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A computational simulation study on the acoustic pressure generated by a dental endosonic file: Effects of intensity, file shape and volume

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ABSTRACT

One of the uses of ultrasound in dentistry is in the field of endodontics (i.e. root canal treatment) in order to enhance cleaning efficiency during the treatment. The acoustic pressures generated by the oscillation of files in narrow channels has been calculated using the COMSOL simulation package. Acoustic pressures in excess of the cavitation threshold can be generated and higher values were found in narrower channels. This parallels experimental observations of sonochemiluminescence. The effect of varying the channel width and length and the dimensions and shape of the file are reported. As well as explaining experimental observations, the work provides a basis for the further development and optimisation of the design of endosonic files.

1. Introduction

Acoustic cavitation is a well-known phenomenon in the field of ultrasound [1]. It can increase mixing and fluid motion in a system, form reactive intermediates which accelerate chemical reactions and aid in cleaning processes [2,3]. Ultrasound is used in dentistry to aid in cleaning. One of the most common applications of power ultrasound in dentistry is in periodontics where ultrasound with frequencies of 20–40 kHz is used in dental descalers to remove dental debris and plaque around the teeth and gums [4]. Apart from the mechanical cleaning effects, recent studies have shown that cavitation can be produced in water around the descalers [5], and the amount of cavitation and its distribution around the instrument has a strong correlation with the shape and design of the tip [6–8].

Another application of ultrasound in dentistry is in endodontics (root canal treatment). Here, ultrasound is applied to a narrow file which is placed within the root canal to improve the dissolution and removal of infected tissues and abscess from an infected root canal [9]. A number of researchers have shown that ultrasonically assisted irrigation improves the cleaning efficiency in root canal treatments [10–12]. Some argued that this was due to enhanced acoustic streaming [13–15] while others suggested that it could be due to the physical effects caused by cavitation [5,8]. The oscillation profiles of endosonic files (i.e. files used during endodontic treatments that involve ultrasonic vibrations) have been measured to investigate correlations between the oscillation profiles and the cleaning effectiveness [16,17]. The areas of cavitation activity around the instruments were assessed by the detection of sonochemiluminescence (SCL). Although it was reported that SCL tended to appear around the vibration antinodes of the oscillating files, there was no clear relation between the vibration amplitudes and the SCL emission [5,6]. Furthermore, it was also reported that there was no correlation between the lengths of the endosonic files and the oscillation profiles [18].

Macedo and co-workers recently suggested that the production of SCL was greatly increased when an endosonic file was operated in a human-sized root canal model as compared with in a cuvette of 10 mm wide and claimed that it was due to higher acoustic intensities formed in a confined system [19]. Production of cavitation potentially plays an important role in root canal cleaning. The production of stable cavitation may enhance streaming and mixing in the canal [20,21], while transient cavitation produces microjets [22] and radicals [23] upon collapse. Given this potential importance of acoustic cavitation in endodontics, there is a need for detailed information with which to optimize the operating parameters for endodontic instruments. In this work, we report

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Nomenclature

SCL	sonochemiluminescence	P	acoustic pressure, Pa
d	diameter of the endosonic file, mm	r	spatial variable ($r = [x,y,z]$)
l	length of the endosonic file, mm	ω	angular frequency, rad s^{-1}
D	diameter of the root canal model, mm	κ	wave number ($\kappa = \omega/c$)
L	length of the root canal model, mm	h	stepsize
P_{US}	ultrasonic power, W	n	normal vector
I	ultrasonic intensity, W m^{-2}	Z	acoustic impedance, Rayl
A	area, m^2	PMMA	polymethylmethacrylate
R	radius of the endosonic file, mm	x	distance from ultrasonic source, m
p_o	acoustic pressure amplitude, Pa	TL	transmission loss, dB
ρ	density, kg m^{-3}	R_c	reflective coefficient
c	speed of sound, m s^{-1}	T_c	transmission coefficient
t	time, s		

computational simulation of the acoustic pressure generated by endosonic instruments with the aim of predicting the occurrence of cavitation since it will occur when the acoustic pressure exceeds a threshold value [1].

Several ultrasonic systems have been studied using computational modelling approaches such as computational fluid dynamics on the fluid flow of an ultrasonic system [24,25] and finite element analyses to predict acoustic pressure fields [26–28]. The latter was shown to give results close to the experimental sonication systems. It was used to predict optimized conditions as it was found that slight changes in geometry of the sonicating system will significantly affect the acoustic pressure fields generated [28]. Studies on fluid dynamics for dental ultrasonic systems [29,30] have been published although there is no clear data on the acoustic pressure fields around ultrasonically driven endosonic systems under different operating conditions.

This paper aims to provide insight into the acoustic pressures generated using a computational modelling approach. In this study, the effects of power supplied, dimensions of root canal model and the dimensions of the endosonic files were examined in order to provide information of the operating conditions for different root canal dimensions with endosonic files used in clinical practice.

2. Materials and methodology

2.1. Endosonic files

The dimensions of the endosonic files used in the models were based on the dimensions of a standard K-file #10, #15, #20 and #25 (Endosonor, Maillefer, Dentsply) which are 15 mm long and have diameters (d) of 0.10, 0.15, 0.20 and 0.25 mm respectively. In clinical use, these endosonic files operate on a MiniPiezon ultrasound generator (EMS, Nyon, Switzerland) at a driving frequency of 30 kHz [17]. Fig. 1 illustrates a standard K-file attached to a piezoelectric hand piece.

2.2. COMSOL simulation procedures

All simulations were performed using the pressure acoustics frequency domain in COMSOL Multiphysics 4.3. Simulations were performed using water as the medium in the model.

2.2.1. Dimensions of the root canal model

Root canals in teeth are complex structures with many channels leading from the main canal. As an initial attempt to develop a model, the root canals were simulated, as shown in Fig. 2, as three dimensional cylinders with diameters (D) of 0.8, 1.0, and 2.0 mm; and lengths (L) of 18, 20, 22, 24 and 26 mm, corresponding to the size ranges of actual root canals [31,32]. Models with cylinders of 5 and 10 mm diameters were studied to simulate operation of the endosonic files in a large working volume. The K files were represented as cylinders with dimensions described in Section 2.1, the surfaces of which acted as the acoustic emitters.

2.2.2. Calculation of pressure amplitude

The power dissipated into the system, P_{US}, was measured by calorimetry [33,34] and was found to be in the range of 1–6 W

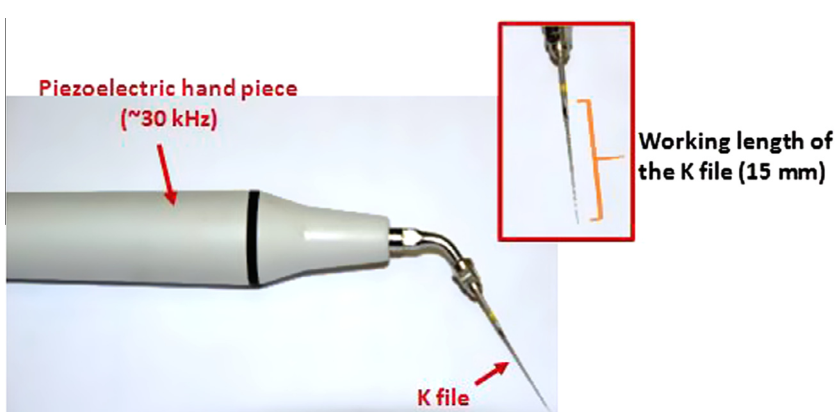

Fig. 1. A standard endodontic K-file attached to a piezoelectic hand piece operating at 30 kHz. Inset: A K-file with a working length of 15 mm and diameter of 0.20 mm.