RESEARCH ARTICLE

Image and surgery-related costs comparing cone beam CT and panoramic imaging before removal of impacted mandibular third molars

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Objectives: The aim of this prospective clinical study was to derive the absolute and relative costs of cone beam CT (CBCT) and panoramic imaging before removal of an impacted mandibular third molar. Furthermore, the study aimed to analyse the influence of different cost-setting scenarios on the outcome of the absolute and relative costs and the incremental costs related to surgery.

Methods: A randomized clinical trial compared complications following surgical removal of a mandibular third molar, where the pre-operative diagnostic method had been panoramic imaging or CBCT. The resources implied in the two methods were measured with health economic tools. The primary outcome was total costs defined as the sum of absolute imaging costs and incremental surgery-related costs. The basic variables were capital costs, operational costs, radiological costs, radiographic costs, overheads and patient resource utilization. Differences in resources used for surgical and post-surgical management were calculated for each patient.

Results: Converted to monetary units, the total costs for panoramic imaging equalized €49.29 and for CBCT examination €184.44. Modifying effects on this outcome such as differences in surgery time, treatment time for complications, pre- and post-surgical medication, sickness absence, specialist treatment and hospitalization were not statistically significant between the two diagnostic method groups.

Conclusions: Costs for a CBCT examination were approximately four times the costs for panoramic imaging when used prior to removal of a mandibular third molar. The use of CBCT did not change the resources used for surgery, post-surgical treatment and patient complication management.

Dentomaxillofacial Radiology (2014) **43**, 20140001. doi: [10.1259/dmfr.20140001](https://doi.org/10.1259/dmfr.20140001)

Cite this article as: Petersen LB, Olsen KR, Christensen J, Wenzel A. Image and surgery-related costs comparing cone beam CT and panoramic imaging before removal of impacted mandibular third molars. *Dentomaxillofac Radiol* 2014; **43**: 20140001.

Keywords: CBCT scanning; panoramic imaging; third molar surgery; cost analysis

Introduction

The use and availability of three-dimensional (3D) radiographic imaging in dentistry has been growing in the past decade owing to cone beam CT (CBCT) technology.

Compared with medical CT, scanning costs for CBCT are lower, and some CBCT systems provide a lower patient radiation dose than does medical CT.¹ Although many studies have been performed during the past 10 years concerning technical modalities and diagnostic performance of CBCT, few have highlighted patient outcome effects. Fryback and Thornbury² suggested

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This study is supported by the University of Aarhus, Aarhus, Denmark.

Received 2 January 2014; revised 8 June 2014; accepted 11 June 2014

a six-tiered hierarchical model for assessing different efficacy levels of a new diagnostic imaging technology, according to which level 6 constitutes studies that describe the societal implications of a new technology. Health economics is an integrated part of this complex and deals mainly with costs, cost-effectiveness, cost-utility and cost-benefit analysis.³ Very few studies in dentistry have evaluated societal and economic aspects of a new technology,⁴ and in dental radiology only four studies concerning this subject were identified in a recent review.^{4–7}

One of the most common surgical procedures in dentistry is removal of mandibular third molars.⁸ The anatomy of the area facilitates the risk for temporary or permanent neurosensory disturbances. According to the SedentexCT guidelines from 2011,¹ only weak evidence (grade level C) exists for the effect of performing a CBCT scan before mandibular third molar removal when a conventional radiograph indicates an intimate relation between the root complex and the mandibular canal.¹ It is unclear how often CBCT is applied worldwide for treatment planning before removal of mandibular third molars. A recent study based on a questionnaire distributed to general dental practitioners with CBCT equipment in Norway estimated the total amount of CBCT scans performed for dental diagnostics and treatment, but the limitations of the study impedes generalization in specific clinical settings and between countries.⁹ As radiographic imaging potentially can induce biological damage, as low as reasonably achievable should be the guiding principle when planning and performing imaging procedures with ionizing radiation.

One previous study has estimated patient risk using CBCT compared with panoramic imaging and highlighted the need for justification.¹⁰ The need for studies to provide evidence-based indications is thus obvious. As part of the evidence, the decision process of choosing a diagnostic method should depend on the relation between achieved benefits and the costs for a given technology. However, only one study seems to have assessed the resources used when implementing CBCT in dental procedures describing differences between some countries with respect to cost structures.⁷

The aim of this prospective clinical study was to derive the absolute and relative costs of CBCT and panoramic imaging before surgical removal of an impacted mandibular third molar. Furthermore, the study aimed to analyse the influence of different cost setting scenarios on the outcome of the absolute and relative costs and the incremental costs related to surgery.

Methods and materials

Patients

This study nested in an ongoing randomized controlled trial measuring neurosensory disturbances following surgical removal of the mandibular third molar as the primary outcome. The study was designed and developed

in co-operation between a private practice, Colosseumklinikken in Copenhagen, Denmark, and the Aarhus University, Aarhus, Denmark. All patients were referred from general dental private practices for removal of a mandibular third molar. The Ethical Committee of the Capitol Region had approved the study (H-4-2010-052). Prior to examination, the patients received written information concerning the study. After reading this, the patients contacted the clinic, if they were interested in participating in the study. The patient was then invited to a session where the investigator once again informed about the study. If the patient agreed to participate, an informed consent according to the principles of the Helsinki Declaration was signed, and the patient was enrolled in the study.

Inclusion criteria were vertical overlap or contact between the root complex and the mandibular canal in a panoramic image and an indication for removal of the tooth according to the Scottish Intercollegiate Guidelines Network guidelines¹¹ for removal of mandibular third molars. Exclusion criteria were existing neurosensory disturbances in the innervation area of the trigeminal nerve and any pathology that might influence the outcome measurement.

Radiographic examinations and randomization

Radiographic examinations were performed with a combined panoramic and CBCT unit (Scanora® 3D; Soredex, Helsinki, Finland). Panoramic imaging was first performed according to the normal protocol for a full adult. If the patient, after the panoramic image was assessed, fulfilled the inclusion criteria and had accepted to participate, she/he was randomized to either the panoramic imaging group (non-scan, no further imaging) or the panoramic imaging + CBCT group (scan). For patients allocated to the scan group, CBCT imaging was performed with a 6 × 6-cm field of view high definition with maximum mA setting. The patients allocated to the non-scan group were also seated in the CBCT unit chair, and a simulated CBCT examination was performed without radiation (patient blinding). The randomization procedure was executed as a block randomization with 20 elements in each block consisting of 4 × 5 balls with different colours. Randomization was performed also for two surgeons, who subsequently each treated the same number of scan and non-scan patients. Two specially trained dental nurses managed the randomization process and performed the radiographic examinations. The randomization codebook was centrally allocated and locked in. The code data for each patient were released only after entering the outcome data (data blinding).

After performing the radiographic examination, the patients were scheduled for removal of the third molar in a surgical practice. 1 week after surgery, the patients visited the investigator again in the study clinic for post-surgical treatment (e.g. suture removal) and data collection. The investigator was blinded to the imaging method. The study thus fulfilled the criteria for a triple-

blind setting. The investigator managed any post-operative complications. The clinical part of the study started in December 2010. Data for the present part of the study were collected until January 2013 and included 68 patients in the scan group and 70 in the non-scan group (Table 1).

Determination of costs

Identification, measurement and valuation are the basic modules that must be determined before executing an analysis of costs. Table 2 shows the identified image and patient-/surgery-related costs. The table also shows the abbreviations for the variables used in the valuation. The baseline for this analysis was the panoramic imaging costs.

The following equation was used to calculate panoramic and CBCT image costs (abbreviations are explained in Table 2): costs panoramic imaging = (CCpano) + (OPpano) + (Rghpano) + (Rdlpano) + (OHpano). Costs CBCT imaging = (CCcbct) + (OPcbct) + (Rghcbct) + (Rdlcbct) + (OHcbct). In the clinical setting of this study, the comparative cost analysis of the two imaging modalities implied the assessment of possible spin-off benefits or drawbacks when using CBCT as the pre-surgical method. If there were fewer/more resources used during surgery, in the post-surgery management as well as patient-related healing/complication parameters, this should be reflected in the analysis. These possible differences express the impact of the CBCT technology on the level of patient- and surgery-related costs. Therefore, the surgery-related costs were estimated as well. However, as these costs are only relevant if they differ between the panoramic and the CBCT methods, we have chosen to include them as incremental differences in the measure of the CBCT cost estimate. Hence, the formula for calculating the CBCT costs differs from the panoramic baseline formula and is defined as (for abbreviations, see Table 2): total costs CBCT image = (CCcbct) + (OPcbct) + (Rghcbct) + (Rdlcbct) + (OHcbct) + (DiffSur) + (DiffSa) + (DiffMed) + (DiffRef). Calculations were based on mean figures in the study clinic measured in the years 2010–12. DiffSur = the difference between time used for assessing panoramic images and CBCT by the surgeon + difference in surgery time for the two groups. DiffSa = difference in patient time at surgeon's office + difference in sickness absence measured in days + difference in time used for complication management. DiffMed = difference between medication in the scan and non-scan groups, including pain control, antibiotics and sedatives. DiffRef = difference in resources used at referrals to specialists or hospitals. All data

in the diff-groups were registered for each patient except the surgeon's time used for assessment of the images. These data were directly reported from the surgeons as mean values. Resource calculations of work hours were based on figures from Statistics Denmark,¹² and medicine costs were calculated based on pro.medicin.dk 2012.¹³

Cost calculations in this study were based on 190 CBCT examinations and 310 panoramic images yearly derived from the actual examinations performed in practice in the years 2010–12 not including the examinations from the study.

Statistical analysis

All data were treated as continuous-scale data, and these were reported as mean values with 95% confidence intervals. Normally distributed continuous-scale variables were compared by Student's *t*-test; non-normally distributed data were compared by the Wilcoxon rank-sum test. Power calculations were based on assessment of relevant monetary/time differences in the registered difference data groups. Data were organized with EpiData™ v. 3.1 (EpiData Association, Odense, Denmark), and Stata® v. 11 (StataCorp LP; College Station, TX) was used for calculations.

Results

Costs for panoramic imaging

Using the described equations for valuation expressed in euros (Figure 1), the following calculations could be executed:

CCpano = $46,000 - [4600/(1 + 0.03)^5]/(5 \times 310)$	Capital costs
OPpano = $[(12 \times 12.2) + (750) + (1740)]/310$	Operational costs
Rghpano = $(10 + 3) \times (24/60)$	Radiographic costs
Rdlpano = $8 \times (55.50/60)$	Radiological costs
OHpano = €0.95	Overheads
Total baseline costs = €49.29	

Costs for cone beam CT examination

Using the described equation expressed in euros (Figure 2), the following calculations could be executed:

CCcbct = $126,000 - [12,600/(1 + 0.03)^5]/(5 \times 190)$	€121.20
OPcbct = $[(12 \times 24.4) + (750) + (1740)]/190$	€14.64
Rghcbct = $(18 + 5) \times (24/60)$	€9.20
Rdlcbct = $35 \times (55.50/60)$	€32.37
OHcbct = €2.40	
Total baseline costs = €179.81	

Comparing costs for scan and non-scan group

To obtain a correct estimation of the true costs for CBCT compared with panoramic imaging in this clinical setting, we included derived differences in costs, which could be a result of a changed surgical procedure and/or changed patient complication outcomes. Table 3 summarizes the costs for the two imaging modalities.

Comparing all relevant data from the two groups only identified a difference in resources spent for pre-surgical

Table 1 Study population

	Scan	Non-scan	Total
Patient observations	68	70	138
Age (years), mean (SD), range	31 (10), 19–74	29 (9), 18–55	
Male	19	30	49
Female	49	40	89

SD, standard deviation.

Table 2 Cost identification, abbreviations and definitions

Cost	Identification	Measurement
Imaging costs		
Cc—equipment costs	The initial investment costs of equipment, hardware, software, changes in building construction and education	Capital costs for the panoramic setting were €46,000 and for cone beam CT €126,000. For both settings, a depreciation of 5 years and a 10% rest value was assumed with a 3% yearly interest rate
Op—operational costs	Maintenance of equipment, quality control, square metre rent, secretary assistance	Costs were calculated as a yearly mean of 3 years in the setting of the study clinic. The data were drawn from the clinic balance in 2010–12
Rgh—costs for radiographic examination	Time used for informing and instructing the patient before imaging. Time used for image recording. Time used for image processing	In 20 examinations, time was measured with a stopwatch. Radiographic professionals' salary data from Statistics Denmark ¹² were used for valuation
Rdl—costs for radiological procedures	Time used for image interpretation. Time used for reporting and processing images and communicating findings	In 20 procedures, time was measured with a stopwatch. Radiologist's salary data from Statistics Denmark ¹² were used for valuation
OH—overheads	compact discs, printing paper, ink, communication costs	Actual costs were drawn from the clinic balance 2010–12 and calculated with the actual materials used for each study patient
Surgery- and patient-related costs		
DiffSur—difference in costs between scan and non-scan groups for surgical procedures	Surgical time in minutes, post-surgical management measured in minutes, surgeon's time in minutes used for image assessment	Surgical time was measured with a stopwatch, post-surgical management in time blocks of 10 min, surgeon's time used for radiological interpretation reported from surgeons as mean values. Specialists' salary data from Statistics Denmark ¹² were used for valuation
DiffSa—difference in costs between scan and non-scan groups concerning productivity loss	Patient-related resources: productivity loss/sickness absence, pre-surgical time used, post-surgical time used	Patient-reported post-surgical productivity loss/sickness absence measured in half days, other values reported in quarter of hours. Mean salary data from Statistics Denmark ¹² were used for valuation
DiffMed—difference in costs used for drugs between scan and non-scan groups	Use of drugs: pain control, antibiotics and sedatives	Patient-reported type and amount of drugs. Costs valued using pro.medicin.dk ¹³ National Drug Register
DiffRef—difference in costs for referrals between scan and non-scan groups	Post-surgical referrals to specialists or hospitals	Information about treatment type and time from specialist or hospital. Specialists' salary and standard hospital cost from Statistics Denmark ¹² were used for valuation

radiological assessment by the surgeon, which is a constant difference in costs. No changes in other patient- and surgery-related costs were found. Table 4 summarizes the most important parameters in the cost differences between the scan and non-scan groups.

Figure 1 Distribution of panoramic imaging costs in five categories.

The following equation expresses the true costs of a CBCT examination compared with panoramic imaging in this clinical setting:

$$CCc(121.20) + OPc(14.64) + Rghc(9.20) + Rdlc(32.37) + OHc(2.40) + DiffSur(4.63) + DiffSa(0) + DiffMed(0) + DiffRef(0)$$

Total costs = €184.44

Influence of number of cone beam CT examinations per year

Figure 3 visualizes the changes in CBCT examination costs with changed capital costs assumptions and number of examinations.

Discussion

Absolute costs

Costs should not be confused with price when taking a societal viewpoint on an imaging diagnostic method. The patient's payment for an image is not necessarily

Figure 2 Distribution of cone beam CT (CBCT) examination costs in five categories.

derived from the actual amount of resources used for the procedure. Market considerations, coincidence, competition, national tradition and politics may decide what the patient must pay. Using basic economy figures gives a more reliable calculation of the costs involved. Furthermore, this approach is beneficial for comparing costs internationally using standard economic tools. Modifying the framework approach suggested by Christell *et al*⁶ involving the standardized basic economy parameters as described above and excluding the price in the calculations should make it possible to develop a more robust and useful model for assessing health economics of diagnostic methods in oral healthcare in specific clinical settings. This does not mean that price should not be involved in a broader analysis of the societal implications. In a more or less free-market setting, the difference between resources used and price can be important for assessing the true costs for individuals and society. Such considerations are beyond the aim of this study.

The capital costs constituted 65% of the total costs for CBCT examination and 54% of the total costs for panoramic imaging in the study setting. There is a directly proportional relationship between the two economic parameters and the capital costs pro image: the investment costs of equipment and the number of performed examinations. Different imaging systems vary in price. As new technology matures, it tends to become cheaper until a certain plateau is reached. This level

probably already exists for panoramic equipment. For CBCT scanners, it must be expected that equipment price will drop and market mechanisms will eliminate some operating companies or products. The number of images taken yearly will of course differ tremendously. In a study determining CBCT costs internationally,⁵ the yearly number of images differed between 435 and 1500 in 4 university clinics. The number of images in our study was much lower, which probably reflects that the CBCT examinations were performed in a private practice without official referral status. The CBCTs taken in the ongoing randomized controlled study were not included in the reported numbers. The following formula more generally simulates the costs for a single image:

$$\frac{Eq - \frac{Eq}{10}}{(1+r)^{Dy}} + \frac{Oc}{n} + R1 + R2 + K = Ic$$

where *Ic* is image cost; *Eq*, equipment cost; *n*, number of yearly images; *Dy*, years of depreciation; *Oc*, operational cost; *R1*, radiological cost; *R2*, radiographic cost; *K*, overheads; and *r*, yearly interest rate. If we consider *R1*, *R2* and *K* as constant figures (which of course vary internationally), we can simplify the equation to obtain an impression of the factors influencing the imaging costs:

$$\frac{0.9Eq}{Dy} + \frac{Oc}{n} = Ic$$

It is obvious that the number of examinations is the main factor for reducing the overall costs. The limitation is the constant factors consisting radiological, radiographic, operational and overhead costs.

The capital costs heavily influence the image costs and so do the number of examinations. Intentionally, CBCT examination is performed only when trustworthy evidence leads to an indication where the benefits for the patients are obvious. In the clinical situation, there is a lack of high evidence studies in this area, leading to a more or less subjectively judged indication spectrum. A report from the National Council on Radiation Protection and Measurements¹⁴ from 2008 estimates a total amount of “non-indicated” diagnostic images of US\$16 billion. Apparently, there is a tendency to use diagnostic imaging technology beyond a scientific horizon. In a strict market economy setting, financial interests may interfere with limits of indications. Other interfering factors could be prestige, beliefs or other expressions for “technofascination”.

In the simulated changes of the assumptions in this study (Figure 3), the operational costs were held constant. It has to be taken into account that a higher number of examinations may lead to higher costs for maintenance and repairs. No data for this topic were available, but maintenance costs only constituted 25% of the operational costs and even a major change in this figure will not substantially affect the outcome. A part

Table 3 Costs for the non-scan and scan groups

Valuation	Non-scan group	Scan group
Capital costs (CC)	€27.12	€121.20
Operational costs (Op)	€8.51	€14.64
Radiographic costs (Rgh)	€5.31	€9.20
Radiological costs (Rdl)	€7.40	€32.37
Overheads (OH)	€0.95	€2.40
DiffSur	–	€4.63
DiffSa	–	No statistical difference
DiffMed	–	No statistical difference
DiffRef	–	No statistical difference
Total	€49.29	€184.44

For abbreviation explanations see Table 2.

Table 4 Surgery- and patient-related costs for the non-scan and the scan group

	<i>Non-scan group</i>	<i>Scan group</i>	<i>Significance</i>	<i>Power</i>
Surgical time per patient (minutes), mean (95% CI)	7.44 (6.57–8.30)	7.72 (6.49–8.94)	Non-significant	0.97 if 20% difference is considered clinically important
Radiological time/surgery (minutes), mean	2	7	Difference directly measured	
Sickness absence in days (95% CI)	1.07 (0.70–1.43)	1.16 (0.76–1.56)	Non-significant	0.8 if 25% difference is considered clinically important
Pain control, € (95% CI)	4.65 (3.93–5.38)	5.52 (4.48–6.56)	Non-significant	0.8 if 25% difference is considered important
Antibiotics, € (95% CI)	4.24 (2.46–6.00)	4.62 (2.82–6.37)	Non-significant	0.8 if 25% difference is considered important
Referrals, no price estimation	One patient hospitalized for infection control	One patient referred to specialist for mandibular fracture control but no treatment	Data not sufficient for statistical test	

CI, confidence intervals.

of the operational costs was the square metre rent, which in this study was relatively high. Other countries, regions or parts of the city may have different rental costs. If data from our study are used for national or international comparative analyses, this should be taken into account. Operational costs in the panoramic settings were relatively high with up to 33% of the total costs in some settings. Radiographic and radiological costs were calculated based on national figures for specialist income. Time was measured in minutes and the absence of reliable computerized automatic diagnostic systems suggests that those figures will be unchanged. The relative weight of the radiological costs on the other hand increased to >50% in one of the CBCT settings (Figure 3).

The overhead costs were relatively small and could probably be minimized in a complete digital referral set up. There were no statistically significant differences in resources used for surgery time and post-surgical

management for either the professionals or the patients. Although a 5–20% higher level of resources could be identified within almost all parameters in the CBCT scan group, this tendency could not be statistically verified in the actual chosen power level. The quantitatively most important parameter in this difference group was the sickness absence measured in days. In this study, it was only possible to test the null hypothesis for a difference of 25% with an acceptable power. There could be a difference of $\leq 20\%$, which expressed as a mean value, would be a maximum of €18.54 difference added or subtracted from the total CBCT costs. From the distribution of post-surgical sick days in the two groups—and considering the fact that most of the patients, owing to their young age, are not yet active in the production sector—the true figures would very likely be lower.

The results of an increase in medical radiation from CBCT will most probably be an increased incidence of

Figure 3 Changes in cone beam CT (CBCT) costs with changed capital cost assumptions and number of examinations.

stochastically induced late cancers. The risk of cancer development is related to dose and patient age.¹⁰ Quantifying this risk and valuating cancer treatment and productivity loss was not a part of this study. These considerations will be a part of a later cost-effectiveness analysis on the population level.

Relative costs

The study data indicated that a CBCT examination requires four times the costs of panoramic imaging. In the assumption change scenario (Figure 3), this difference will be reduced to a three times difference with lower investment costs and a higher number of images. A radiological diagnostic procedure is a stepwise decision based on the expectation (evidence supported or not) that a more advanced, more radiation intensive and more costly image will bring new and relevant information, which should be beneficial for the patient concerning diagnostic accuracy, treatment decision, treatment security, treatment prognosis, morbidity and/or patient subjective understanding, information and acceptance. The resources calculated for a CBCT examination will therefore also include the resources used for panoramic imaging and probably an intra-oral image. This will in most cases be reflected in the pricing of the examination to the patient. The patient will probably have to pay for a panoramic as well as a CBCT examination. These price/cost considerations are not included in this analysis.

Costs and beyond

Although the importance of the costs for a given medical procedure is obvious, there is a need to develop an

understanding for the connection between costs and achieved benefits. With limited resources and expanding technology possibilities, the priority of decisions concerning use of new technological equipment is necessary. A part of this priority is not only the quantification of costs related to patient outcome figures (cost-effectiveness) but also an assessment of the outcome of different diagnostic and treatment modalities on a societal level: cost–utility and cost–benefit analysis. Furthermore, there is a need to assess other social implications such as equality aspects, environment considerations and ethics in a broad global context. Part of this decision-making is not medical, but political and ethical. To achieve the best possible foundation in this process, resource thinking should be integrated in future clinical research.

Conclusions

The costs for a CBCT examination were 3–4 times the costs for panoramic imaging when used for treatment planning before mandibular third molar removal. In this study setting, the costs for a CBCT examination varied between approximately €70 and €180, and the costs for a panoramic image varied between €25 and €50, depending on variations in capital costs and number of performed examinations yearly. There were no significant differences between the scan and non-scan groups with respect to resources used for surgery and post-surgically, nor in resources used for patient complication management.

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