RESEARCH PAPER

ROLE OF CBCT IN ENHANCING IMPLANT PLANNING PRECISION AND REDUCING IMPLANT-RELATED COMPLICATIONS: A NARRATIVE REVIEW

Narendra Prakash Rai[1,2*], Ganiga Channaiah Shivakumar[3], Ismat Fakhra[4], Sai Prannoy Nagella[5], Kiran Prabhakar Singbal[6], Akshay Agarwal[7]

[1]PhD student, Department of Oral Medicine & Radiology, People's College of Dental Sciences, People's University, Bhopal, Madhya Pradesh, India;

[2]Department of Oral Medicine & Maxillofacial Radiology, MAHSA University, Selangor 42610, Malaysia

[3]Department of Oral Medicine & Radiology, People's College of Dental Sciences and Research Centre, People's University, Bhopal, India

[4]Department of Oral Medicine & Maxillofacial Radiology, MAHSA University, Selangor 42610, Malaysia

[5]Department of Pediatric Dentistry, MAHSA University, Selangor 42610, Malaysia

[6]Department of Conservative Dentistry, MAHSA University, Selangor 42610, Malaysia

[7]Department of Oral Medicine & Radiology, People's Dental Academy, People's University, Bhopal, India

Corresponding author: Narendra Prakash Rai, narendraprakash@mahsa.edu.my

ABSTRACT

Cone Beam Computed Tomography (CBCT) is widely used in implant dentistry because it provides three-dimensional images of the jaws. It helps clinicians assess bone availability and nearby anatomical structures more accurately than conventional two-dimensional radiographs. To review the role of CBCT in improving implant planning precision and in reducing implant-related complications. A narrative review was carried out focusing on CBCT applications in implant diagnosis, treatment planning, guided surgery, and prevention of common complications such as nerve injury, sinus perforation, and implant malposition. CBCT improves implant planning by allowing accurate measurement of ridge height and width, evaluation of bone morphology, and identification of vital structures such as the mandibular canal, mental foramen, maxillary sinus, and nasopalatine canal. It supports digital workflows and guided implant placement, leading to better surgical accuracy. CBCT also helps in identifying anatomical variations and planning augmentation procedures when required. CBCT plays an important role in enhancing implant planning precision and reducing complications when used with proper justification and optimized radiation protocols.

Keywords: Cone Beam Computed Tomography, Dental implants, Implant planning, Guided implant surgery, Implant complications, Radiographic assessment.

1. INTRODUCTION

Dental implants are now widely used to replace missing teeth because they offer good function, comfort, and long-term success. However, implant treatment is not only about placing a fixture in bone. A successful implant must be placed in the correct position, at the correct depth, and with the correct angulation to support a stable and cleanable prosthesis. Even a well-integrated implant can fail functionally if it is placed too buccally, too lingually, too close to a vital structure, or in a position that makes prosthetic restoration difficult.

Preoperative imaging is therefore essential in implant dentistry. Traditional two-dimensional (2D) radiographs such as periapical and panoramic images remain useful, but they cannot provide complete information about ridge width, bone contour, and the three-dimensional relationship of the implant site to vital structures. Cone Beam Computed Tomography (CBCT) has become an important imaging tool because it provides three-dimensional visualization of the jaws, allowing clinicians to plan implants more accurately and safely. CBCT is especially helpful in cases with limited bone, proximity to nerves or sinus, multiple implant sites, or the need for guided implant surgery. [1]

This review discusses the role of CBCT in improving implant planning precision and reducing implant-related complications. It also highlights the practical clinical value of CBCT and its limitations, so that it can be used responsibly and effectively.

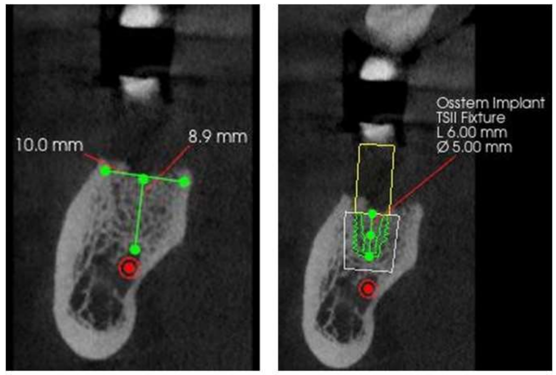
2. WHY CBCT IMPROVES IMPLANT PLANNING PRECISION

The main advantage of CBCT in implant dentistry is that it provides three-dimensional information. With CBCT, clinicians can evaluate the implant site in axial, sagittal, coronal, and cross-sectional views. This helps in selecting implant dimensions and positioning implants in a prosthetically guided manner. [2]

2.1. Accurate assessment of bone height and width

Bone height and width are the foundation of implant planning. CBCT allows precise measurement of vertical bone height from the crest to the mandibular canal in the posterior mandible, and from the crest to the sinus floor or nasal floor in the maxilla. Unlike panoramic radiographs, CBCT measurements are not affected by magnification errors in the same way. [3]

Ridge width is often underestimated in 2D radiographs because the buccolingual dimension cannot be visualized. CBCT provides cross-sectional images that clearly show ridge width and the thickness of cortical plates. This is critical when selecting implant diameter and deciding whether ridge augmentation or ridge splitting is needed. [4] (Figure 1A)



A B

Figure A: Implant site assessment measuring available width and height. Right inferior alveolar canal marked red also note the presence of an undercut or right submandibular gland fossa.(arrow) B: Virtual implant placed in same region allowing three-dimensional evaluation of fixture within bone.

2.2. Evaluation of ridge contour and undercuts

Ridge morphology is not always straight or uniform. Concavities and undercuts are common, especially in the posterior mandible where a lingual undercut may be present. (Figure 1A) If such undercuts are not identified, there is a risk of cortical perforation and severe complications. CBCT helps visualize ridge contour, making implant placement safer. [5]

2.3. Planning implant angulation and prosthetic position

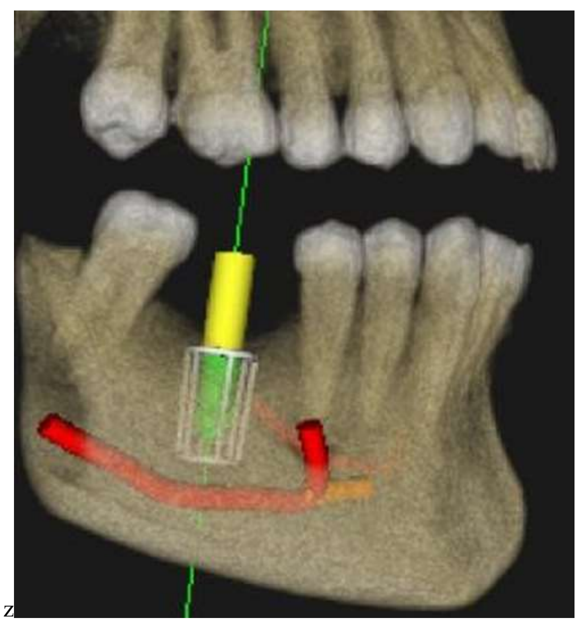
Modern implant dentistry aims for prosthetically driven implant placement. This means implants should be placed in a position that supports the final crown or prosthesis. CBCT datasets can be combined with intraoral scans or scanned casts to plan implant positions virtually. (Figure 1B) This improves accuracy and reduces guesswork, particularly in aesthetic zone cases. [2]

3. CBCT ASSESSMENT OF ANATOMICAL STRUCTURES AND VARIATIONS

Anatomical variations are common in the jaws, and many of them cannot be reliably seen on 2D imaging. CBCT helps in identifying these structures clearly, which reduces the risk of injury during surgery.

3.1. Mandibular canal and inferior alveolar nerve

The inferior alveolar canal carries the inferior alveolar nerve and vessels. Implant placement too close to the canal can lead to nerve injury, which may cause numbness, tingling, or pain. CBCT allows accurate visualization of the canal position and course. It is also useful for detecting variations such as bifid canals, which may increase the risk of complications if not recognized. [6], [7] (Figure 2)



z

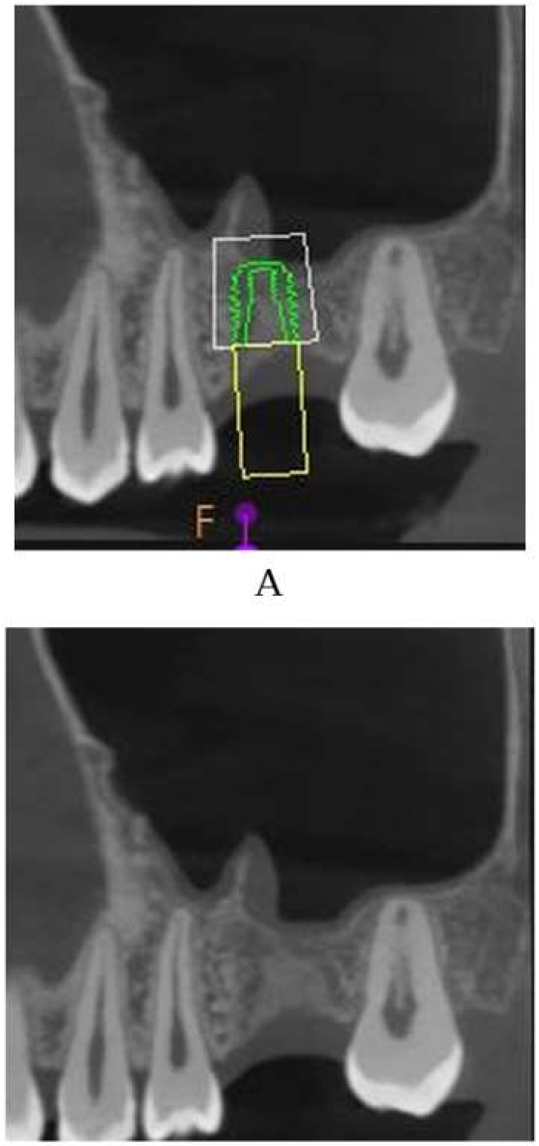
Figure 3D rendered image of mandible showing virtual implant placed in 46 region. Right inferior alveolar canal marked red showing anterior loop and anterior branch marked yellow.

3.2. Mental foramen and anterior loop

The mental foramen is usually located near the premolar region, but its position can vary. In some patients, the anterior loop of the mental nerve extends beyond the foramen. This loop cannot be reliably evaluated on panoramic radiographs, and implants placed without considering this anatomy can cause nerve injury. CBCT helps identify the mental foramen and assess the possible presence and length of the anterior loop. [8] (Figure 2)

3.3. Maxillary sinus and sinus septa

The posterior maxilla is often a challenging region due to sinus pneumatization and limited bone height. CBCT helps evaluate residual bone height, sinus floor anatomy, and sinus septa. (Figure 3) Sinus septa are important because they can increase the risk of Schneiderian membrane perforation during sinus lift procedures. Identifying septa on CBCT supports safer and more predictable sinus augmentation planning. [9]



A

B

Figure A: Oblique sagittal image of left posterior maxilla showing virtual implant placed in 26 region nearly in bi-cortical plate engagement. B: In same section anatomic landmarks like maxillary sinus septa (i) and floor of maxillary sinus (ii) are annotated.

3.4. Nasopalatine canal

The nasopalatine canal is a key structure in anterior maxillary implant planning. Its size and position can vary, and in some patients, it occupies a large portion of the anterior maxillary bone. CBCT allows assessment of canal morphology and helps avoid placing implants too close to the canal, which can cause bleeding, pain, or implant failure.[10] (Figure 4)

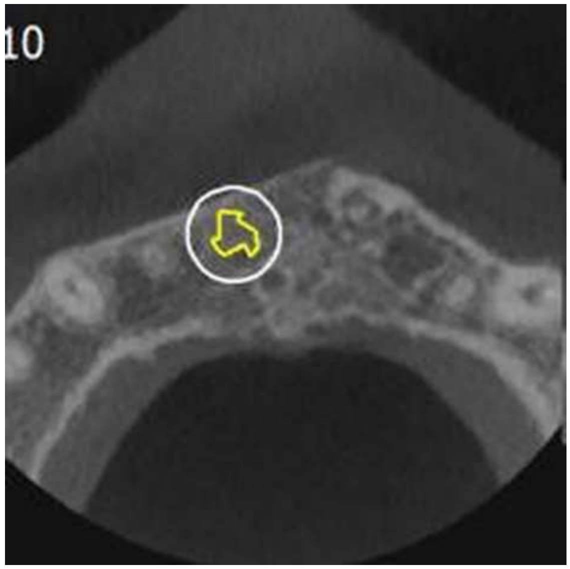


Figure A: Axial image of maxilla showing virtual implant assessment in 11 region. Close proximity between implant and incisive canal (arrow) can be assessed and safer positioning of implant be planned.

4. CBCT IN GUIDED IMPLANT SURGERY AND DIGITAL WORKFLOWS

CBCT is central to computer-guided implant surgery. In guided workflows, the clinician plans implant placement virtually using CBCT data and surface scans. (Figure 5) A surgical guide is then fabricated to transfer the planned position to the patient.

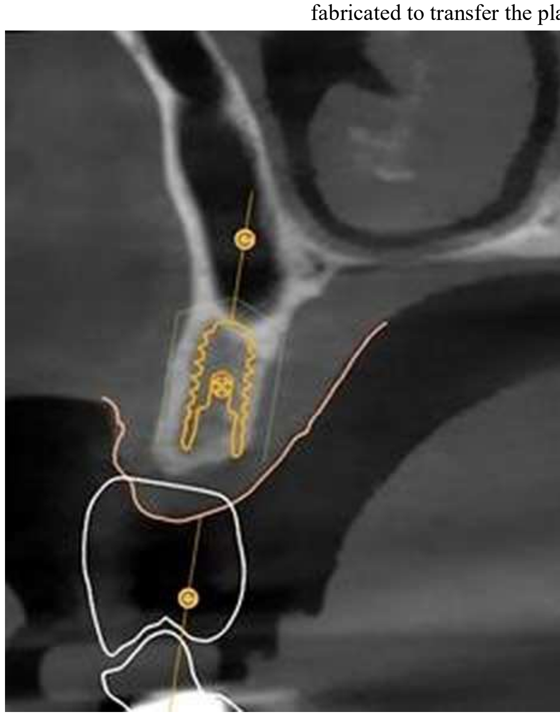


Figure Cross section of maxilla in 15 region showing surgical guide planning after merging CBCT data with stereolithogrpahy data for guided implant placement (annotations: prosthetically driven implant positioning; soft tissue data merged with CBCT; virtual prosthesis planned).

Guided surgery can improve accuracy by reducing deviations in implant angulation and position, especially in complex cases. It is particularly helpful when implants are placed near vital structures or when the prosthetic plan demands high precision. A randomized controlled trial comparing static computer-assisted implant surgery and freehand surgery reported smaller deviations in planned versus placed implant positions in the guided group. [11]

However, guided surgery is not error-free. Errors can occur due to poor scan quality, incorrect merging of datasets, inaccurate guide fit, or movement during surgery. Therefore, CBCT planning must be combined with proper clinical judgment and careful verification.

5. ROLE OF CBCT IN REDUCING IMPLANT-RELATED COMPLICATIONS

Many implant complications occur because of poor assessment of anatomy and inadequate planning. CBCT helps reduce complications mainly by improving precision and risk assessment. [12]

Prevention of nerve injury - Nerve injury is one of the most serious implant complications. CBCT helps avoid nerve trauma by showing the exact canal location and enabling the clinician to select implant length and position safely. This is especially important in the posterior mandible. [6]

Prevention of sinus-related complications - Sinus perforation can occur when implants are placed too close to the sinus floor (Figure 6) or when sinus lift is performed without recognizing septa. CBCT helps plan sinus lift procedures and supports the selection of alternative strategies such as short implants when needed. [9]

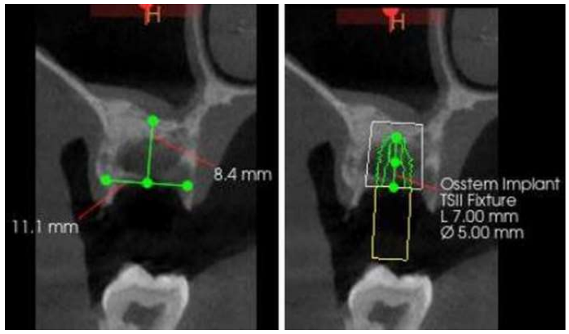


Figure Oblique coronal images of maxilla showing virtual implant planning for a case of immediate implant placement in subantral region.

Reduction of cortical perforation and malposition - CBCT helps prevent buccal or lingual cortical perforation by showing ridge width and undercuts. It also reduces implant malposition by enabling virtual planning and guided placement. This improves prosthetic outcomes and makes oral hygiene easier, which can improve long-term success. [2]

Better planning for augmentation procedures - Bone grafting and sinus augmentation are common in implant dentistry. CBCT helps determine whether augmentation is needed and allows the clinician to plan the extent of grafting. This improves predictability and reduces unnecessary surgical trauma. [1]

6. LIMITATIONS AND SAFETY CONCERNS OF CBCT

Although CBCT has major advantages, it also has limitations that must be considered.

6.1. Radiation exposure

CBCT exposes patients to ionizing radiation. The dose varies depending on the machine, field of view, voxel size, and scan settings. CBCT should be used only when it is clinically justified. Evidence-based guidelines recommend using the smallest field of view necessary and applying optimized low-dose protocols where appropriate. [12–14]

6.2. Artifacts and reduced image quality

Metal restorations, implants, and orthodontic appliances can produce beam hardening and scatter artifacts. These artifacts may reduce diagnostic accuracy, especially when evaluating peri-implant bone defects or adjacent structures. Understanding artifacts is essential for correct interpretation. [15] (Figure 7)

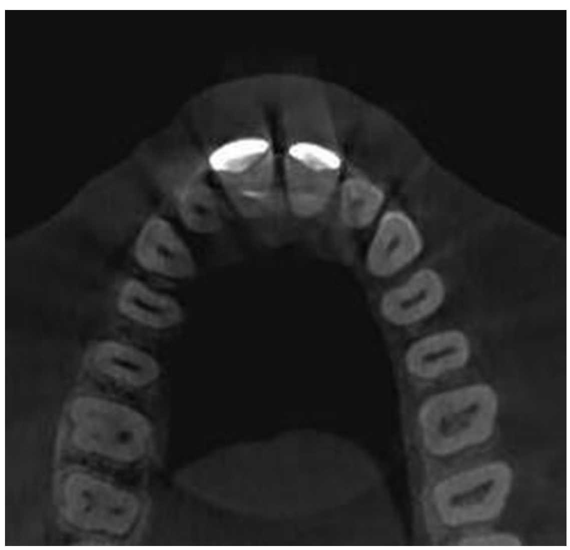


Figure Axial image of maxilla showing various CBCT artifacts associated with metallic restoration in teeth 11 21.

6.3. Limitations in soft tissue evaluation

CBCT is primarily designed for hard tissue imaging. It cannot accurately represent soft tissue lesions compared to medical CT or MRI. For implant planning, this limitation is usually acceptable, but clinicians should be aware of it. [16–20]

Table 1. Clinical impact of CBCT in implant planning and complication prevention

CBCT finding / Assessment	What CBCT helps identify	Clinical benefit	Complications reduced
Ridge height and width	True bone dimensions	Correct implant length and diameter	Cortical perforation, implant failure
Ridge undercuts	Lingual/buccal concavity	Safer angulation	Perforation, bleeding
Mandibular canal	Exact canal course	Safe implant placement	Nerve injury
Mental foramen & anterior loop	Variation in location/loop	Risk reduction in premolar implants	Paraesthesia
Maxillary sinus & septa	Sinus floor, septa	Safer sinus lift planning	Sinus perforation
Nasopalatine canal	Canal morphology	Safer anterior implant placement	Bleeding, pain
Digital planning	Virtual implant placement	Better prosthetic outcome	Malposition, prosthetic issues

7. CLINICAL SUMMARY AND CONCLUSION

CBCT has become a valuable tool in implant dentistry because it improves diagnosis and treatment planning. It enhances implant planning precision by allowing accurate measurement of bone dimensions, evaluation of ridge contour, and identification of vital anatomical structures. CBCT also helps detect anatomical variations such as bifid mandibular canals, sinus septa, and nasopalatine canal variations, which may influence implant placement decisions.

CBCT contributes to complication prevention by reducing the risk of nerve injury, sinus perforation, and implant malposition. It also supports guided implant surgery and digital planning workflows, improving predictability in complex cases. However, CBCT must be used responsibly, with attention to radiation safety and awareness of artifacts. When properly justified and interpreted, CBCT plays an important role in improving implant outcomes and reducing implant-related complications.

REFERENCE

Jacobs R. Dental cone beam computed tomography in implant dentistry: recommendations for clinical use. BMC Oral Health. 2018;18:88.

Guerrero ME, Jacobs R, Loubele M, Schutyser F, Suetens P, van Steenberghe D. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. Clin Oral Investig. 2006;10(1):1–7.

Tadinada A, Fung K, Thacker S, Mahdian M. Role of cone beam computed tomography in implant dentistry: an update. J Calif Dent Assoc. 2015;43(12):711–718.

Bornstein MM, Scarfe WC, Vaughn VM, Jacobs R. Cone beam computed tomography in implant dentistry: a systematic review focusing on guidelines, indications, and radiation dose risks. Int J Oral Maxillofac Implants. 2014;29 Suppl:55–77.

Greenstein G, Cavallaro J, Tarnow D. Practical application of anatomy for the dental implant surgeon. J Periodontol. 2008;79(10):1833–1846.

de Oliveira-Santos C, Souza PHC, de Azambuja Berti-Couto S, Stinkens L, Moyaert K, Rubira-Bullen IRF, et al. Assessment of variations of the mandibular canal through cone beam computed tomography. Clin Oral Investig. 2012;16(2):387–393.

Naitoh M, Hiraiwa Y, Aimiya H, Ariji E. Observation of bifid mandibular canal using cone-beam computerized tomography. Int J Oral Maxillofac Implants. 2009;24(1):155–159.

von Arx T, Friedli M, Sendi P, Lozanoff S, Bornstein MM. Location and dimensions of the mental foramen: a radiographic analysis by using cone-beam computed tomography. J Endod. 2013;39(12):1522–1528.

Pommer B, Ulm C, Lorenzoni M, Palmer R, Watzek G, Zechner W. Prevalence, location and morphology of maxillary sinus septa: systematic review and meta-analysis. J Clin Periodontol. 2012;39(8):769–773.

Bornstein MM, Balsiger R, Sendi P, von Arx T. Morphology of the nasopalatine canal and the surrounding bone using cone-beam computed tomography: an evaluation of anatomical variations in implant patients. Clin Oral Implants Res. 2011;22(6):639–645.

Smitkarn P, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of static computer-assisted implant surgery compared with freehand implant surgery in single edentulous space: a randomized controlled trial. Clin Oral Implants Res. 2019;30(6):505–514.

Almog DM, LaMar J, LaMar FR, LaMar F. Cone beam computerized tomography-based dental imaging for implant planning and surgical guidance, Part 1: single implant in the mandibular molar region. J Oral Implantol. 2006;32(2):77–81.

Dula K, Bornstein MM, Buser D, Dagassan-Berndt D, Ettlin DA, Filippi A, et al. SEDENTEXCT guidelines for CBCT in dental and maxillofacial radiology. Dentomaxillofac Radiol. 2012;41(7):507–517.

Razavi T, Palmer RM, Davies J, Wilson R, Palmer PJ. Accuracy of measuring the cortical bone thickness adjacent to dental implants using cone beam computed tomography. Clin Oral Implants Res. 2010. July;21(7):718–25.

Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003. October;96(4):508–13.

Schulze R, Heil U, Gross D, Bruellmann DD, Dranischnikow E, Schwanecke U, et al. Artefacts in CBCT: a review. Dentomaxillofac Radiol. 2011;40(5):265–273.

Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008;52(4):707–730.

Kuribayashi A, Watanabe H, Imaizumi A, Tantanapornkul W, Katakami K, Kurabayashi T. Bifid mandibular canals: cone beam computed tomography evaluation. Dentomaxillofac Radiol. 2010;39(4):235–239.

Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. J Istanb Univ Fac Dent. 2017 Dec 2;51(3 Suppl 1):S102-S121.

Tischler M. In-office cone beam computerized tomography: technology review and clinical examples. Dent Today. 2008. June;27(6):102.