihvaćen dokument o "referentnim dozama" za intraoralne zubne rtg-snimke za različite vrste rtg-filmova (1).

Takve vrste mjerenja mogu se s pravom opremom jednostavno obaviti i omogućuju korisne podatke, no imaju i velika ograničenja. Tako se kod metode ESE ne uzima u obzir veličina područja zahvaćenog zrakom, ni specifična osjetljivost konkretnog tkiva. Na primjer, rtg-snimka prsnog koša površinom je znatno veća nego ugrizna snimka, ali je ukupna ESE-doza mnogo manja zbog korištenja kaseta s pojačavajućim zaslonima i manje gustoće izvrgnutoga tkiva (rebra, pluća i druga meka tkiva). Ne bi li i količina ukupno izloženoga tkiva trebala utjecati na razmjere moguće štete od zračenja?

Odgovor je, naravno, potvrdan i to je razlog da se danas sve češće koristi pojam efektivna doza, premda ju je teže izračuna(va)ti. Jednostavno rečeno - efektivna doza je ona izmjerena prosječna doza na lokalnom tkivu, preračunana i raspodijeljena preko cijeloga tijela, što omogućuje usporedbu radioaktivne kontaminacije nakon niza rtg-pregledâ i tzv. pozadinskog zračenja. Efektivna doza najčešće se izračunava tako da se mjeri zračenje apsorbirano u različitom tkivima tijekom rtg-pregleda, a za to se koriste posebni fantomski i termosvjetleći dozimetri. Kad se izmjere, te se doze klasificiraju prema tome kolika je količina kojega tkiva bila u vidnom polju i zatim pomnože sa specifičnim faktorom koji uzima u obzir osjetljivost konkretnog tkiva na zračenje – zapravo njegovu sklonost za nastanak karcinoma. Izmjerene doze po tkivima zatim se zbroje i daju jedinstvenu brojčanu veličinu - efektivnu dozu.

Efektivna doza izražava se jedinicom zvanom Sievert (Sv), točnije njezinim manjim jedinicama

can be obtained with optimum protocols with levels that are frequently used in dental practice, and then to summarize the techniques that we can use to put the ALARA principle into effect.

Radiation Measurement

There are a number of quantities of radiation that can be measured, but the two most common measurements for diagnostic radiology are the Entrance Surface Exposure (ESE) and the effective dose. As is suggested by the name, the ESE measures the amount of radiation that strikes a tissue. This is easy to measure simply by exposing a meter, usually an ionization chamber, in the x-ray beam. This dose is frequently used by advisory or regulatory agencies to make recommendations on appropriate exposure levels for different types of imaging examinations. For example, there are Dose Reference Levels published for intraoral dental radiographs with various types of films (1).

While this type of measurement is easy to do with the right equipment and it provides some useful information, there are some significant limitations. With the ESE there is no consideration for the size of the area covered by the beam nor for the sensitivity of the tissues exposed. For example, a chest radiograph is significantly larger in area than a dental bitewing but the ESE is much smaller because of the use of cassettes with intensifying screens and the low density of the structures exposed (ribs, lungs, other soft tissues). Shouldn't the amount of tissue exposed also affect the amount of potential damage from the radiation?

The answer, of course, is yes, which is why the *effective dose* is more commonly used today, even though it is much more difficult to calculate. In simple terms, the effective dose is a weighted average of the dose to a local tissue over the entire body, making it easier to compare radiation detriment from a variety of x-ray examinations and also from background radiation. The effective dose is most commonly calculated by measuring the amount of radiation absorbed in various tissues during a radiographic examination, using a special phantom and thermoluminescent dosimeters (TLDs). Once the doses are measured, they are adjusted by the amount of that tissue in the field of view, and multiplied by a weighting factor that takes into account the radiation sensitivity of the tissue, essentially the likelihood of developing cancer. The weighted tissue doses are then summed to provide a single number, the effective dose.

milisievertima (mSv) i mikrosievertima (μSv). Za ulaznu površinsku izloženost (ESE) obično se rabi jedinica zvana Gray (Gy), odosno mGy ili μGy. Prije su se koristile druge mjerne jedinice, najčešće milirentgeni (mR) ili miliradi (mrad). Jedan mR ili mrad odgovara 10 μGy odosno 0,01 mGy.

Međunarodno povjerenstvo za radiološku zaštitu - International Commission on Radiological Protection (ICRP) – kao savjetodavna međunarodna organizacija, objavilo je faktore za pojedina tkiva za izračunavanje efektivne doze (2,3). Kod rtg-pretraga glave, tkiva koja se trebaju zaštiti su: površina kostiju, koštana srž, mozak, štitna žlijezda, žlijezde slinovnice i koža. Mjere se, naravno, i količine za ostale organe, ali one su obično vrlo male, jer se ti dijelovi tijela ne nalaze na izravnom putu zrake.

Kad se izračuna, efektivna doza može se lako uspoređivati s onima iz različitih pretraga, čak i kada su one pokrile različite površine tkiva. Na primjer, zbog veličine i vrsta izloženih tkiva, rtg-snimka prsnog koša ima veću efektivnu dozu u odnosu prema ESE-u, nego što je to slučaj kod snimke zuba.

Osim što se efektivne doze mogu uspoređivati između različitih obavljenih pretraga, mogu se koristiti i za usporedbu količine zračenja primljenog dijagnostičkim pregledom s onim koje se tijekom određenog broja dana primi pozadinskim zračenjem. Tako se može predvidjeti ukupna količina zračenja. U prosjeku, prirodno pozadinsko zračenje u SAD-u iznosi 3000 μSv/god (4), a razlike su zbog različitih nadmorskih visina te ima li ili ne u tlu prirodno raspoređenih radioaktivnih tvari. Podaci su slični i u drugim zemljama.

Doze za uobičajene stomatološke preglede

Tijekom godina tiskano je mnogo tekstova u kojima se izvještavalo o dozama za širok raspon uobičajenih stomatoloških pregleda, uključujući ugriznu snimku, snimku statusa zubala i ortopan(ogram) kod različitih brzina filma, a sada i za digital(izira)na snimanja. U nekima su objavljene doze (ESE) koje omogućuju laganu usporedbu s referentnim vrijednostima. No, u novijim se studijama uglavnom navode doze u smislu efektivne doze. Tablica 1. prikazuje raspon primljenih (ESE) doza i efektivnih količina za različite preglede. Razlike u dozama mogu biti i zbog razlika u načinu mjerenja, kao što je, na primjer, broj i točan raspored dozimetara na fantomu, ili tehnički parametri samoga uređaja (potencijal katodne cijevi izražen u kV-u, struja u katodnoj cijevi u mA-ima) ili, pak, ukupan broj filmova uporabljenih za snimanje. Osim toga, bilo

The effective dose is reported in units of Sieverts (Sv) or milli- (mSv) or microsieverts (μSv). Entrance exposure doses are frequently given in Grays (Gy) or mGy or μGy. Earlier reports used older units, typically the mR (milliroentgen) or mrad (millirad). One mR or mrad equals 10 μGy or 0.01 mGy.

The International Commission on Radiological Protection (ICRP), an international advisory organization, has published tissue-weighting factors for calculating effective doses (2,3). For examinations of the head, tissues of interest include bone surface, bone marrow, brain, thyroid gland, salivary glands, and skin. Doses to other organs are measured also, but the doses are usually quite small because the organs are not in the direct path of the beam.

Once the effective dose has been calculated, it becomes easy to compare the doses of various examinations, even if they cover different amounts of tissue. For example, because of its size and the tissues exposed, a chest radiograph has a higher effective dose compared with its ESE than does a dental bitewing.

In addition to comparing the dose of one examination to another, the effective dose can be used to compare the amount of radiation from a diagnostic examination to that from a certain number of days of background radiation. That may help put the amount of radiation into perspective. The average natural background radiation in the United States of America (USA) is 3000 μSv/year (4), with most variations in levels depending on altitude and the presence of naturally occurring radioactive materials in the soils. This is similar to most other countries in the world.

Doses for common dental examinations

Over the years there have been many publications reporting doses for a variety of common dental examinations, including bitewing, full-mouth intraoral examinations (FMX), and panoramic radiographs, with different film speeds and now with digital imaging. Some of these report the dose in terms of ESE, which makes it easy to compare with reference dose levels. Most of the recent reports, however, give the dose in terms of effective dose. Table 1 shows the range of entrance and effective doses for a variety of examination types. Differences in doses may reflect differences in measuring technique, for example the number and exact placement of the dosimeters in the phantom, or imaging parameters (tube potential [kVp], tube current [mA]) or number of films in the examination. In addition, there have been changes in the way effective dose is calculated, particularly with je nekih promjena u načinu izračunavanja efektivne doze, osobito u vezi s tretiranjem doze kod žlijezda slinovnicâ. U najnovijim preporukama, ICRP dodaje žlijezdama slinovnicama poseban faktor i one se više ne navode zajedno s ostalim organima (2). Budući da su tijekom stomatoloških rtg-pretraga slinovnice obično na izravnom putu zrake, efektivna doza kod njih obično je viša kada im se pridruži njihov faktor. To se uočava i na tablici. Kada čitamo članke o dozama zračenja, važno je znati jesu li (ICRP 2007. (2)) ili nisu (ICRP 1990. (3)) u efektivne doze bile uračunane i slinovnice, kako bi se točno mogle usporediti doze.

Na Tablicama 1. i 2. uočava se da se i ulazna i efektivna doza smanjuju ako se koristi veća brzina filma (na primjer brzina E ili F umjesto brzine D) ili u slučaju digital(izira)nog snimanja. Osim toga, pravokutno sužavanje snopa zrake također smanjuje efektivnu dozu, jer je tada ukupno izloženo manje tkiva. Ortopantomogrami zahtijevaju manju efektivnu dozu, nego status-snimke.

I dok su već objavljene optimalne doze za različite pretrage, neke studije pokazuju da su stvar-

respect to treatment of the dose to the salivary glands. In the latest ICRP recommendations, salivary glands are given their own weighting factor instead of being group with the rest of the "remainder" organs (2). Since the salivary glands are usually in the direct path of the x-ray beam with dental radiographic examinations, the effective dose tends to be higher when the salivary glands are given their own weight. This is reflected in the table. When reading papers on radiation doses, it is important to know whether the effective doses include the salivary glands (ICRP 2007 (2)) or not (ICRP 1990 (3)) in order to make an accurate comparison of doses.

It can be seen from Table 1 and 2 that, in general, both entrance and effective doses are reduced when higher film speed (E-speed or F-speed instead of D-speed) or digital imaging is used. In addition, rectangular collimation of the beam also reduces the effective dose because less tissue is exposed in total. Panoramic radiographs require a lower effective dose than a full-mouth intraoral examination.

While optimal doses for various examinations have been published, other studies have shown that

Tablica 1. Srednja površinska izloženost za ugrizne snimke*
Table 1 Median Entrance Surface Exposure for Dental Bite-Wing*

	Napon katodne cijevi (kV) • Tube Potential (kVp)		
	50-59	**60-69**	**70-79**
Film brzine "D" • D-speed film	419 mR	287 mR	258 mR
Film brzine "E" • E-speed film	240 mR	155 mR	149 mR
Digitalno snimanje • Digital imaging	193 mR	87 mR	88 mR

*Stvarno provedeno mjerenje u stomatološkim ustanovama u saveznoj državi Michiganu, SAD, 2003.-2007. Rasponi su vrlo veliki. Može se pogledati na: http://www.michigan.gov/mdch • *Actual exposures measured in dental facilities in State of Michigan, USA, 2003-2007. The ranges were very large. Available at http://www.michigan.gov/mdch.
Skinuto s interneta 13. kolovoza 2008. • Accessed 13 August 2008

Tablica 2. Efektivne doze za maksilofacijalne snimke, intraoralne, panoramske i kraniograme
Table 2 Effective Doses for Maxillofacial Imaging - Intraoral, Panoramic, Cephalometric

Vrsta pretrage • Examination	E μSv (bez sal gl) • (without sal gl)	E μSv (sa sal gl) • (with sal gl)	Referenca • Reference
FMX, brzina filma "D", kružni kolimator • FMX, D-speed, round collimator	150		Pogledati pod 4 • Reported in 4
FMX, brzina filma "E", pravokutni kolimator • FMX, E-speed, rectangular collimator	33		Pogledati pod 4 • Reported in 4
Panoramska (film) • Panoramic (film)	4.0-10.0	9.0-16.4	16
Panoramska (digitalno) • Panoramic (digital)	2.4-6.2	5.5-22.0	16
Kraniogram (film) • Cephalometric (film)	2.3		17
Kraniogram(digitalno) • Cephalometric (digital)	1.6-1.7	2.2-3.4	18
Prirodno zračenje • Background radiation	3 mSv/godišnje, ~8 μSv/po danu • 3 mSv/yr, ~8 μSv/day		Pogledati pod 4 • Reported in 4

FMX: puna intraoralna rtg. snimka; E μSv (bez sal gl): efektivna doza izražena u μSv temeljena na ICRP-u 1990.; E μSv (sa sal gl): efektivna doza izražena u μSv temeljena na ICRP-u 2007. • FMX: full-mouth intraoral x-ray examination; E μSv (without sal gl): effective dose in μSv based on ICRP 1990; E μSv (with sal gl): effective dose in μSv based on ICRP 2007 ne doze za dobivanje zubnih snimki često veće od očekivanih u idealnim situacijama. Tako je, na primjer, u studiji nedavno tiskanoj u Španjolskoj u kojoj je analizirana ulazna doza (ESE) u nekoliko tisuća zubnih ordinacija, istaknuto da često nije bilo nikakve razlike u količini zračenja kada se mjerilo prema različitim uporabljenim filmovima i različitim mjestima u usnoj šupljini (5). Autori te studije pretpostavili su da bi se ti problemi mogli dovesti u vezu s načinom razvijanja filmova, no nisu uspjeli pronaći znatnije razlike između ručno i automatski razvijenih filmova. Zaključili su kako je jedini način da se smanji količina zračenja dosljedan prijelaz s filmskoga na digitalno snimanje.

Zubni implantati u mnogim zemljama sve brže postaju najsuvremeniji način na koji se nadomještaju izgubljeni prirodni zubi. Pritom je za određivanje količine i kvalitete rezidualnog grebena na planiranom mjestu usatka potreban neki od oblika dijagnostičke vizualizacije. I dok se neki stomatolozi u tom slučaju i dalje koriste samo periapikalnim i ortopanskim rtg-snimkama, sve se češće rabe neke vrste poprečnih snimki kojima se mogu odrediti širina i visina grebena. Kako bi se dobio taj podatak, potrebna je trodimenzionalna vizualizacija - bilo da se radi o standardnoj ili kompjutorskoj tomografiji. Neki ortpantomogramski rtg-uređaji imaju i posebne programe koji određuju tomografiju linearnih i kombiniranih kretnji na različitim mjestima u čeljusti, što je prikladno za procjenjivanje implantacije. Osobito su dobri za ona mjesta na kojima se ugrađuje samo jedan umjetni zub.

No, ako je potrebno više implantata, ili u nekim kompliciranim slučajevima, nužne su potanke informacije, a njih se može dobiti samo uz pomoć kompjutorizirane tomografije (6). Kako je CT općenito metoda s visokom dozom zračenja, preporučuje se - kad god je to moguće - koristiti se CBCT-om. Naime, doze kod CBCT-a općenito su niže nego kod standardnih CT-uređaja (v. Tablicu 3.), premda ima tehnika kojima se doza primljena od medicinskog CT-a može smanjiti gotovo na razinu CBCT-a. Posljednjih nekoliko godina mnogobrojni proizvođači prodaju CBCT-uređaje. No, podaci o dozama zračenja dostupni su samo za neke (7,8,9). Iako će uskoro biti poznati i za ostale uređaje, ne treba očekivati znatnije odstupanje od sadašnjih CBCT uređaja, premda će senzori i filtri za zrak te promjene u broju baznih snimki potrebnih za rekonstrukciju slike u određenoj mjeri smanjiti doze. Ostaje činjenica da će CBCT i dalje imati veću dozu zračenja nego standardni ortopanografski uređaj.

the doses actually used to obtain dental radiographs are frequently higher than what can be obtained in ideal situations. For example, a recent study done in Spain that measured entrance doses in several thousand dental offices reported that there was frequently no difference in radiation dose with different films and in different locations within the mouth (5). The authors postulated that the problems were related to the way the films were processed, although they did not find significant differences between manual and automatic film processing. They concluded that the only way to reduce radiation dose consistently was to switch from film to digital imaging.

Dental implants are rapidly becoming state-of-the-art treatment for the replacement of missing teeth in many parts of the world and some type of diagnostic imaging is required for the evaluation of the quantity and quality of the residual ridge in the prospective implant site. While some dentists continue to use only periapical or panoramic radiographs for this purpose, it is becoming more common to use some type of cross-sectional imaging so that ridge width, as well as ridge height, can be determined. Some type of three-dimensional imaging is required to provide this information, either conventional tomography, computed tomography, or cone-beam computed tomography. Some panoramic x-ray machines have special programs that will produce linear or complex-motion tomography of sites in the jaws, suitable for dental implant evaluation. These are particularly useful for single implant sites.

However, for multiple implant sites or in complex situations, the more detailed information provided by some type of computed tomography is needed (6). Since CT in general is a high-dose technique, CBCT is preferred when it is available. The doses for CBCT are generally lower than for standard or medical CT (see Table 3), although there are techniques available that can lower the dose of medical CT almost to the level of CBCT. In the last few years many x-ray machine manufacturers have introduced CBCT units to the market. However, published dose information is available only for some of the machines (7,8,9). While reports of radiation doses for the rest of the newer machines should be available soon, they may not differ much from the doses from the other CBCT machines, although new sensors and beam filters and changes in the number of basis images required for image reconstruction will allow some dose reduction. However, CBCT will still require a higher radiation dose than standard dental panoramic imaging.

Tablica 3. Efektivne doze za maksilofacijalne snimke (CT i CBCT),
Table 3 Effective Doses for Maxillofacial Imaging - Computed Tomography (CT), Cone-Beam Computed Tomography (CBCT)

Vrsta pretrage • Examination	E μSv (bez sal gl) • (without sal gl)	E μSv (sa sal gl) • (with sal gl)	Referenca • Reference
CBCT (Large FOV)			
NewTom 3G	42	68	
CB MercuRay	464-806*	569-1073	
New generation i-CAT	37	74	9
Iluma	50-252	98-498	
CBCT (Medium FOV)			
CB MercuRay	264	560	
Classic i-CAT	29	69	
Next generation i-CAT	36	87	9
Galileos	28-52	70-128	
CBCT (Small FOV)			
CB MercuRay	156	407	
Promax 3D	151-203	488-652	9
PreXion 3D	66-154	189-388	
Multidetector CT			
Somaton 64	453	860	9

FOV: vidno polje; E μSv (bez sal gl): efektivne doza izražena u μSv temeljena na ICRP-u 1990.; E μSv (sa sal gl): efektivna doza izražena u μSv temeljena na ICRP-u 2007. • FOV: field of view; E μSv (without sal gl): effective dose in μSv based on ICRP 1990; E μSv (with sal gl): effective dose in μSv based on ICRP 2007
* neki CBCT uređaji omogućuju različite postavke za kvalitetu slike koje utječu na efektivnu dozu • * Some CBCT machines provide different image quality settings, which can affect dose

Smanjivanje doze zračenja

Budući da je i najmanja doza zračenja u stomatologiji potencijalno biološki štetna, važno je rabiti najmanju količinu zračenja potrebnu za dijagnostičku informaciju. Neke od tih načina smanjivanja propisuju državna tijela, a neke ovlaštene ustanove kao obvezujuće preporuke.

Možda bi najvažnija takva tehnika smanjivanja doze zračenja bila odluka o tome koju vrstu snimanja valja primijeniti i je li snimanje doista potrebno. Postoje smjernice koje stomatolozima pomažu u odabiru najbolje tehnike u određenom slučaju (1,10), a nazivaju se i kriteriji odabira ili referalni kriteriji. Kako bi se njima koristio, stomatolog mora najprije odrediti kakvu informaciju zapravo treba - na primjer, ima li pacijent zubni karijes, ili kakve su dimenzije i anatomska ograničenja predloženog mjesta za implantat. Sljedeći je potez izabrati tehniku snimanja kako bi se dobila potrebna informacija. Da bi se, na primjer, procijenio zubni karijes na proksimalnim plohama, bolja je ugrizna snimka, a ne periapikalna ili ortopanogram. Odabir najbolje tehnike za zubne implantate je složeniji, jer ovisi o broju i mjestu planiranih usadaka te o količini raspoložive kosti, a to se određuje drugim sredstvima, uključujući i klinička mjerenja te uporabu modela. Snimanje za ugradnju usadaka zahtijeva ortopanogram i poprečne snimke.

Kad se odluči da je rtg-snimka potrebna, to se mora učiniti s najmanjom mogućom dozom zrače-

Reducing radiation dose

Because even the small radiation doses used in dentistry have the potential to cause biological damage, it is important that the least amount of radiation be used that is compatible with the need for diagnostic information. Some of the dose reduction techniques are mandated by governmental organizations, while others are highly recommended by advisory groups.

Perhaps the most important dose reduction technique is the decision of which imaging technique to use –if any – to provide the desired information. There are some decision-making guides available that help the dentist determine the best technique to use in a given situation. (1,10) These guidelines are sometimes called selection criteria or referral criteria. To use them, the dentist first determines what type of information is needed, for example, the presence or absence of dental caries or the dimensions and anatomical limitations of a proposed dental implant site. The next step is to determine which imaging technique can provide the desired information. For example, to assess dental caries on proximal surfaces, a bitewing radiograph is better than a periapical or panoramic radiograph. Selecting the best technique for implant imaging is more complicated because it depends on the number and location of implants planned, as well as the amount of bone available as determined by other means, including clinical measurements and the use of models. Imnja, a da se ipak dobije potreban podatak. Ako je odabrana intraoralna snimka, poželjno je koristiti se najbržim filmom, ili izabrati digitalno snimanje. U mnogim se studijama upozorava da nema razlika u dobivenim dijagnostičkim podacima kod uporabe filmova, uz uvjet da se s njima ispravno postupalo, što se odnosi i na razvijanje (11). Valja paziti na to da se kemikalije za razvijanje filmova mijenjanju dovoljno često da ne bi izgubile jakost, a mora se poštovati i vrijeme razvijanja kako se sporije razvijanje ne bi kompenziralo predugom ekspozicijom.

Neki suvremeni rtg-uređaji imaju precizan elektronički brojač, odgovarajući potencijal katodne cijevi izražen u kV-u i filtriranje zrake, kako bi sliku proizveli s prihvatljivom količinom zračenja. No, neki stariji uređaji s nižim potencijalom katodne cijevi, ili mehaničkim brojačima-"tajmerima", mogu emitirati više zračenja nego što je potrebno. U nekim je zemljama propisan redovit pregled rtg-uređaja, obično jedanput na godinu, a obavlja ga fizičar, stručnjak za zračenja. Čak i kada se to ne zahtijeva izričito, dužnost je stomatologa paziti na to da rtg-uređaj bude ispravan. To je i jedna od sastavnica prije spomenutog načela ALARA-e.

Daljnji način smanjivanja doze zračenja jest usmjeravanje zrake na najmanju upotrebljivu veličinu, jer se tako smanjuje opseg izloženog tkiva, a time i količina upijene radijacije, te konačno i razina opasnosti od nastanka biološke štete. U SAD-u je standardni stomatološki rendgenološki kolimator valjak promjera 7,5 centimetara, a u mnogim europskim zemljama njegov je promjer 6 centimetara. Još je bolje umjesto okrugloga koristiti se *pravokutnim* kolimatorom – on je dimenzijama tek nešto veći od zubnog rtg-filma. Na taj se način može smanjiti količinu zračenja za oko 50 posto u usporedbi s kružnim kolimatorom promjera 7 centimetara, ponajprije zato što je tada štitnjača izvan dometa primarne zrake (12). Kod male zrake, bilo da se radi o cilindru promjera 6 centimetara ili o pravokutniku, važno je koristiti se nekom vrstom vodilice za zrake i uređajem za pridržavanje filma, kako bi se na najmanju mjeru svele mogućnosti da se "izreže" neki važan dio informacije zbog nepodudaranja (smjera) zrake i filma.

Neki moderni ortopanski rtg-uređaji imaju posebne programe za rtg-snimanja djece. Na njima se može smanjiti veličina vidnog polja, kako bi se neke osjetljive organe - kao što su oči i štitna žlijezda - udaljilo od primarne zrake. Mogu se dodati i posebni kolimatori na kefalometrijske uređaje kako bi se smanjilo zračenje prema mozgu i štitnjači.

plant imaging may require a panoramic radiograph and some type of cross-sectional imaging.

Once the decision is made to take a radiograph, the next important step is to do it with the lowest dose possible that will provide the needed information. If intraoral imaging is selected, using the fastest film available or digital imaging is appropriate. There have been many studies that have demonstrated no differences in diagnostic information with the various film types, provided the films are handled appropriately, including appropriate film processing (11). Care to make sure that processing chemicals are changed often enough so their strength is not depleted and that the correct processing time is used will help prevent under processing of film and thus the need for overexposure to compensate.

Most modern x-ray machines have an accurate electronic timer and adequate tube potential (kVp) and beam filtration to produce radiographs with a reasonable dose. However, some older machines that operate at lower tube potential or have mechanical timers may deliver more radiation to the patient than is necessary. Some countries require that x-ray machines be checked periodically, sometimes annually, by a radiation physicist. Even if it is not a legal requirement, making sure that the x-ray machine is working properly is the responsibility of the dentist and an important component of ALARA.

Another method to reduce radiation dose is to collimate the beam to the smallest size practical because limiting the volume of tissue exposed reduces the amount of radiation absorbed and thus the potential for biological damage. In the USA, the standard dental x-ray collimator is a cylinder of 7 cm diameter, while in many European countries, the diameter of the cylinder is 6 cm. It is even better to replace the round collimator with a rectangular one that is only slightly larger than the dental film. This permits a reduction of the effective dose by about 50% compared to the 7 cm round collimator, primarily by removing the thyroid gland from the primary beam (12). With a small beam, whether 6 cm round or rectangular, it is important to use some kind of beam-guiding, film-holding instrument to minimize chances of cutting off some of the desired information due to misalignment of beam and film.

Some modern panoramic x-ray machines have special programs for pediatric radiographs that decrease the size of the field of view to remove some sensitive organs, such as the eyes and thyroid gland, from the primary beam. Special collimators can be added to cephalometric machines to reduce dose to

Osobito je važno smanjivanje doza na ortodontskim snimkama, jer su djeca najosjetljivija na učinke zračenja (13).

Kad je riječ o CBCT-uređajima, oni najčešće imaju mehanizam za smanjivanje skeniranog volumena, tako da mnogu pokriti samo onu čeljust za koju je potrebna pretraga. Ako se kolimator ostavi širom otvoren da bi pokrio glavu, a bez očitog razloga kao što bi bila sumnja u neku bolest, to se ne smatra dobrom radiološkom praksom.

Kako bi se smanjila količina zračenja, važno je ne ponavljati snimanja. Naprave za izravnanje zrake, osim što sprječavaju konusne rezove, mogu pomoći radiologu da dobije geometrijski ispravne snimke bez preklapanja zuba ili iskrivljavanja njihove duljine, što omogućuje dobru rtg-sliku iz prvog pokušaja.

Digitalno snimanje možda manje zrači nego klasičan film, ali se često mora ponoviti nekoliko puta, jer se slike odmah pregledaju, pa ako ne zadovoljavaju postupak se odmah ponavlja. Važno je imati na umu da se i kod digitalnog snimanja još koriste x-zrake i valja nastojati da se već iz prvog pokušaja dobije dobra snimka.

Razlikuju se mišljenja o valjanosti olovne pregače kod smanjivanja izloženosti pacijenta x-zrakama. U mnogim je zemljama, među njima i u SAD-u, uporaba olovne pregače uobičajena, a u nekima je stvar izbora, ili se uopće ne koristi. Njezina je svrha zaštititi tkiva spolnih žlijezda od sekundarnog zračenja. No, ako se koriste suvremeni uređaji, spolne žlijezde ionako nisu ozračene, jer se ne nalaze na izravnom putu zrake. Mogu primiti tek sekundarno zračenje koje se raspršeno odbija od lica pacijenta. Sve što smanjuje facijalnu dozu (a to vrijedi i za brze filmove i za digitalno snimanje te za male kolimatore), smanjuje i gonadalnu dozu. U SAD-u je Nacionalno vijeće za radiološku zaštitu (NCRP) ustvrdilo da olovna pregača nije potrebna ako se stomatolog koristi svim drugim načinima kojima se smanjuje količina zračenja (14). No, kako se mnogi još ne koriste pravokutnom kolimacijom i filmovima brzine F, a ni digitalnim snimanjem, pregača se i dalje preporučuje. U nekim državama mogu biti na snazi drugačije preporuke u vezi s korištenjem ili nekorištenjem pregače. No, bez obzira na to koliko bila izgledom dojmljiva, pregača je najmanje efikasna u smanjivanju doze zračenja.

Godine 2004. objavljen je članak o povezanosti male tjelesne težine tek rođene djece i rtg-snimki majke dok je bila trudna (15). Autori su istaknuli da je za to kriva promijenjena funkcija majčine

the brain and thyroid gland. Dose reduction in orthodontic imaging is particularly important because children are more vulnerable to the effects of radiation (13).

With respect to CBCT, most of the machines have a mechanism to reduce the height of the volume scanned to cover only the jaw of interest. Leaving the collimator wide open to cover the head without a specific reason to do so, such as the suspicion of disease, is not considered good radiation practice.

Reducing the number of "retakes" is important in reducing the amount of radiation the patient receives. Beam alignment devices, in addition to preventing "cone cuts", can help the operator produce geometrically correct radiographs with no overlapping of teeth or distortion of tooth length, thus ensuring a good radiograph on the first attempt.

The use of digital imaging can lead to a lower radiation dose than with film, but it can also lead to a higher number of retakes because of the ease in which images can be viewed and retaken immediately if they are not perfect. It is important to remember that digital imaging still uses x rays and care should be used to obtain a correct image the first time.

There are differences of opinion on the value of the leaded apron in reducing x-ray exposure to the patient. In many countries, including the USA, the use of the leaded apron is standard practice while in others it is optional or not used at all. The purpose of the leaded apron was to protect the gonadal tissues from stray radiation, but with modern dental x-ray machines and films the gonads receive almost no radiation since they are not in the direct beam and receive only secondary radiation scattered off the patient's face. Anything that reduces the facial dose, including fast films or digital imaging and small collimators, reduces the gonadal dose. In the USA the National Council on Radiation Protection (NCRP) has stated that the leaded apron is not necessary if dentists use all other available dose reduction techniques (14). However, since most dentists do not use rectangular collimation and F-speed film or digital imaging, the apron is still recommended. Other countries may have different recommendations about the use of the apron or not. While it is the most visible, the apron is probably the least effective dose reduction technique.

In 2004 a paper was published linking low birth weight of newborns to dental radiographs of the mother taken while she was pregnant (15). The authors postulated that the effect was due not to direct exposure of the fetus but rather to changes in štitne žlijezde zbog njezine izloženosti zračenju, što je utjecalo na smanjenu tjelesnu težinu čeda. Ni jedan drugi autor nije to potvrdio, no ipak je Američka stomatološka udruga (ADA) kao mjeru opreza preporučila uporabu olovnih štitnika za štitnu žlijezdu za svu djecu i sve trudnice (10).

I na kraju, budući da x-zrake, čak i u vrlo malim količinama, mogu učiniti biološku štetu, stomatolozi moraju s radijacijom postupati oprezno i mudro. To znači da trebaju procijeniti kakve dijagnostičke informacije žele i zatim prema tome odabrati tehniku snimanja koja će tu informaciju pružiti uz najmanju stopu zračenja. To također znači da se oprema, uključujući i uređaje i kemijske otopine za razvijanje filmova, mora održavati te da valja primijeniti dobre tehnike snimanja kako bi se izbjegla ponavljanja. Uporaba brzih filmova ili digitalnih načina snimanja te mala kolimacija gdje god je to moguće, također će pomoći da dozu zračenja održimo na najnižoj mogućoj razini, kao što to sugerira načelo ALARA-e, a to je cilj kojemu moramo težiti.

thyroid function of the mother due to radiation exposure, leading to a reduction in weight gain of the fetus. The study has not been replicated and others have refuted the proposed mechanism, but this study led the American Dental Association to recommend the use of leaded thyroid shields on all children and young women of childbearing age as a precaution (10).

In summary, because x-rays have the potential to cause biological harm, even in small amounts, it is our responsibility as dentists to use radiation wisely. That means to evaluate the diagnostic information we need and to select the imaging technique that will provide that information with the lowest radiation dose. It also means that we must keep our equipment in good condition, including our film processing apparatus and solutions, and use good technique to avoid retakes. Using fast film or digital imaging and small collimation, whenever feasible, will also keep the radiation dose As Low As Reasonably Achievable, a goal worth pursuing.

Abstract
Even low doses of radiation have the potential to cause biologic harm by way of stochastic effects, those, like carcinogenesis, whose probability of occurrence is dependent on radiation dose. Effective radiation doses range from 4-16 μSv for panoramic radiographs to 33-150 μSv for a full-mouth intraoral series, depending on exact technique used. Effective doses from cone-beam CT vary significantly, depending on the specific equipment used, but in general are much higher than for panoramic radiographs but less than for multidetector CT. Methods to reduce the dose from dental x-ray examinations include the use of selection criteria to determine whether a radiograph is needed, the use of fast image receptors, and increased beam collimation, particularly for children.

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