Dental radiation risks

CONCERNS ARE OFTEN RAISED ABOUT THE RADIATION RISKS FROM DENTAL IMAGING. ANTHONY REYNOLDS ANSWERS QUESTIONS ABOUT THE RADIATION DOSE FROM DENTAL CT SCANS

Q. Dr Reynolds, as you are well aware a number of articles have appeared both in the scientific literature and in the popular press expressing concerns about the high levels of radiation dose delivered by computed tomography (CT) scanners. What reassurance can you give to dental implantologists to help them explain the risks and benefits of CT scanning to their patients?

A. Fair question! The first thing to say is that, while radiation doses from diagnostic X-ray examinations are already very low, they should always be kept 'As Low As Reasonably Practical' (ALARP). In essence this means that the dose should be made as low as possible, but not so low that the examination no longer provides the information required for diagnostic interpretation or pre-surgical planning.
Having said that, it turns out that for various technical reasons the dose from a dental CT scan can be substantially reduced without significant loss of image quality – much lower than a routine CT scan of the brain, for example.

Q. But how does the dose compare to other standard dental X-ray procedures such as intraoral films, Dental Panoramic Tomography (DPT) or more sophisticated devices such as the Scanora?

A. The whole-body effective dose from intraoral films is very low indeed, and with recent improvements in technology is getting even lower. A table published by Goaz and White (1994) puts the effective dose from a Complete Mouth Set (CMS) consisting of 20 E-speed films taken with rectangular collimation as low as 33μSv (microsievert) or 0.033mSv (millisievert). Our own measurements indicate that excellent CT scans can be obtained for around 0.3mSv per jaw, so on this scale at least, the dose from a dental CT scan is about 10 times the dose from a CMS.

Of course, a CMS includes both jaws so perhaps we should say that the dose from a dental CT scan is 20 times as much. There is little point in trying to be more precise than this because the actual dose a patient receives depends on the equipment and technique used and also on the size of the patient.

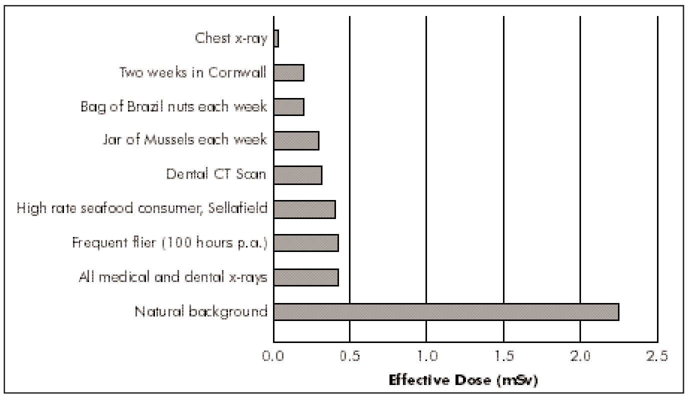
The dose from DPT is also very low, around 3 to 10μSv (Danforth and Clark, 2000).

The point to be made is that every diagnostic procedure carries both benefits and risks. The benefits from a CT scan are very clear: measurements can be made to within a fraction of a millimetre without magnification or distortion, and CT can show subtle changes in tissue density that would not show up on a conventional X-ray film. In addition, CT can provide a quantitative assessment (for example, a histogram) of bone quality based on the numerical values of the pixels.

The question is whether or not the slightly increased risk from radiation dose is more than outweighed by the greatly reduced risk of complications at the time of surgery. The risk/benefit ratio is something that must be assessed individually, for each patient, by the person carrying out the patient's treatment.

'EXCELLENT CT SCANS CAN BE OBTAINED FOR AROUND 0.3MSV PER JAW'

Q. But what about the Scanora? I've heard that it provides the same



Relative effective doses of radiation compared to a dental CT scan (adapted from Hughes, 1999)

Anthony Reynolds BA, MSc, PhD, studied physics at Trinity College, Dublin and has specialised in computerised medical imaging since 1973. In 1985 he devised one of the earliest algorithms for 3D volume rendering, which is still in use today. In 1991 he was a co-founder of Image Diagnostic Technology Ltd (IDT) and now serves as its managing director

information as CT at a much lower radiation dose.

A. There appears to be some confusion on this topic. The publications that I've seen indicate that for a complete jaw examination, the dose delivered by the Scanora is very much the same as a CT scan – i.e. not a lot different from the 0.3mSv previously quoted.

For example, Dula et al (1996) quote 0.25-0.58mSv for CT maxilla and 0.48mSv for CT mandible. In a subsequent paper (1997) they quote 0.39mSv for a complete maxilla and 0.39 mSv for a complete mandible on the Scanora. In my view, the difference between these two sets of results is not meaningful in practice.

It is only when the examination can be restricted to a small region of the jaw (perhaps for a single tooth implant) that the dose from the Scanora can be reduced by a factor of about 4 to 6.

Q. Let me go back to the original topic. I've heard that CT scanners can deliver very high radiation doses – as much as 10mSv. Is this not a cause for concern?

A. A car might reach 200mph on a racetrack, but still be driven safely within the speed limit in a built-up area. It all depends on how it is used, and what it is used for.

It is true that some CT procedures, typically involving the abdomen and pelvis which are where most radiosensitive organs are located, deliver doses much higher than a dental CT scan. The National Radiological Protection Board (NRPB) maintains a website at www.nrpb.org.uk which lists typical effective doses for a number of different medical examinations. A CT scan of the abdomen/pelvis is listed as 10mSv as you said, but interestingly enough, this isn't the highest dose on the list – some nuclear medicine procedures can deliver as much as 18mSv!

At the bottom end of the scale, dental X-rays (single bite-wing or panoramic) are listed as <0.01mSv.

A CT scan of the head is listed as 2mSv. However, this refers to a diagnostic scan of the entire brain, whereas a dental CT scan encompasses a much smaller region. A brain scan must demonstrate very subtle density differences between grey and white matter, and is typically performed at around 350mAs per slice, whereas a dental CT scan can be performed at around 80mAs per slice.

An earlier report from the NRPB (Shrimpton, 1992) provides a more detailed breakdown. A 'routine head' CT examination is listed as 1.8mSv whereas an 'IAM' (Internal Auditory Meatus) exam is listed as 0.35mSv. Our own measurements lead us to believe that a dental CT scan is more similar to an IAM scan than to a routine head scan.

Q. You seem to be saying that doses can vary from one CT procedure to another, and that a lot depends on the skill and expertise of the radiographer who actually performs the scan.

A. In a nutshell, yes! It is very important that the radiographer knows the exact anatomical region to be scanned, and also the optimal machine settings to get the best image quality at the lowest dose practical. Usually this means following a strict protocol for dental CT scans.

As stated earlier, IDT's own measurements indicate that excellent dental CT scans can be obtained for around 0.3mSv per jaw. There may be hospitals where ten times this dose is routinely delivered; there has been one such report in the literature – Scaf et al (1997) but this is wholly unnecessary for a dental CT scan and in my view, irresponsible.

Part of my work at IDT is to make sure that all scans performed for us are within acceptable radiation dose limits.

Artefact can be minimised by choosing a scanning plane parallel to any metallic restorations

Q. You said that IDT performs its own radiation dose measurements. Can you explain how this is done?

A. Basically we go out to the hospitals that perform scans for us and make our own measurements on the CT scanners that are used. We know from experience that some older CT scanner models cannot meet our image quality and dose criteria (and therefore we would not use them for dental CT scans) but thankfully in the year 2000 most of these older machines have now been replaced.

If a scanner model meets our minimum criteria and the hospital wants to perform scans for IDT we would then visit the hospital, taking along a head phantom and an ionization chamber.

The head phantom is used to demonstrate to the radiographers the exact patient positioning required, and also allows us to do some test scans to check on image quality. The ionisation chamber is used to measure the dose to be expected from a typical dental CT scan. I won't go into the technicalities here, but we follow a procedure outlined in a Medical Devices Agency report (1998). May I just take this opportunity to acknowledge the physicists at ImPACT (Department of Medical Physics and Bioengineering, St. George's Hospital, London) for their invaluable advice and assistance with these measurements.

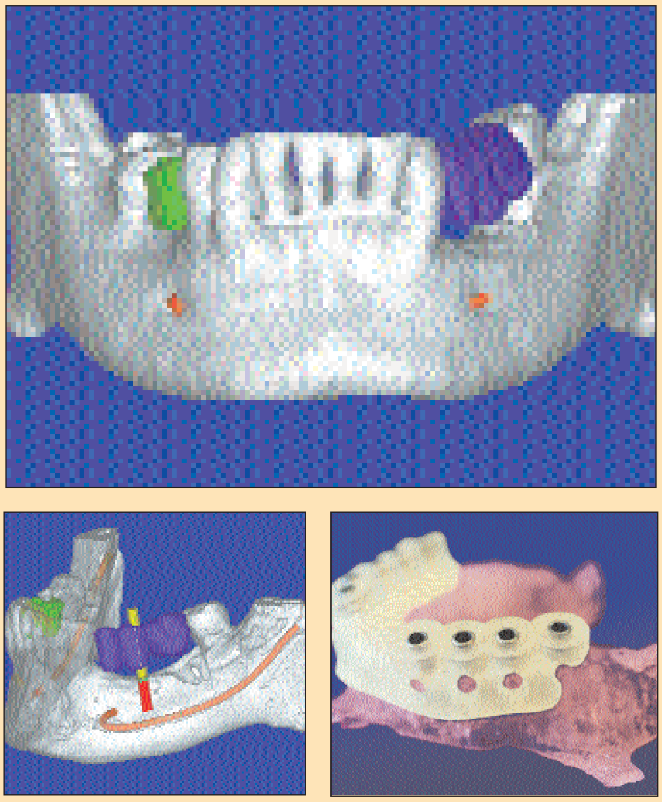
The point is that radiation dose and image quality are very closely related. The dose is controlled (among other factors) by the mAs setting. The lower the mAs, the lower the dose but the noisier the image. However, if you can reduce any noise that is caused by factors other than photon statistics, then you can get away with a lower dose.

You can't get something for nothing, but you can definitely get nothing for something if you don't establish an optimal protocol for the radiographers to follow!

Q. What else can affect image quality other than photon statistics and radiation dose?

A. Artefact caused by metallic restorations. I want to distinguish this from true 'scattered radiation' in the sense of X-ray photons that do not follow a straight-line path between the X-ray tube and the detector. When a conventional X-ray film is taken, one makes the assumption that any X-ray photon that leaves the tube goes directly to the film, but if it happens to get deflected off something at the wrong angle it will end up in the wrong place on the film. This effectively creates a background fog, which is a form of noise. It turns out that in CT, true scattered radiation is not much of a problem as the X-ray beam is very well collimated.

However, CT scanners are very sensitive to small changes in density as previously mentioned. So, if a very large change in density is introduced – a piece of dense metal such as a gold crown or amalgam for example - the system cannot deal with a change in density that is outside its normal range. The result of this, as you may have seen is a starburst that streaks across the image emanating from the metal. This is a characteristic of CT scanners – they all do it. Please note it is 'artefact' not scattered radiation. If the offending object cannot be removed (permanent restorations for example), artefact can best be avoided by choosing the scanning plane to be parallel to the restorations – in most cases, this means scanning parallel to the occlusal plane.



Top and above left: 3D representations of the mandible using SurgiCase software
Above right: Drill guide automatically fabricated from the implant plan created using the SurgiCase software

Another very important factor is patient motion. A dental CT scan is made up of 30 or 40 thin slices parallel to each other, and thus relies on the patient remaining absolutely still while the table advances from one slice to the next. If the patient moves at all – even to swallow – the study may be useless.

Luckily the modern generation of 'spiral' or 'helical' CT scanners are very much faster than the older machines. A complete jaw can now be acquired in less than 30 seconds, so patient movement is much less of a limitation on image quality.

Lastly there are a number of technical factors such as kVp, pixel size, reconstruction kernel - and for Spiral scanners, pitch - that can have a significant effect on the image quality achievable.

Q. You mentioned Spiral scanners. Is it true that these machines have a much lower radiation dose?

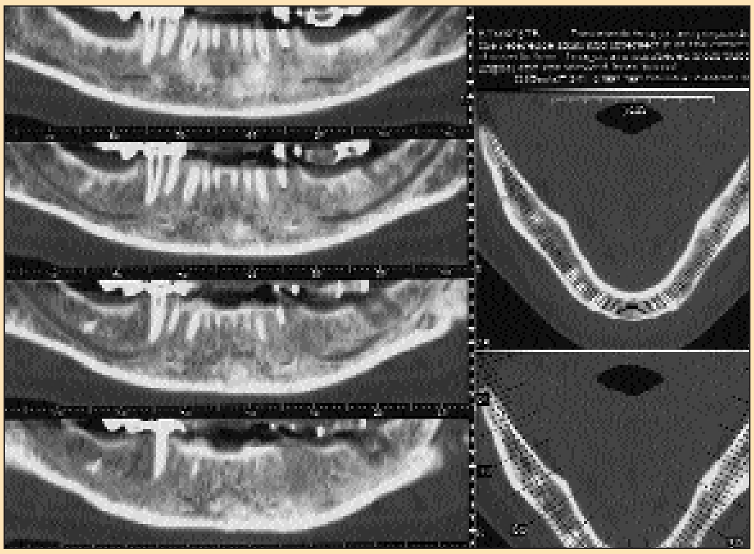
A. Again there is some confusion on this topic. The short answer is 'no'. This is because the image quality is dependent on the dose, so for a given CT scanner you need to use the same radiation dose to get the same image quality irrespective of whether the scanner is operated in spiral or in standard axial mode.

What is true is that Spiral scanners are very much faster, and this results in enormous improvements both in patient comfort and in avoiding poor quality studies caused by patient motion. It is also true that Spiral scanners tend to be among the most modern, and as such have benefited from advances in electronics and detector engineering which may make lower mAs settings acceptable.

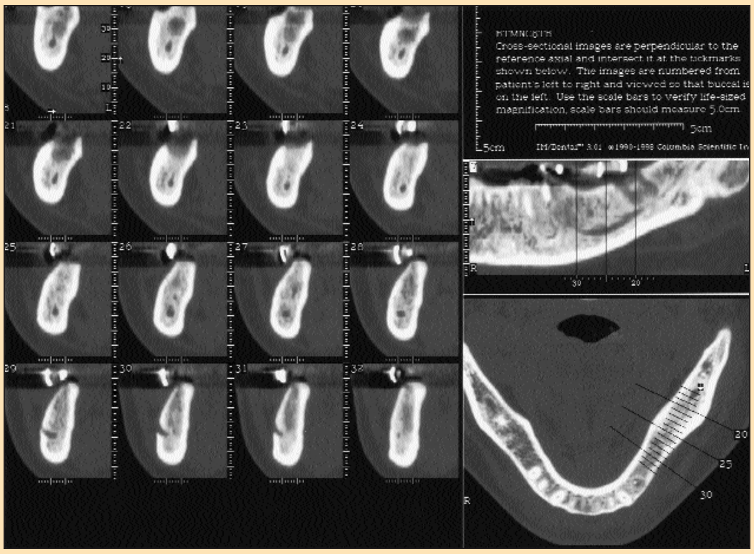
The latest generation of CT scanners operate in 'multislice mode' – in other words, they acquire several slices simultaneously, which makes them even faster. Physicists are still arguing about whether the dose in multislice mode is higher or lower than the dose in standard axial mode, but it is likely that when the dust settles and the technology matures the dose will turn out to be very much the same.

Q. There's something that I'm still confused about. You mentioned that dental CT studies consist of 30 or 40 slices. Doesn't that mean that the patient dose should be higher than for a brain scan requiring only nine or ten slices?

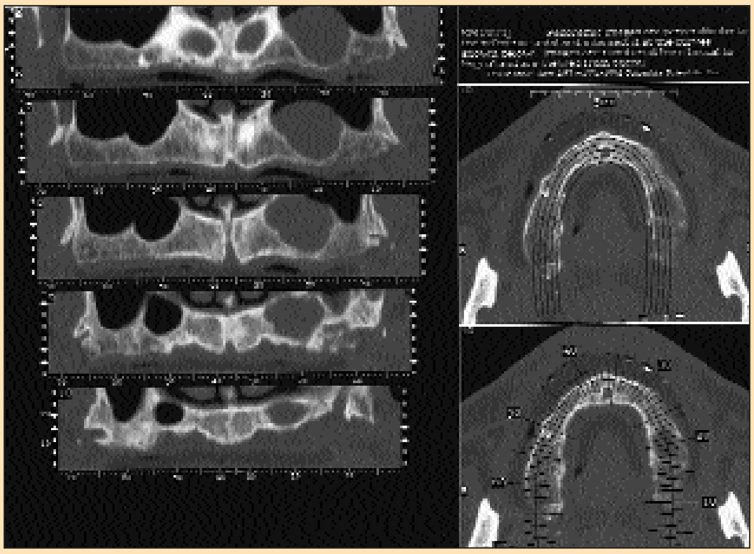
A. Again the short answer is 'no'. To explain this, we have to understand what is meant by 'effective dose'. In days gone by, people used to quote 'skin doses' measured in milliGray (mGy). This was because dose to the skin is easy to measure, however we now know that the organs deep within the body are much more sensitive to radiation than the skin surface itself. Also we know that 1mGy to the lungs or stomach is much more likely to be harmful than 1mGy to the



Computer-generated panoramic images of a mandible



Computer-generated cross-sectional images of a mandible



Computer-generated panoramic images of the maxilla

The above images have been computer-generated using Columbia Scientific Inc software and are normally presented as life-size and of photographic quality

hands or feet.

In order to express the radiation dose in numbers that relate directly to the risk to the patient, the International Commission on Radiological Protection (ICRP) in 1990 came up with the quantity known as 'effective dose', measured in millisievert (mSv). The effective dose is based on the local dose delivered to the various organ systems within the body (gonads, lungs, stomach and thyroid etc) but weighting factors are applied which take into account:

- the volume of the organ irradiated
- the type of radiation used
- how radiosensitive that particular organ is believed to be. Skin, for example, gets a weighting factor of 0.01 whereas the gonads get a weighting factor of 0.20.

The effective dose depends on the volume of tissue irradiated, and also on the part of the body involved. A brain scan consisting of 10 x 10mm slices (100mm total) irradiates more tissue than a dental scan consisting of 40 x 1mm slices (40mm total). Provided the mAs per slice is the same or less, the effective dose from the dental CT scan will be lower.

The concept of effective dose allows us to compare one type of radiological investigation with another (e.g. a CT scan of the head versus a nuclear medicine scan of the abdomen), and also to compare the doses from medical and dental procedures with whole-body doses received from other sources.

For example, everyone on this planet receives a certain amount of background radiation from natural causes, mostly from radon gas and cosmic rays but also from eating slightly radioactive food – Hughes (1999). The average annual dose in the UK from natural sources (excluding medical and dental irradiation) is currently about 2.2mSv, but in some regions such as Cornwall it can be as high as 7.4mSv. So, you could say that the risk from having a dental CT scan is about the same as spending your holidays in Cornwall!

Q. That brings us to the topic of risk. What sort of risks are we talking about?

A. This is a very complex area and there are a number of factors that need to be considered. Basically there are believed to be two very different types of effects that can occur following exposure to ionising radiation:

DETERMINISTIC EFFECTS

'Deterministic' means that the severity of the effect is proportional to the dose received – skin erythema is a good example - the more dose received, the more red the skin gets. Deterministic effects are never seen in diagnostic radiology unless a bad mistake has been made. They do not set in below a threshold of 1 or 2Sv, so we need not consider them further.

STOCHASTIC EFFECTS

'Stochastic' means that they are based on a probability-based or statistical model. In this model, the risk of a certain event occurring depends on the dose – but not the severity of the event itself. A good analogy is crossing a busy street. The more times you cross the street, the more likely you are to be knocked down by a car – but the severity of the accident doesn't depend on how many times you have crossed the street previously. Stochastic effects include the possibility of the patient developing a fatal cancer within the next 20 years or so following the CT scan. Let me emphasise that these risks are entirely theoretical. Nobody can say for certain that because you received 0.3mSv of radiation therefore you will definitely get cancer in 20 years time. There is no evidence at all to support this. In fact there is no evidence at all that anyone has ever got a cancer from a dose of radiation as low as 0.3mSv.

'THE PATIENT WOULD RECEIVE THE SAME DOSE OF RADIATION FROM NATURAL CAUSES BY SPENDING A 3-WEEK HOLIDAY IN CORNWALL INSTEAD OF WALES'

There is, however, evidence that cancer has developed when doses of around 500mSv have been experienced – mostly from atomic bomb survivors. So, the risk is calculated from these figures and then extrapolated back.

To conclude, there is a small theoretical risk that the patient might someday develop a fatal cancer and it is prudent therefore to keep radiation doses as low as reasonably practical. The risk is usually expressed as 1 in 20,000 per mSv received. So, on this basis, a dental CT scan carries a theoretical risk of approximately 1 in 65,000 that the patient will develop a fatal cancer later in life. Of course as stated this has never been observed in practice.

To put things in perspective, here are some other activities that carry a 1 in 65,000 risk of a fatality:

- A round-trip transatlantic flight
- Smoking 20 cigarettes just once in your life
- Travelling 750 miles by car
- Working in a factory for 150 days
- Rock climbing for 20 minutes.

Q. To summarise, let me return to the original question. What is the radiation dose from a dental CT scan?

A. .The best answers I can give you are as follows:

- The patient will receive about 0.3mSv per jaw, i.e. very much the same dose as from other medical procedures such as an X-ray examination of the hip
- The patient would receive the same dose of radiation (0.3mSv) from natural causes by spending a 3-week holiday in Cornwall instead of Wales
- The risk of developing a fatal cancer later in life is about 1 in 65,000, which is about the same risk of fatality as flying to America and back.

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