Ocjena točnosti mjerenja okomitih dimenzija na ortopantomogramima

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Acta Stomatol Croat
1998; 283—289

Sažetak

Svrha istraživanja bila je ocijeniti točnost prikaza okomitih dimenzija na ortopantomogramima.

Različite okomite udaljenosti označene su na 25 mandibula s pomoću metalnih markera veličine 1 mm². Označene udaljenosti izmjerene su pomičnom kliznom mjerkom (TMA-MEBA), a zatim su napravljeni ortopantomogrami tih mandibula. Iste udaljenosti izmjerene su i na panoramskim snimkama. Dobiveni rezultati analizirani su statistički. Čimbenik povećanja izračunan na osnovi dobivenih rezultata uglavnom je manji od deklariranog (1,22x), iako razlika nije statistički znatna za većinu mjerenih varijabla.

Nasuprot stajalištima u literaturi, naši rezultati pokazuju da je moguće precizno mjeriti okomite udaljenosti na ortopantomogramima čak i u anteriornoj regiji mandibula, pod uvjetom da se mandibule ispravno pozicioniraju i da su obuhvaćene fokalnim kanalom radiološkog aparata.

Ključne riječi: *ortopantomografija, indeks povećanja*

IZVORNI ZNANSTVENI RAD
Primljeno: 28. listopada 1987.

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Uvod

Ortopantomografija je panoramska tehnika snimanja orofacijalnog područja. Snimkom su obuhvaćeni gornja i donja čeljust s pripadajućim strukturama i oba temporomandibularna zgloba. Panoramska radiografija temelji se na načelu laminografije objekta zavijene površine. Anatomske strukture koje su u snimanome sloju na filmu oštro su prikazane, a strukture koje su izvan snimanoga sloja toliko su uvećane i iskrivljene da na filmu nisu ni vidljive.

U Sjedinjenim Američkim Državama preporučuje se prije svakoga protetskog tretmana snimiti pacijenta panoramskom tehnikom snimanja. Takvim pregledom pacijenata (screening) često se dobiju neočekivani nalazi poput impaktiranih zuba, ostatnih korijena, cista, stranih tijela, pa čak i neoplazmi u potpuno bezubim čeljustima i bez klinički vidljivih znakova (1-3). Panoramska se radiografija upotrebljava i u procjeni resorptivnih i osteopeničkih procesa čeljusti (4-8).

Ortopantomografija, kao vrsta panoramskoga snimanja, ima znatnu ulogu u implantologiji jer pruža informaciju o okomitoj dimenziji kosti i o lokaciji određenih anatomskih struktura orofacijalne regije. Postoje i modernije tehnike snimanja koje su znatno preciznije od ortopantomografije, poput kompjutorizirane tomografije (CT) ili magnetske rezonancije (MRI), no one su i mnogo skuplje (6).

Osnovni nedostatak ortopantomografije jest mogućnost da dimenzije struktura prikazanih na filmu ne odgovaraju stvarnim dimenzijama snimljenih struktura. Distorzija i magnifikacija utječu na dimenzije snimljenih struktura na filmu. Magnifikacija ovisi o čimbenicima projekcije, što su udaljenosti između objekta i rendgenske cijevi te objekta i filma (9,10). U okomitoj ravnini magnifikacija ovisi samo o čimbenicima projekcije, a u horizontalnoj pak ravnini na magnifikaciju utječu još i brzina rendgenske cijevi i filma prigodom orbitiranja oko objekta snimanja te brzina prolaska filma ispred zazora na kaseti u kojoj je film. Brzinu je unaprijed programski odredio proizvođač. Tijekom snimanja kaseta s rendgenskim filmom i rendgenska cijev orbitiraju oko nepomične pacijentove glave. Ako se poremeti brzina orbitiranja rendgenske cijevi i filma oko pacijentove glave, zbog pada napona ili slično, snimljene strukture bit će uvećane ili umanjene, ovisno o tome smanjuje li se ili povećava brzina prolaska filma iza zazora na kaseti.

Ispravno pozicioniranje glave pacijenta unutar žarišnoga sloja aparata postiže se uporabom plastičnoga kefalostata. Time se pacijent snimi na ponovljiv način, što omogućuje usporedbu pacijentovih panoramskih snimaka učinjenih prije, u tijeku i nakon terapije (11).

Čimbenik magnifikacije jednak je u vodoravnoj i okomitoj ravnini za strukture koje su unutar žarišnoga sloja. Snimka strukture koja je u žarišnome sloju aparata neoštra je, distorzirana i promijenjena položaja (9-24).

Prema nekim autorima okomite udaljenosti mjerene na panoramskim snimkama pouzdane su u lateralnim dijelovima čeljusti, no u anteriornome dijelu nisu pouzdane zbog uskoga žarišnog sloja ortopantomografskog aparata u toj regiji.

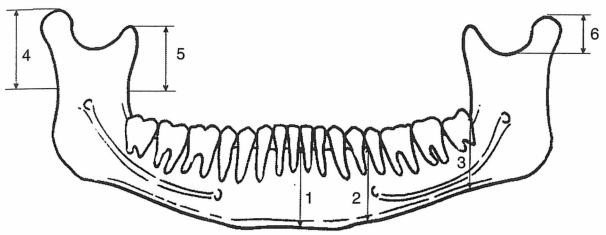
Širina i oblik žarišnoga sloja, te čimbenik magnifikacije, razlikuju se od proizvođača do proizvođača, ali i između raznih uređaja istoga proizvođača (14). Prema Lundu i Welanderu (15,17,18) geometrije projekcije, koje se razlikuju od proizvođača do proizvođača, razlog su razlikama u magnifikaciji, distorziji i dispoziciji struktura koje su izvan žarišnog sloja.

Zbog toga je svrha istraživanja bila procijeniti točnost mjerenja okomitih udaljenosti na panoramskim snimkama učinjenim ortopantomografskim aparatom Orthophos D 3200 (Simens, Njemačka) koji se upotrebljava na Stomatološkom fakultetu u Zagrebu.

Materijal i metode

Različite okomite udaljenosti (Slika 1) izmjerene su na 25 čeljusti sa Zavoda za anatomiju Medicinskog fakulteta Sveučilišta u Zagrebu. Čeljusti su slučajno odabrani uzorak, 16 je bilo muških i 9 ženskih, u dobi od 27 do 78 godina.

Udaljenosti su označene metalnim markerima četvrtastog oblika površine 1mm^2. Sva su mjerenja izvršena pomičnom mjerkom preciznosti 0,1 mm (TMA MEBA, Republika Njemačka). Čeljusti su najprije izmjerene, a nakon toga su snimljene ortopantomografskim aparatom Orthophos D3200, serijski broj 07786, proizvođač Siemens, Republika



Slika 1, 3. *Vertikalne udaljenosti mjerene na mandibulama i njihovim ortopantomogramima*

1. UBM - LBM(S.) = *udaljenost između gornjeg i donjeg ruba mandibule u sagitalnoj (medijalnoj) liniji,*

2a. R.UBM - LBM(FM) = *udaljenost između gornjeg i donjeg ruba mandibule na okomitoj liniji koja prolazi kroz medijalni otvor desnog foramena mentale,*

2b. L.UBM - LBM(FM) = *udaljenost između gornjeg i donjeg ruba mandibule na okomitoj liniji koja prolazi kroz medijalni otvor lijevog foramena mentale,*

3a. R.UBM - LBM(8.) = *udaljenost između gornjeg i donjeg ruba mandibule na okomitoj liniji koja prolazi distoaproksimalnim obrisom desnog zadnjeg molara, ili mezijalnom granicom trigonuma retromolare kod bezubih mandibula,*

3b. L.UBM - LBM(8.) = *udaljenost između gornjeg i donjeg ruba mandibule na okomitoj liniji koja prolazi distoaproksimalnim obrisom lijevog zadnjeg molara, ili mezijalnom granicom trigonuma retromolare kod bezubih mandibula,*

4a. R. Co - WP = *udaljenost između najviše točke kondila i točke stražnje širine ramusa na desnoj strani,*

4b. L. Co - WP = *udaljenost između najviše točke kondila i točke stražnje širine ramusa na lijevoj strani,*

5a. R. PM - WA = *udaljenost između najviše točke kondila i točke prednje širine ramusa na desnoj strani,*

5b. L. PM - WA = *udaljenost između najviše točke kondila i točke prednje širine ramusa na lijevoj strani,*

6a. R. Co - Inc = *visina desnog kondila, određeno prema Kjellbergu et al.(14),*

6b. L. Co - Inc = *visina lijevog kondila, određeno prema Kjellbergu et al.(14).*

Figure 1,3. *Vertical variables measured on dry mandibles and orthopantomograms*

1. UBM - LBM(S.) = *distance between the upper and the lower border of the mandible in the sagital line,*

2a. R.UBM - LBM(FM) = *distance between the upper and the lower border of the mandible in the line perpendiculary drawn at the medial opening of the right mental foramen,*

2b. L.UBM - LBM(FM) = *distance between the upper and the lower border on the mandible in the line perpendiculary drawn at the medial opening of the left mental foramen,*

3a. R.UBM - LBM(8.) = *distance between the upper and the lower border of the mandible in the line perpendiculary drawn at the distal border of the crown of the right third molar, or at the mesial border of the trigonum retromolare in the edentulous mandible,*

3b. L.UBM - LBM(8.) = *distance between the upper and the lower border of the mandible in the line perpendiculary drawn at the distal border of the crown of the left third molar, or at the mesial border of the trigonum retromolare in the edentulous mandible,*

4a. R. Co - WP = *distance from the highest point of the condylar process to the point of the posterior ramus width on the right side,*

4b. L. Co - WP =*distance from the highest point of the condylar process to the point of the posterior ramus width on the left side,*

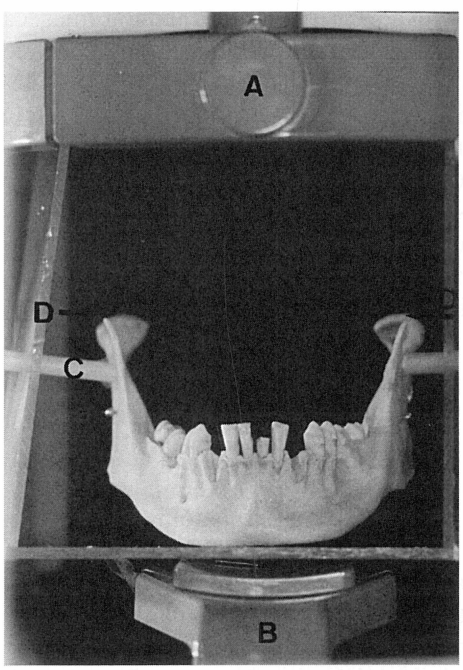
5a. R. PM - WA = *distance from the highest point of the coronoid process to the point of the anterior ramus width on the right side,*

5b. L. PM - WA = *distance from the highest point of the coronoid process to the point of the anterior ramus width on the left side,*

6a. R. Co - Inc = *the right condylar height, determined by the method proposed by Kjellberg et al.(11)*

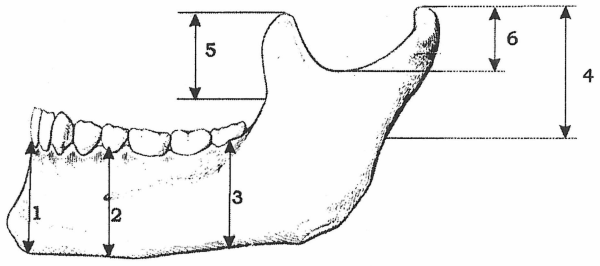
6b. L. Co - Inc = *the left condylar height, determined by the method proposed by Kjellberg et al.(11)*

Njemačka. Proizvođač za svoj aparat navodi čimbenik maginifikacije od 1,22x. Čeljusti su za snimanje pozicionirane u kefalostat ortopantomografskog aparata s pomoću posebno izrađenoga plastičnog držača i svjetlosnog orto-križa (Slika 2).



Slika 2. *Plastični držač postavljen u kefalostat Orthophos-a D 3200*
A - Držač za čelo kefalostata
B - Držač za bradu kefalostata
C - Plastične cijevčice (prilagođuju se širini mandibule i drže mandibulu u određenom položaju)
D - Dvije strelice smještene na lateralnim stranama plastičnog držača za određivanje položaja najviše točke kondila

Figure 2. *Plastic holder mounted in a cephalostat of Orthophos D 3200*
A - Forehead holder of a cephalostat
B - Chin holder of a cephalostat
C - Plastic tubes (adjustable to mandible width) which hold a mandible in determined position
D - Two arrows placed on lateral sides of the plastic holder to denote the highest points of condyles



Slika 3. *(strana 285)*
Figure 3. *(page 285)*

Pošto su izrađeni panoramski snimke svih čeljusti, mjerenja su ponovljena na samim snimkama (Slika 3).

Kako bi se procijenila pouzdanost trojice ispitivača izrađen je test pouzdanosti. Ispitivači su mjerili 6 okomitih parametara na 7 čeljusti i na snimkama tih 7 čeljusti, s razmakom od jednog mjeseca između mjerenja. Statistička raščlamba provedena je metodom koju su predložili Slakter et al. (24) i Fleiss et al. (25). Intra-ispitivačka pouzdanost kretala se je između 0,85-0,95, u ovisnosti o mjerenoj varijabli, a inter-ispitivačka pouzdanost kretala se je između 0,90-0,95. Vrijednost pogrješke mjerenja bila je u rasponu od 0,0013-0,0031, što se drži zadovoljavajućim. Najkonzistentniji ispitivač određen je prema najnižoj vrijednosti standardne pogrješke između mjerenja, te je odlučeno da on mjeri sve ostale varijable u ovoj studiji.

Indeks povećanja izračunan je za svaku varijablu prema formuli: indeks povećanja=udaljenost$_{snimak}$: udaljenost$_{mandibula}$ ($x_{povećanje} = x_{rendgen} : x_{mandibula}$).

Rezultati svih mjerenja statistički su obrađeni (aritmetička sredina x, standardna devijacija SD, standardna pogrješka SE i 95%-tni interval pouzdanosti). T-testom je uspoređena razlika između čimbenika magnifikacije izračunatnih za sve mjerene varijable i vrijednosti čimbenika magnifikacije koji navodi proizvođač aparata (26).

Rezultati

Tablica 1 prikazuje rezultate (x, SD, SE) a) za okomite udaljenosti izmjerene na čeljustima; b) za okomite udaljenosti izmjerene na ortopantomografskim snimkama; c) indeksa povećanja.

Tablica 2 prikazuje 95% interval pouzdanosti za indekse povećanja okomitih udaljenosti i t-test za aritmetičke sredine izračunanih indeksa povećanja i indeksa povećanja od 1.22 x koji navodi proizvođač ortopanotomografskog aparata.

Rasprava

Vrijednosti okomitih udaljenosti izmjerenih na ortopantomografskim snimkama čeljusti bile su veće od vrijednosti istih udaljenosti izmjerenih na čeljustima, što je očekivan rezultat obzirom na indeks povećanja koji navodi proizvođač aparata (Tablica 1).

Indeksi povećanja izračunani iz rezultata mjerenja raznih okomitih udaljenosti na čeljustima i njihovim panoramskim snimkama bili su niži od indeksa povećanja koji navodi proizvođač uporabljenog ortopantomografskog aparata (1.22), premda razlike između dvaju indeksa za većinu varijabla nisu bile statistički znatne ($p>0.05$, Tablica 2). Proizlazi da su okomite udaljenosti izmjerene na ortopantomogramima snimljenima aparatom Orthophos D 3200 bliže stvarnim dimenzijama snimljenih struktura no što to navodi proizvođač aparata. Naš nalaz je u skladu s Kjellbergom koji je izračunao indekse povećanja za tri različita panoramska rendgenska aparata te je i on našao da su izračunane vrijednosti indeksa povećanja niže od onih koje navode proizvođači upotrebljenih aparata (14).

Distorzija, karakteristična za panoramsku tehniku snimanja, pripisuje se različitim čimbenicima povećanja u okomitoj i horizontalnoj ravnini izvan središta oštro ograničenoga žarišnog sloja.

Welander (17) je pokazao matematički, a Lund (10,15,18) svojim istraživanjima, da žarišni sloj ima oblik potkove, uzak je u anteriornoj regiji i širi se prema lateralno u posteriornoj regiji čeljusti. Snimke čeljusti koje su zbog neispravnog pozicioniranja prigodom snimanja izvan žarišnoga sloja neprihvatljive su za mjerenje raznih udaljenosti. Strukture u anteriornoj regiji najpodložnije su takvoj pogrješci zbog najužeg žarišnog sloja.

Kjellberg (14) je pokazao da unutar određenih granica pozicioniranje čeljusti u radiografski aparat ne utječe na rezultate mjerenja. Pronašao je veće varijacije između triju različitih aparata nego između triju različitih položaja čeljusti (mandibule nagnute 10° anteriorno i posteriorno). Pretpostavka je da su sve nagnute pozicije čeljusti bile pokrivene žarišnim slojem aparata.

Tablica 1. Vertikalne udaljenosti mjerene na mandibulama i na njihovim ortopantomogramima (rendgen) i indeksi povećanja izračunati prema formuli: $x_{povećanje} = x_{rendgen} : x_{mandibula}$

Table 1 Vertical distances measured on the mandibles and their panoramic images (Rtg), as well as the magnification indexes calculated using the formula: $x_{magnification} = x_{ray} : x_{mandible}$; x = arithmetic mean, SD = standard deviation, S.E. = standard error.

Vertikalna udaljenost Vertical distances	Rendgen / x-ray		Mandibule / Mandible		Index		S.E.
	x	SD	x	SD	x	SD	
1. UBM-LBM (S.)	32,33	5,31	26,69	4,66	1,21	0,057	0,012
2a. R. UBM-LBM (FM)	29,60	6,22	25,11	5,84	1,19	0,096	0,012
2b. L. UBM-LBM (FM)	29,55	6,00	24,00	4,98	1,23	0,066	0,013
3a. R. UBM-LBM (8.)	25,33	4,96	20,93	3,53	1,21	0,080	0,016
3b. L. UBM-LBM (8.)	24,26	5,25	20,36	4,23	1,20	0,061	0,013
4a. R. Co-W_p	40,24	3,86	35,61	4,03	1,15	0,097	0,020
4b. L. Co-W_p	40,56	5,19	35,29	3,95	1,15	0,094	0,019
5a. R. Co-Wa	32,89	4,49	29,53	3,95	1,11	0,065	0,013
5b. L. Co-Wa	34,18	5,25	31,94	4,42	1,11	0,069	0,014
6a. R. Co-Inc	20,39	3,76	17,56	3,18	1,17	0,108	0,022
6b. L. Co-Inc	20,18	3,88	17,94	3,10	1,13	0,118	0,024

Tablica 2. *Testiranje značajnosti razlika izmedju izračunatih indeksa povećanja (indeksi su izračunati nakon mjerenja vertikalnih udaljenosti na mandibulama i njihovim ortopantomogramima prema formuli $x_{povećanje} = x_{rendgen} : x_{mandibula}$) i indeksa povećanja kojeg navodi proizvodjač (1,22x); t = t vrijednost; p = p vrijednost; C.I. = 95% interval pouzdanosti*

Table 2 *The significance of the difference between the calculated magnification indexes after the measurements of the vertical variables on the radiographs and the mandibles and the magnification index listed by the manufacturer of the device used (1.22x); t = t value; p = p value; C.I. = 95% confidence interval.*

Vertikalna udaljenost Vertical distances	t	p	C.I.
1. UBM-LBM(S.)	0,58	>0,05	1,18-1,25
2a. R. UBM-LBM(FM)	-1,7	>0,05	1,13-1,25
2b. L. UBM-LBM(FM)	1,08	>0,05	1,19-1,27
3a. R. UBM-LBM(8.)	-1,81	>0,05	1,15-1,27
3b. L. UBM-LBM(8.)	-2,03	>0,01	1,12-1,28
4a. R. Co-W_p	-3,55	<0,01	1,09-1,21
4b. L. Co-W_p	-3,56	<0,01	1,09-1,21
5a. R. Co-Wa	-8,15	<0,01	1,08-1,14
5b. L. Co-Wa	-8,00	<0,01	1,08-1,14
6a. R. Co-Inc	-2,45	<0,01	1,11-1,23
6b. L. Co-Inc	-3,83	<0,01	1,07-1,19

Unatoč Kjellbergovim (14) nalazima, odlučeno je upotrijebiti plastični držač za ispravno i ponovljivo pozicioniranje čeljusti u kefalostat rendgenskog aparata kako bi se osigurao optimalan položaj, a time i veća preciznost mjerenja. Čeljusti su pažljivo bile postavljene uz pomoć svjetlosnoga križa ortopantomografskog uređaja.

Larheim (12) je mjerio duljine zuba na panoramskim snimkama i pronašao je da 14%-17% nije mjerljivo, uglavnom u anteriornoj regiji, što se pripisuje žarišnom sloju koji je najuži upravo u toj regiji.

Nasuprot nalazima Larheima, Lund (18) je u svojemu istraživanju pronašao da žarišni sloj obuhvaća sve položaje zuba u 240 pacijenata, iako su se u anteriornoj regiji središnji dijelovi zuba bili na rubu žarišnoga sloja.

Habets (19) je mjerio okomite dimenzije metalnih kuglica, montiranih na posebno izrađeni držač, na panoramskim snimkama. Našao je 6%-tnu pogrješku u odnosu na razliku položaja od 10 mm. On smatra da je 6%-tna pogrješka prihvatljiva i u granicama normale za panoramsku tehniku snimanja. Na osnovi tih rezultata predložio je da se razlika veća od 6% između visine lijevog i desnog kondila smatra asimetrijom kondila (19). U svojoj sljedećoj

studiji Habets je pokazao da je razlika u visini kondila veća u pacijenata s kraniomandibularnim poremećajima nego u zdravih osoba (20).

Nasuprot nalazima Habetsa, Türp (21) nije pronašao nikakve korelacije između visine kondila na 25 lubanja i njihovih panoramskih snimaka i odbacio metodu preciznog mjerenja okomitih dimenzija kondila, tj. mjerenje visine kondila na panoramskim snimkama.

Prema Midgardu, Björk and Linder-Aronsonu (22) varijabilnost metode ne bi smjela prelaziti 3% ukupne varijabilnosti za pravilno mjerenje na bilo kojim panoramskim snimkama.

Larheim (23) je pokazao prihvatljivu ponovljivost dimenzija okomitih i angularnih udaljenosti na ortopantomografskim snimkama koja nije prelazila 1% od ukupne varijabilnosti, s iznimkom anteriorne regije čeljusti, gdje je pronašao najveću varijabilnost, prikazanu i najvećom standardnom devijacijom (SD). Rezultati su bili gotovo jednaki i za seriju snimaka koju je napravio s čeljusti nagnutom 15° u posteriornom smjeru, ponovno s najvećom varijabilnosti u anteriornoj regiji čeljusti. Najveću varijabilnost objasnio je najužim žarišnim slojem upravo u anteriornoj regiji (23).

Nasuprot nalazima Larheima (23), naša su mjerenja okomitih udaljenosti pokazala prihvatljivu preciznost, čak i u anteriornoj regiji (Tablica 1,2).

Razlika između naših nalaza i rezultata drugih autora može se objasniti činjenicom da su naše čeljusti, zbog pažljiva pozicioniranja, bile unutar žarišnoga sloja rendgenskog aparata. Ovakav nalaz je ipak u skladu s Lundom i njegovim istraživanjem s 240 čeljusti (18), i s Tronje (9) koji navodi da su okomite dimenzije na panoramskim snimkama pouzdane ako je pacijent ispravno pozicioniran.

Prema našim rezultatima, mjerenja okomitih udaljenosti precizna su čak i u anteriornoj regiji ako se čeljusti pažljivo i točno pozicioniraju. Nalaz je vrlo važan pri planiranju raznih tretmana u slučajevima nedostatka preciznijih tehnika snimanja.

Zaključci

Rezultati raščlambe mjerenja udaljenosti na čeljustima i na njihovim panoramskim snimkama upućuju na činjenicu da je moguće linearno mjeriti okomite udaljenosti, čak i u anteriornoj regiji čeljusti.

Čimbenici povećanja za izmjerene okomite udaljenosti manji su nego što to navodi proizvođač, te su okomite dimenzije na snimkama bliže stvarnim dimenzijama na čeljustima.

Ortopantomografija se, unutar svojih ograničenja, pokazala pouzdanom metodom prikazivanja određenih dimenzionalnih parametara.

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Assessment of the Precision of Vertical Measurements of Orthopantomographic Radiographs

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Acta Stomatol Croat
1998; 291—294

Summary

The objective of this study was to evaluate the precision of the vertical dimensional measurements on orthopantomographic images, and therefore to evaluate their dimensional reliability.

Different distances denoted by metal markers were measured on 25 dry mandibles. The same measurements were repeated on panoramic radiographs of those mandibles and the results were statistically analysed.

The calculated magnification factors for the vertical measurements were, in general, smaller than the manufacturer of the X-ray device declares, although the difference was not statistically significant for the most variables. Opposite to some opinions, our results reveal that the vertical measurements on orthopantomograms are precise enough even in the anterior region of the mandible, if the mandibles are adequately positioned and encompassed in the focal through of the machine.

Key words: *orthopantomographic radiographs, vertical distances*

ORIGINAL SCIENTIFIC PAPER
Received: October 28, 1997

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Introduction

Orthopantomography is a technique of panoramic radiography of the oral region for producing a single image of the facial structures including both maxillary and mandibular arches with temporomandibular joints and their supporting structures. Panoramic radiography utilises the principle of curved-surface laminography, in which anatomic structures in a selected plane are recorded while the intervening parts are so blurred that they are not discernible on film. Orthopantomography is recommended in the USA for screening of patients before prosthetic treatment as it may sometimes reveal roots, cysts, foreign bodies and even neoplasm in completely edentulous jaws with no clinically visible signs (1-3). It also helps in evaluation of resorptive and osteopenic processes of the jaws (4-8).

Orthopantomography is of considerable value to implantology, as it offers information about verti-

cal dimensions of the bone and locations of certain anatomical structures in the orofacial region, although other more precise techniques, much as computed tomography or magnetic resonance have higher precision, but also increase treatment costs (6).

The main objection to panoramic radiography is the possibility that the dimensions of the structures shown on radiographs do not correspond to real dimensions of the exposed structures. The dimensions on radiographs are influenced by two types of distortions and magnifications. One type of inaccuracy is due to the distance of the object between the X-ray tube and the film; if the object is positioned more posteriorly from the centre of the machine, closer to the X-ray tube, the image will be more magnified, and conversely, if the object is placed more anteriorly, closer to the X-ray film, the image of the object will be demagnified (9,10). In the vertical plane, magnification is dependent upon projection factors alone. Horizontal magnification is influenced not only by projection factors, but also by regulation of tube and film speed, which is programmed into each machine. During exposures, both the cassette with the X-ray film and the X-ray tube orbit the patient's head which has to be properly positioned, which is accomplished by a plastic cephalostat. A cephalostat is used for centering the patient's head in the focal trough of the machine in a repeatable way in order to allow comparison of radiographs of patient's status acquired before, during and after the treatment (11). If the film moves past the slot in the film shield too quickly, too much film becomes available for the object and the object is magnified. Conversely, if the film moves past the slot too slowly, not enough film is available and the object is demagnified.

In the sharply depicted plane the image is free of distortion, which means that the magnification factor is the same for both vertical and horizontal planes. Objects outside this layer will appear distorted and magnified (or demagnified) (10, 15,18).

The panoramic image is therefore affected by both magnification errors and displacement. According to some authors vertical distances are relatively reliable in the posterior region. However, in the anterior region they are un reliable, due to the very small focal trough of orthopantomographic machines in this region. If the filmed object is out of the focal trough of the machine, it will appear distorted, blurred and displaced on the radiographic image (9-24).

The focal trough, as well as the magnification factors of radiographic machines, vary between different manufacturers, as well as between different devices of the same manufacturer (14). The magnification factor varies from one manufacturer to another,due to the different projection geometry of different radiographic machines, as described by Lund and Welander (15,17,18). This results in differences in magnification and in the amount of distortion and displacement of structures which are out of the focal trough.

The aim of this study was, therefore, to evaluate the precision of vertical dimensional measurements on panoramic radiographs made on the Orthophos D 3200 (Simens, Germany) orthopantomographic device, which is used at the School of Dental Medicine, University of Zagreb.

Material and Methods

Various vertical distances (Figure 1) were measured on 25 dry mandibles acquired from the Department of Anatomy, School of Medicine, University of Zagreb. The mandibles were randomly selected, 16 were male and 9 were female. Age varied between 27 and 78 years. Dental status varied between the selected mandibles from fully dentate, to completely edentulous.

Metal markers shaped in 1 mm2 squares were used as landmarks to denote the points which determined the distances measured. The measurements were first made on the dry mandibles using a precise calliper with a precision of 0.1 mm (TMA MEBA, Germany). Following the first step, all 25 mandibles were exposed in an orthopantomographic machine "Orthophos D 3200", serial number 07786, manufactured by Siemens, Germany. The manufacturer lists the magnification factor of 1.22x for the apparatus used to make orthopantomographic images. During exposures, dry mandibles were centred in a plastic holder which was designed to fit to the machine's cephalostat, in the midline of the orthopantomograph and horizontally perpendicular to the midline, the light-cross of the orthopantomograph being a guide (Figure 2).

The same vertical distances which had been measured on the dry mandibles were then measured on the radiographs of the same mandibles (Figure 3).

A reliability test was designed to assess the reliability of three different examiners. The examiners measured 6 vertical parameters on 7 mandibles, as well as on their images twice during a one-month period. Statistical analysis for intra- and inter-examiner reliability was performed according to the method proposed by Slakter et al. (24) and Fleiss et al. (25). Intra-examiner reliability varied from 0.85 - 0.95, depending on the measured variable, while inter-examiner reliability varied from 0.90 - 0.95. The measurement error varied in the range of 0.0013 - 0.0031, which was considered satisfactory. The most consistent examiner was determined by the lowest standard error within the measurements, and consequently this escaminer measured all the other variables for this experiment.

The magnification index was calculated for each variable using the formula: magnification index = $distance_{radiograph} : distance_{dry\ mandible}$ ($x_{magnification} = x_{ray} : x_{mandible}$).

After all measurements had been completed, statistical analysis was made for acquired results. Descriptive statistics was calculated (arithmetical mean (x), standard deviation (SD), standard error (S.E.) and the 95% confidence interval). T-test was used to compare the significance of the difference between the calculated magnification factors for all the measured variables (which was calculated using the formula: $x_{magnification} = x_{ray} : x_{mandible}$) and the value of the magnification listed by the manufacturer (26).

Results

Table 1 shows the descriptive statistics (x, SD, S.E.) for all vertical variables measured a) on the mandibles; b) on the radiographs; c) for the calculated magnification index (using the formula: $x_{magnification} = x_{ray} : x_{mandible}$).

Table 2 shows the 95% confidence interval of the magnification indexes calculated for the vertical variables using the formula $x_{magnification} = x_{ray} : x_{mandible}$, as well as the t-test between the arithmetical means of the indexes which were calculated after the measurements, and the magnification index of 1.22x listed by the manufacturer of the orthopantomographic device used in this study.

Discussion

The values of vertical measurements on orthopantomographs were higher than the same measurements on the dry mandibles, as expected due to the index of magnification of the orthopanthomographic device (Table 1).

The exact values of the magnification indexes for different vertical variables, which were measured on acquired panoramic images using the Orthophos D 3200 device were calculated using the formula: $x_{magnification} = x_{ray} : x_{mandible}$ (Table 1). The magnification indexes based on the measurements in this study were mostly lower than the index listed by the manufacturer of the orthopantomographic device used (1,22x), although the difference between the manufacturer's index and the calculated magnification index was not statistically significant for most of the variables studied ($p>0.05$, Table 2).

This means that the vertical values measured on orthopantomograms made by Orthophos D 3200 are even closer to the real dimensions than the manufacturer declares. This is in agreement with Kjellberg, who calculated magnification indexes of three different panoramic machines and also found calculated values to be lower than those listed by manufacturers of these machines (14).

All characteristic distortion effects inherent to orthopantomographic technique are due to different magnification factors, which are valid for the vertical and the horizontal dimensions outside the centre of a sharply depicted layer or the focal trough.

Welander (17) has shown mathematically and Lund (10,15,18) through his experiments, that the focal trough of the orthopantomographic machine is narrow in the anterior region and flares laterally in the posterior region. This means that the measurements of the images would be unreliable for mandibles which are not properly positioned and which are out of the focal trough of the machine; the anterior region being the most susceptible because of the narrow focal trough.

Kjellberg et al. (14) showed that within certain boundaries the positioning of mandibles in the radiographic machine did not affect the results of measurements. He found larger variations between three different machines than between three different mandible positions (mandibles were tilted 10°

anteriorly and posteriorly). Assumably all the tilted positions of the mandibles were covered by a focal trough.

Nevertheless, it was decided to use a plastic holder for positioning the mandibles in the cephalostat in our experiments in order to ensure the best positioning and, therefore, accuracy of measurements. The mandibles were carefully centred using the light cross of the orthopantomographic machine.

Larheim (12) measured tooth lengths on panoramic images and found that 14%-17% of the tooth length were unmeasurable, mostly in the anterior region, which he attributed to the thinnest image layer anteriorly.

In comparion to Larheim, Lund (18) showed experimentally that the focal trough of the orthopantomograph encompassed all tooth positions of 240 patients, although anteriorly tooth centres lie on the edges of the trough.

Habets et al. (19) measured vertical images of bullets mounted in a specially designed holder and found that 6% of the difference between the left and the right images for a 10 mm change in position is inherent to the panoramic radiography, and based on these results he suggested that discrepancy of more than 6% of the condylar height should be considered asymmetry (19). In a following study Habets found that the difference in the condylar height was larger in craniomandibular dysfunction patients than in healthy individuals (20).

On the other hand T(rp (21) did not find any correlation for the rami and condylar heights between 25 dry skulls and their images and discredited the method of precise measurements of vertical dimensions for the condyles, i.e. for the condylar height on panoramic images.

According to Midgard, Björk and Linder-Aronson (22) the method variance should not exceed 3% of the total variance for appropriate measurements on any panoramic images.

Larheim (23) found acceptable reproducibility for vertical and angular variables on the orthopantomographic images not exceeding 1% of the total variance, except in the anterior region of the mandible, where he found the greatest variation, as reflected by the greatest SD. When he tilted the skull 15° posteriorly during one series of exposures the results were almost the same, again with the greatest variability in the anterior region.

Our measurements of vertical distances show adequate precision, even in the anterior region (Tables 1,2) although Larheim (23) found the greatest variations in this region which he appended to the thinnest focal trough anteriorly.

This difference between our findings and those of other authors could be due to the fact that our mandibles were encompassed in the focal trough of the machine, because of careful positioning, which is in agreement with Lund and his experiments with 240 different jaws (18), as well as with Tornje (9) who stated that vertical dimensions are reliable if patients are properly positioned.

According to our results, vertical dimensions are precise, even in the anterior region when the mandibles are carefully positioned. All this is of great importance when planning different treatments, for which more precise techniques are not available.

Conclusions

Based on the results of analysis of measurements on dry mandibles and their panoramic images if can be concluded that it is possible to use orthopantomography for linear measurements of vertical variables, even in the anterior region.

The magnification indexes for the vertical variables measured are even smaller than declared by the manufacturer, which means that the vertical distances on the images are closer to the real dimensions of structures of the dry mandibles.

Within certain limitations the orthopantomographic radiograph has proved to be a very reliable method the showing certain dimensional parameters.