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Advantages of fitting contrast curves using logistic function: a technical note

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Objective. The aim of this article is to demonstrate how the contrast properties of an imaging system can be ideally fitted with the use of stripe patterns and the logistic function.

Study Design. Stripe patterns with defined amounts of line pairs (lp/mm) per mm (10-20 lp/mm) were recorded with the use of digital photostimulable storage phosphor. Scan data and normalized image data were analyzed with the use of ImageJ and MatLab to calculate different contrast curves.

Results. For original scan data, the goodness of fit was 0.0000019 (sum of squared error [SSE]). The R-square was 0.9998. For normalized data the goodness of fit was 0.0007 (SSE) and the R-square 0.998. An amount of 50% contrast could be calculated to be found on 11.67 lp/mm in normalized images.

Conclusions. This article addresses a potentially new approach to compare digital x-ray modalities using a direct assessment of a known technical target. (Oral Surg Oral Med Oral Pathol Oral Radiol 2013;115:e60-e63)

The logistic function was introduced by Pierre François Verhulst in 1838 to model population growth.[1] Generally, it is a sigmoid-shaped curve, which can be used to describe data starting at zero and reaching a state of nonextendable saturation. The initial stage of expansion is approximately exponential until saturation begins. Due to the inability of further increase (i.e., limited space to build more houses in a certain area or defined range of gray levels for the depiction of images) the expansion slows and reaches an upper bound where no longer expansion is possible.

The modulation transfer function (MTF) or contrast transfer function (CTF) as obtained by square-shaped stripe patterns, is a graphic description of the spatial resolution characteristics of an imaging system or its individual components and for separating the individual causes of image degradation. It can be calculated either by means of a slit or a sharp edge and the Fourier transform of its line spread function or by the use of a stripe pattern with different spatial resolution.[2] MTF or CTF describes the response of an optical system to an image decomposed into pattern of exactly defined spatial resolution (an image of line pairs for example).[3,4] The local contrast m at a given spatial resolution can be calculated as:

$$m = \frac{(I_{max} - I_{min})}{(I_{max} + I_{min})} \quad (1)$$

where I_{max} denotes the maximum intensity (gray level), and I_{min} denotes the minimum intensity found in the region of interest.[5] The CTF then can be derived by plotting every calculated contrast *m* against its spatial resolution. The graph relating to the contrast that is transfered to the image is known as the CTF when the test chart is made up of square patterns of different defined sizes. When the periodic lines consist of sinusoidally varying intensities instead of square-wave profiles, the curve relating output as fractions of input intensities versus signal frequency is called the modulation transfer function.[6,7]

A drawback of this method in contrast to the edge method is that the gathered CTF is slightly greater and it is impossibile to extract the zero-frequency component.[8,9] Furthermore, CTF equals the MTF only at high spatial frequencies.[6] Therefore, the CTF curve has to be modeled in this case. The aim of the present article is to explain how digital x-ray contrast modalities can be compared by means of a well known technical target (stripe patterns) and the use of logistic regression to approximate CTF curves.

MATERIALS AND METHODS

Test images and artificial degradation

An image of a stripe pattern with defined amounts of line pairs per mm (10-20 lp/mm; Huettner Roentgen-

Statement of Clinical Relevance

Information about intraoral sensors often lacks contrast data. This article introduces a method to calculate modulation transfer function curves by using samples of a stripe pattern. With this method, spatial resolution of each amount of contrast can be easily calculated.

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Fig. 1. Stripe patterns recorded with Vistascan storage phosphor. The upper inserts show possible sampling points of I_{max} and I_{min} (left) and contrast changes after image enhancement (right).

teste, Hetzles, Germany) was recorded with the use of digital photostimulable storage phosphor plates (Vistascan; Dürr Dental, Bietigheim-Bissingen, Germany) and a Sirona Heliodent DS x-ray tube (Sirona, Bensheim, Germany) on an optical bench in a distance of 20 cm between focal spot and storage plate with 60 kV and 200 ms exposure time. All images were taken as given in the default mode of DBSWin software with the intrafine filter mode for noise reduction and a default resolution of 20 lp/mm. The obtained image (see Fig. 1) was exported from DBSWin Software (Duerr, Bietigheim-Bissingen, Germany) in the available 8-bit export function and analyzed using ImageJ 1.44p (Wayne Rasband, National Institutes of Health, United States) for simulated MTF calculations. All line profiles to each corresponding spatial resolution were sampled 3 times in original scan data and the same data changed with graylevel normalization by the "enhance contrast" function of ImageJ. The median value of these 3 samples was chosen and recorded in Excel 2010 (Microsoft, Redmond, Washington).

Curve fitting

MTF data was fitted to a logistic function y of the unknowns *a*, *b*, and *c* in the general form:

$$y = \frac{ca}{cb + (a - cb)e^{-ax}} \qquad (2)$$

with the use of the MatLab R2011a curve fitting tool (Mathworks, United States).[10] Because MTF starts from 100% contrast and then goes down to 0, the logistic regression have to be brought in its inverse form:

$$y = 1 - \frac{ca}{cb + (a - cb)e^{-ax}} \qquad (3)$$

The desired contrast can be calculated as variable x ($x = 0.1$ for 10% contrast; $x = 0.5$ for 50% contrast) can be obtained with the use of its root of x:

$$x = \frac{\ln\left(\frac{a(-y) + a + bcy = bc}{c(a + by - b)}\right)}{a} \qquad (4)$$

MatLab is able to give a direct evaluation of the obtained goodness of fit as the sum of squares due to error of the fit (SSE), where a value closer to 0 indicates that the obtained fit corresponds closely to the data that was given. The R-square value provided by the fitting tool is the square of the correlation between the response values and the predicted response values. A value closer to 1 indicates a better fit and therefore a high correlation between data and the chosen curve model.

RESULTS

The goodness of fit for the scanned data given by the curve fitting tool was 0.001136 SSE. The calculated R-square was 0.998 (Table I). The MTF achieved was:

$$y = 1 - \frac{0.008114039}{0.008378 + (0.631022)e^{-0.6394x}}$$

The goodness of fit for the normalized data was 0.0005081 SSE and R-square was 0.9993 (Table I). The MTF achieved was:

$$y = 1 - \frac{0.000001}{0.000001 + (1.202999)e^{-1.203x}}$$

The measured gray levels and the calculated contrast corresponding to their spatial resolution are listed in Table II. For the normalized data the 50% contrast level could be calculated to be found on 11.67 lp/mm (compare with values in Table II and Figure 2).

DISCUSSION

The method described here is a potentially new approach to compare digital x-ray modalities with the use