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Clinical Report

CLINICAL VALIDITY OF THE INTERACTIVE AND LOW-DOSE THREE-DIMENSIONAL DENTO-ALVEOLAR IMAGING SYSTEM, TUNED-APERTURE COMPUTED TOMOGRAPHY

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Abstract

Based on technical studies and clinical examinations, the clinical value of a new three-dimensional dento-alveolar imaging system, Tuned-Aperture Computed Tomography (TACT®), were examined for dental applications. TACT is a conventional and low-cost tomosynthesis method in which the benefit of digitization is fully utilized. The clinical information yield of TACT has been examined for the detection of dental caries, periodontal defects and radicular fractures, and also for the pre-surgical assessment of implant placement and impacted teeth. In this article, we introduce basic TACT technology, review the literature pertaining to in vitro and in vivo studies, and describe the outline of our study of TACT to determine its clinical value in the assessment of impacted maxillary teeth.

Key words: Tuned-aperture computed tomography—Intraoral radiography—Tomosynthesis—Impactions—Flat panel detector

INTRODUCTION

Because newly developed, small, flat-panel detectors with high sensitivity to X-ray and comparatively low-noise characteristics have been utilized for intraoral radiography, tomosynthesis has become practical for dento-alveolar imaging. TACT®, Tuned-Aperture Computed Tomography, is an interactive, low-dose, low-cost, three-dimensional (3-D)
tomosynthesis system in which the benefit of
digitization is fully utilized\(^{29,30}\). A 3-D image-
forming algorithm, TACT, which can be
implemented with virtually any projection-
based imaging system capable of digitized
output, produces true 3D data from any num-
ber of arbitrarily oriented two-dimensional
projections.

In the middle of the 1990’s, the principal
theory of TACT was described by Webber
(Wake Forest University, School of Medicine,
Winston-Salem, North Carolina, USA)\(^{29,30}\).
The outline of TACT theory will be described
in this article. We also introduce basic TACT
technology, review the literature pertaining
to TACT, and outline our study of TACT to
determine its clinical value in assessment of
impacted teeth in the maxillary incisor region.

**THEORY**

TACT is a technique for 3-D diagnostic
imaging which can be carried out with low
dosage. Application of the algorithm is not
only applied to dento-alveolar imaging but
also to digital mammography\(^{24,32}\) and scinti-
mammography\(^8\). TACT technology is now
licensed to Instrumentarium Imaging (Tuusula,
Finland).

As shown in Fig. 1, intraoral radiographs
are made in different directions while a small
flat-panel detector is held in the oral cavity.
The images are obtained by “component pro-
jections” and are called TACT basis images.
The projections are made at with different
angles and repeated four to six times. The
TACT workbench (Verify Software, Winston-
Salem, North Carolina, USA) stacks the images,
inputs locations of fiduciary markers for each
basis image, and reconstructs a series of arbi-
trary multi-planar cross-sectional images. Such
reconstruction of a series of arbitrary section
images can produce pseudo-holograms. Itera-
tive restoration to remove blurring is also
available after three-dimensional models are
built. TACT is based on tomosynthesis and
 aperture theory\(^{29,30}\).

**LITERATURE REVIEW**

Dental Caries: Abreu et al. studied TACT in
dental caries detection\(^{1-4,25}\). Effects in caries
detectability were examined under various
acquisition parameters of basis images, pres-
ence or absence of iterative restorations, and
the choice of reconstruction algorithms. Their
1999 report\(^4\) indicated that TACT images did
not improve caries detection over that using
film or digital radiography, but they neverthe-
less used their research data to calculate the
optimum parameter settings of TACT for
caries detection. In 1997, Tyndall et al. had
previously explained that the relatively poorer
performance yielded by the digital control
images suggested that increased information
capacity associated with more modern CCD
detectors might improve the diagnostic per-
formance of TACT displays\(^{25}\). In contrast,
in 1998, Nair et al. showed that TACT images
held the promise of a more effective imaging
modality than film or individual digital images
for the detection of recurrent caries\(^{26}\).

Periodontal status: Chai-U-Dom et al. exam-
ined TACT for the *in vitro* detection of peri-
crestal and periodontal bone gain\(^6,7\). They
indicated that TACT associated with digital
subtraction radiography provided greater sen-
sitivity while the technical flexibility remained.
Nair et al. concluded that TACT was a more
effective and accurate imaging modality for
non-destructive quantification of osseous changes within healing bony defects\textsuperscript{(20,21)}. Ramesh \textit{et al.} conducted research on the detection of simulated periodontal defects and concluded that TACT images processed by weak iterative restoration provided the best performance\textsuperscript{(23)}. Nair \textit{et al.} also reported that TACT performed significantly better than planar images for the detectability of trauma-induced radicular fractures, vertical root fractures, and mandibular fractures in their \textit{in vitro} studies\textsuperscript{(18,19)}.

Implants: The clinical value of TACT for presurgical implant imaging was examined by Liang \textit{et al.}, who found that TACT may provide an alternative to conventional tomography for dental implant imaging\textsuperscript{(14,15)}. Morant \textit{et al.} reported that TACT was significantly more accurate than standard application of the buccal object rule for assessing the relationship between tooth roots and the inferior alveolar canal\textsuperscript{(17)}.

Since 1998, we have also reported several basic studies of TACT, including collaborative work with the inventor, Webber\textsuperscript{(9,34,35,39)}. We analyzed the accuracy of depth discrimination affected by projection geometry and the number of projections in our studies.

**CLINICAL APPLICATION:**

**IMPACTED TOOTH ASSESSMENT**

As a further step in our research, we performed a clinical study on the diagnostic information yield of TACT in the assessment of impacted teeth in comparison with conventional dentoalveolar imaging\textsuperscript{(11,36–38)}.

1. \textbf{Procedures for TACT}

A small flat-panel detector system, CompuRay\textsuperscript{®} (Yoshida Dental Trading, Tokyo, Japan) was employed as the intraoral X-ray detector. This is known as the RVG-ui sensor (Trophy Radiology, Marne-la-Vallée, France) in the rest of the world. Basis images are collected and stacked. The input of each projection position using the fiduciary marker on individual images is carried out, and a reconstruction algorithm is applied. Stability for maintaining continuity in geometric projection conditions is required for the generation of 3D images, such as CT, at the time of collection of image data. However, TACT enables an arbitrary setup of projection directions, because the position of the fiducial marker is always available. The operation for cross-sectional reconstruction can be carried out interactively. The
reconstruction of a series of dento-alveolar depths is easily realized in compliance with diagnostic tasks. A selected screen of the TACT Workbench is shown in Fig. 2.

In accordance with the results of previous in vitro studies\textsuperscript{34,35,39}, in which influences of the number of and the angle of component projections to the accuracy of depth discrimination were reported, five or six component projections with conical beam-projection array per reconstruction, and approximately 20 degrees of angular disparity were chosen. The fiduciary marker we used was a 1.5 mm diameter X-Spot\textsuperscript{®} lead pellet (Beekley, Bristol, Connecticut, USA). The X-Spot was packed under an adhesive tab used to help keep track of sensor positioning. The coordinates on each image were inputted into a reconstruction algorithm as reference points.

2. Case presentation

The case presented in Fig. 3 is an examination of an impacted tooth in the anterior region of the maxilla. Impacted teeth do often occur in the anterior maxilla, and their occurrence is significant in early mixed dentition in view of both esthetics and occlusion. TACT was applied for the radiological diagnosis of the status of the impacted tooth and its positional relationship with surrounding tissue and adjacent teeth. Various radiographic techniques have been reported for recognizing the position of an impacted (clinically “missing”) tooth. Radiological diagnosis is necessary for clarifying the morphologic status of impacted teeth and their relationship with the surrounding tissues. Traditionally, the intra-oral radiograph with an orthogonal projection has been used with an additional mesial, distal, inferior, or superior projection. With such parallax methods, the position of the impacted tooth in relation to its surrounding tissues can be estimated, but with limited accuracy. Given these limitations, it is possible that TACT might be used to study the morphology of impacted teeth in the incisor and canine regions of the maxilla.

As indicated in Fig. 3, TACT revealed the morphological relationship between the impacted tooth and surrounding tissues,
including the regular teeth. Both the impacted tooth and the roots of adjacent teeth are sharply depicted in different sectional images with different depths in the buccolingual direction. All the TACT images were processed by the installed iterative restoration to remove blurring.

3. Statistical analysis

Previously, TACT has been compared variously with conventional intraoral, occlusal, rotational panoramic, and lateral cephalographic examinations of impacted maxillary incisors. Since the results are already published\(^{37,38}\), only a brief outline is given in this report. TACT was used to examine 20 dental impactions in 20 patients. Sixteen dentists trained to read TACT image reconstructions independently carried out the following tasks: (1) clarity of depiction of the impacted tooth and its surrounding tissues, (2) estimation of confidence in clinical assessments of the patient by using the provided images, and (3) estimation of the diagnostic potential of TACT for altering the selection of treatment options. Table 1 lists the seven objective criteria for the evaluation of image clarity and an additional two subjective assessments. The continuous confidence-rating method was employed for each evaluation (Fig. 4). Mean scores compare the observers’ evaluations for structural clarity, observers’ perceptions of the potential for TACT altering patient’s treatment options, and observers’ confidence in the reading of the position of the impacted tooth. Collected data were analyzed by means of \(t\)-tests performed with StatView (Abacus Concepts, Berkeley, Calif. USA). The \(a\) \(p\)riori was set at 0.05.

Mean scores and 95% confidence intervals

![Continuous confidence rating scale](Fig. 4.png)
The first such study was reported by the inventor, Webber and Messura. His group concluded that TACT displays were more diagnostically informative and had more impact on potential treatment options than did conventional radiographs. Some in vitro studies, which were mentioned in the short review section, indicated that TACT is sensitive or compatible in comparison with conventional dento-alveolar radiography examinations to detect dental caries, periodontal bone dynamics and other diagnostic tasks.

Since the image detector of intraoral radiography is changed from film to flat-panel detector (CCD or C-MOS sensor), TACT becomes convenient as such digital procedures are utilized. The digital revolution of the recent decade has put interactive and low-dose three-dimensional imaging systems, such as TACT tomosynthesis, into practice. In a recent study, TACT projection data was utilized for rendering 3-D models for quantitative analysis of image subtraction methods. In addition to research for the optimization of TACT procedures and algorithms, Webber recently used a hand-held X-ray system, in an attempt to increase the user-

DISCUSSION

Our research on TACT imaging, which was recently published, is the second in vivo study. The first such study was reported by the inventor, Webber and Messura. His group concluded that TACT displays were more diagnostically informative and had more impact on potential treatment options than did conventional radiographs. Some in vitro studies, which were mentioned in the short review section, indicated that TACT is sensitive or compatible in comparison with conventional dento-alveolar radiography examinations to detect dental caries, periodontal bone dynamics and other diagnostic tasks.

Since the image detector of intraoral radiography is changed from film to flat-panel detector (CCD or C-MOS sensor), TACT becomes convenient as such digital procedures are utilized. The digital revolution of the recent decade has put interactive and low-dose three-dimensional imaging systems, such as TACT tomosynthesis, into practice. In a recent study, TACT projection data was utilized for rendering 3-D models for quantitative analysis of image subtraction methods. In addition to research for the optimization of TACT procedures and algorithms, Webber recently used a hand-held X-ray system, in an attempt to increase the user-
friendliness of TACT for the use in dental offices.

For the last decade, researchers have carried out 3-D dento-alveolar imaging by using single- or multi-row spiral CT and cone-beam CT images. In comparison with such CT systems, TACT is characterized by a low-cost and low-dose 3-D image-forming system, which has been demanded by the medical and dental community in recent years. In this article, we introduced the basic TACT technology, reviewed the literature, and described the outline of our study. Our in vivo study shows the validity of using interactive 3-D TACT to improve the benefits of a digital flat-panel detector employed for intraoral radiography in the assessment of dental impactions.

REFERENCES


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