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# In vitro rapid intraoral adjustment of porcelain prostheses using a high-speed dental handpiece

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**Abstract**

In vitro rapid intraoral adjustment of porcelain prostheses was conducted using a high-speed dental handpiece and diamond bur. The adjustment process was characterized by measurement of removal forces and energy, with scanning electron microscopic (SEM) observation of porcelain debris, surfaces and subsurface damage produced as a function of operational feed rate. Finite element analysis (FEA) was applied to evaluate subsurface stress distributions and degrees of subsurface damage. The results show that an increase in feed rate resulted in increases in both tangential and normal forces (analysis of variance (ANOVA), $P < 0.01$). When the feed rate approached the highest rate of 60 mm min$^{-1}$ at a fixed depth of cut of 100 μm, the tangential force was nearly seven times that at the lowest feed rate of 15 mm min$^{-1}$. Consequently, the specific removal energy increased significantly (ANOVA, $P < 0.01$), and the maximum depth of subsurface damage obtained was approximately 110 and 120 μm at the highest feed rate of 60 mm min$^{-1}$ using SEM and FEA, respectively. The topographies of both the adjusted porcelain surfaces and the debris demonstrate microscopically that porcelain was removed via brittle fracture and plastic deformation. Clinicians must be cautious when pursuing rapid dental adjustments, because high operational energy, larger forces and severe surface and subsurface damage can be induced.


*Keywords:* In vitro; Intraoral adjustment; Porcelain prostheses; Dental handpiece/bur; Fracture

## 1. Introduction

Porcelains are attractive for dental prostheses because of their superior biocompatibility and outstanding esthetics [1–3]. In the past two decades, their material properties have been significantly modified for dental restorations [3]. For instance, fine-structured feldspar porcelains with crystalline reinforcements have been proven to possess numerous positive attributes, such as comparable wear resistance to natural tooth structure and excellent color matching [4–7]. However, their inherent brittleness has caused noticeable failures in porcelain prostheses despite their widespread application in restorative dentistry [8–10]. Clinical data in all-ceramic prostheses veneered with porcelains have shown that the failure rate is high, approximately 3% each year [11].

Intraoral adjustments, or in situ grinding processes, are routine in dental practice to achieve accurate fit and proper function of prostheses. However, they are also an important factor that contributes to clinical failure in porcelain restorations [12]. In intraoral adjustments, indenting, scratching and cutting of inner and outer surfaces of prostheses are involved using dental handpieces and diamond burs, which are, by their nature, material removal processes [13,14]. These frictional and removal activities normally induce surface and subsurface damage in prosthetic materials [15–19], especially in brittle porcelains with a high proportion of glassy phase [20,21]. Generally, brittle damage

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results in degradation in the strength and survival probability of prostheses [12,22]. Studies of failed prostheses have demonstrated that flaws largely induced by intraoral adjustments in the prostheses where stresses are concentrated are the major cause of catastrophic fracture [23–25].

In dental practice, rapid intraoral adjustments are required to achieve proper interdigitation of the teeth in occlusion. Normally, dentists use coarse diamond burs, or exert larger forces or perform more rapid movements of the burs to modify the prosthesis quickly. These operations can also cause potential adjustment-induced damage to the ceramic restorations [17]. Improving the adjustment process requires a fundamental understanding of the material responses to rapid intraoral adjustments when using dental handpieces and burs, which include factors such as removal forces, energy, material removal mechanisms, and surface and subsurface damage. However, few studies addressing these issues have been reported in the ceramic restorations literature.

The aim of this investigation was to conduct an in vitro study of material responses to rapid intraoral adjustments of porcelain prostheses using a high-speed dental handpiece and diamond bur. In clinical practice the adjustment processes are very complex and mainly controlled by an individual dentist's experience [13]. They can involve a wide range of process parameters. For example, depths of cut and feed rates are constantly variable during clinical adjustments. Since we were interested in a quantitative analysis of the prosthesis adjustment, we developed a computer-controlled adjustment process in which the applied adjustment parameters can be precisely measured. We observed clinical practice when dental handpieces were manipulated by dentists. In seeking high removal rates, dentists can either cut the prosthesis deeply (increase the depth of cut) or move the handpiece quickly (increase the feed rate). For the present study, a single depth of cut of 100 μm was used, which dentists generally consider appropriate for clinical removal of tooth tissues. The feed rates in our study ranged from 15 to 60 mm $min^{-1}$, which cover the range of feed rates used by most dentists. A feed rate of 15 mm $min^{-1}$ is considered slow by most dentists, while most dentists would consider the rate of 60 mm $min^{-1}$ to be rapid. The adjustment process was characterized by measuring the removal forces, force ratios and specific removal energy, with scanning electron microscopic (SEM) observation of the adjusted porcelain surfaces, debris and subsurface damage as a function of feed rate. A finite element analysis (FEA) was performed to estimate subsurface stress distributions and degrees of subsurface damage to the adjusted porcelain prostheses.

## 2. Experimental procedure

### 2.1. Material

The material selected for this investigation was a feldspathic porcelain, Vita Mark II V5-12 A1C (Vita Zahnfabrik, Bad Säckingen, Germany), of dimensions 15 mm × 12 mm × 5 mm for Vita Cerec Dental CAD/CAM systems. Its microstructure comprises approximately 30% of irregularly shaped feldspar crystals of sanidine, nepheline and anothoclase [15] of 1–7 μm in size [26] and a glass matrix. The mechanical properties of the material are: Vickers hardness $H = 6.2$ GPa, Young's modulus $E = 68$ GPa, fracture toughness $K_{IC} = 0.9$ MPa $m^{1/2}$, strength $\sigma = 100$ MPa and Poison's ration $\nu = 0.2$ [27,28]. One surface of 12 mm × 5 mm was boned to a metal shaft for mounting the sample in the in vitro dental adjusting apparatus.

### 2.2. In vitro intraoral adjustments

In vitro intraoral adjustments were conducted on a novel computer-assisted apparatus. The detail of the apparatus has been described previously [29]. It consisted of a computer-aided high-speed air-turbine dental handpiece (DENCEN CST61, Shanghai Medical Instruments, China) with a two-degrees-of-freedom movement capability, a piezoelectric force dynamometer (9257A, Kistler, Switzerland), a charge amplifier (5006, Kistler, Switzerland) and a data acquisition system (LMS SCADAS III 305, LMS International, Belgium). During in vitro intraoral adjustments, the handpiece was manipulated precisely by a computer-controlled system to realize feed and down-feed movements for simulation of common operations in clinical dental adjustments.

A new nickel-coated diamond dental bur (SF-21, ISO 110523014, Mani, Japan) was used in the investigation. The bur had a cylindrical cutting section with a diameter, $d_s$, of 1.4 mm and a length of 7 mm, and a steel shank for insertion into the metal friction chuck of the dental handpiece. The diamond bur was driven by air pressure of 0.2 MPa, which generated a speed of 318,000 rpm when unloaded. The cutting portion of the bur is coated with a layer of diamond abrasive grits with average grit diameters of 105–125 μm, as determined by SEM (XL-30, Philips, Holland).

Fig. 1 shows the dental handpiece/bur–prosthesis contact with the operational parameters involving surface adjustments of the prosthesis. The bur was arranged parallel to the 12 mm × 5 mm surface of the prosthesis. Its 7 mm cutting portion engaged the entire thickness of the prosthesis. During adjustment, the bur, rotating at a high rotational speed, $V_s$, was moved along the prosthetic surface at a feed rate $V_w$ and a depth of cut $a$. When the bur traversed the 12 mm × 5 mm prosthetic surface, a layer of material with thickness $a$ was removed from the bur–prosthesis contact zone, coincident with dental clinical adjustments. Water spray at a flow rate of 30 ml $min^{-1}$ was supplied to the bur–prosthesis contact zone to keep the handpiece cool and to flush away debris. Plunge surface removal adjustments were conducted at a fixed depth of cut of 100 μm and feed rates of 15, 30, 45 and 60 mm $min^{-1}$. The in vitro dental adjustment conditions are summarized in Table 1.