An Approach to Computer Aided Porcelain Forming System

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To examine a new concept for computerized production of dental prostheses, an experimental porcelain forming system was devised. Unlike other dental CAM systems, the system is intended to form porcelain much as human technicians do. The system builds up an object by alternately applying water and droplets of porcelain powder. Test specimens were made by forming porcelain powder into square plates under different forming conditions. Surface characteristics and shapes of formed porcelain were found to be affected by conditions such as quantity of water, forming area and forming thickness. The proper quantity of water for forming was influenced by evaporation. It was concluded that investigation into feedback control of the water supply in response to varying forming conditions is required.

Key words: CAD/CAM system, Porcelain, Porcelain forming

INTRODUCTION

With the recent great progress of computer aided design and manufacturing (CAD/CAM) technologies in industry, numerous studies have addressed dental CAD/CAM systems1–7). Aiming at replacing the traditional method for manufacture of dental prostheses, various new methods such as milling8–22), electrical discharge machining19–22) and laser lithography23–25) have been introduced. Several systems are already in clinical use, although there is still room for improvement in areas such as fit precision, working time and cost.

On the other hand, dental work like porcelain forming done by skilled hand can be considered a fine art, especially from a cosmetic point of view. We may, therefore, say that such work cannot easily be entirely automated, and it is important to take into account the compatibility of CAD/CAM systems with the conventional porcelain forming technique. CAD/CAM systems for porcelain which manufacture restorations by means of milling have been studied8–11,13,20), and some of them are now commercially available. However, we know of no attempts to build up porcelain automatically, by applying porcelain slurry as in the brush-on technique performed by dental laboratory technicians. In this way, not only could a machined work be retouched by hand if necessary, but also fine design of inner structures of prostheses by computer may become possible. The concept of making prostheses by building up materials using a computer has potential for wide application.

This paper considers the feasibility of developing a new dental CAM system evolved from conventional techniques. As a fundamental attempt at the concept, a prototype system
was built. The system was employed for experimental porcelain forming in order to discover problems and issues to be investigated in the further development of automated porcelain forming.

MATERIALS AND METHODS

To experimentally approximate porcelain bonded metal restorations, the system shown in Fig. 1 was devised. The system consists of four functional parts: the porcelain feeder, the water jet unit, the XY stage, and the computer. After the surface of a forming object (workpiece) placed on the XY stage is moistened by the water jet unit, the porcelain feeder ejects a succession of porcelain droplets. These droplets absorb water and form a slurry, taking on a certain form. The experimental system is shown in Fig. 2.

The porcelain powder feeding mechanism is shown in Fig. 3. First, porcelain powder is rubbed into a reservoir hole of a tray by a wiper. Next an outer piston compacts the porcelain powder. Then an inner piston forces a quantity of porcelain powder from a nozzle. Finally the coaxial piston is pulled up to its original position. Both the wiper and the coaxial piston are driven simultaneously by a stepping motor. The inner piston measures 0.3mm in diameter, whereas the nozzle measures 0.35mm in diameter, 0.5mm in thickness. The nozzle of the porcelain feeder is located 30mm above a surface of a workpiece placed on the XY stage.

A modified ink jet printer was used as the water jet unit, for its high resolution positioning and controllability. The principles of color ink jet printing, incidentally, are applicable to future dental CAD/CAM systems for facilitating the automatic staining process. The head of the printer was separated from the body, and distilled water was used instead of ink. Nozzles in the head directed water droplets to a workpiece. The head was positioned at a 45° angle, 25mm from the workpiece.

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Fig. 1  Block diagram of the porcelain forming system.
A personal computer equipped with parallel i/o and GPIB interfaces controlled the other devices of the system. The experimental porcelain forming program consisted of three fundamental procedures: (1) wetting a forming point on a workpiece; (2) feeding porcelain; and (3) moving the workpiece to the next forming point. Two simple patterns for forming porcelain into square plates are shown in Fig. 4: (a) 10mm × 10mm and (b) 5mm × 5mm in the scanning area of the stage. The starting points of both forming patterns were set in the lower right-hand corner of each scanning area. The scanning sequence was alternately in longitudinal direction (Y axis of the stage), proceeding from right to left (X axis of the stage),
at 0.5mm intervals. Hence, the number of forming points per layer were (a) 441 and (b) 121 for the two patterns. Multiple layered forming was done by repeating the same sequence from the origin. With the automatic forming program, the quantity of porcelain powder was set to a fixed value of 100µg per forming point, whereas water quantity was selected from four fixed values of 0, 100, 200 and 300µg per forming point. Forming speed was a little under 6 seconds per forming point, amounting to about 40 minutes for the 10mm×10mm pattern.

Plates of type 304 stainless steel, 20mm×20mm×1mm in size, were used as metal bases for the workpieces. Opaque porcelain## was formed manually on the plates and fired prior to automatic forming. Body porcelain@ was applied to the tray of the porcelain feeder.

To determine the influence of water quantity on automatic forming by the system, test specimens were made with four different water-to-powder ratios and their surface characteristics and outlines were compared. Then, using the most effective quantity of water of the four conditions, forming patterns of two different surface areas and four thicknesses were tested. Formed test specimens were fired according to manufacturers' instructions and their shapes were compared.

RESULTS

Test specimens formed with different quantities of water are shown in Fig. 5. The quantities of water per forming point were 0, 100, 200 and 300µg. The 10mm×10mm forming pattern was used. Formed with no water, spaces between porcelain droplets were observed on test specimen (a). The outline of the formed porcelain measured about 11.5mm×11.5mm, larger than the 10mm×10mm scanning area of the stage. In test specimen (b), water was insufficient and spaces between the porcelain droplets were again observed. The porcelain droplets on this workpiece were larger than those of test specimen (a), due to adhesion of neighboring porcelain droplets by water. The formed porcelain of test specimen (c) had a

## Vintage PA3O, Shofu, Kyoto, Japan
@ Vintage A3B, Shofu, Kyoto, Japan
smoother surface than test specimens (a) and (b). Formed with excessive water, the shapes of porcelain droplets were completely indistinguishable on test specimen (d), but the outline of formed porcelain had spread widely.

Test specimens fired after forming with the two patterns are shown in Fig. 6. Scanning areas were (a) 10mm × 10mm and (b) 5mm × 5mm. Both test specimens were formed with 200μg of water per forming point. Although there were no apparent defects before firing, longitudinal cracks appeared after firing on test specimen (a) as shown.

Test specimens formed into different thicknesses are shown in Fig. 7. The numbers of layers were 1, 2, 3 and 4, using 200μg of water per forming point, and a forming pattern of 5mm × 5mm. The porcelain was expected to form square plates with well-defined edges if slip flow of slurry did not occur. However, layering increased distortion. Fig. 8 shows a side view, after firing, of test specimen (d) shown in Fig. 7. Water was sprayed from above and left of the plate. Both the right and left side walls, the latter in particular, were slanted.

![Fig. 5 Test specimens formed with different quantities of water.](image)
DISCUSSION

The new system is expected to use CAD technology to design dimensions and colors of dental prostheses, followed by use of a CAM system for porcelain forming and firing. Our concern here is to examine an automatic porcelain forming method as a step toward a new CAM system. For the reasons mentioned earlier, it is preferable to take advantage of conventional materials and methods in developing a computer aided porcelain forming system. Accordingly, regular commercial porcelain powder was used rather than new materials. A method of alternately feeding water and porcelain powder was adopted on trial.
The results show that surface characteristics and shapes of porcelain formed by the experimental system were affected by various conditions, such as quantity of water, surface area, and thickness. When insufficient water was supplied during forming, spaces remained between porcelain droplets. Conversely, when too much water was supplied, the porcelain slurry became runny and outlines of formed porcelain spread widely due to slip flow. The outlines exceeded the scanning area of the stage even when formed without water. There are several reasons for this. One is the size of the porcelain droplets. Another is that droplets from the porcelain feeder deviate slightly from their forming target. These are fundamental factors of forming precision to be considered. Not only excess water, but also an oblique jet of water led to the slanted side walls of the layered porcelain. In addition, the tilted mount of the water jet unit caused target shift as the formed porcelain become thicker. To avoid these problems and to successfully carry out thicker forming, the system needs to be modified by moving the nozzles of the water jet unit closer to the nozzle of the porcelain feeder or by adding a Z stage to lower the workpiece in accordance with the thickness of the formed porcelain.

The proper quantity of water for forming is related to complex forming conditions. In spite of the same water-to-porcelain powder ratio, the two tested forming patterns yielded different results as shown in Fig. 6. The larger, and hence more time-consuming, forming pattern gave rise to cracks. Based on observations of similar cracks by re-wetting a formed and dried test specimen, this phenomenon appears to depend not on firing, but on evaporation during forming. Forming points were moistened locally by the water jet unit and gradually became dry. Thus wetting a portion beside formed porcelain caused discontinuities of density. With the scanning sequence, forming was done successively at short time intervals in a longitudinal direction. For these reasons, formed porcelain had a tendency to come apart at the seams, resulting in longitudinal cracks. Meanwhile no cracks were observed in the smaller forming pattern. This can be explained by the difference in time required for
forming: It was about one-fourth that of the larger forming pattern, so evaporation was thought to be less influential. One means of solving this problem would be to increase the forming speed of the system. Another possibility is changing the forming sequence to eliminate seams. Forming thickness as well as area are influential in determining optimum water supply. When forming a first layer on a dry workpiece, more water is needed than for the second and subsequent layers. That is to say, the water supply must be reduced as the formed porcelain becomes thicker. The marginal portion of formed porcelain should not be over-moisturized, otherwise it will become distorted.

In conventional forming, the consistency of porcelain slurry is maintained at a certain level. Condensation of formed porcelain is regulated properly and escaping water is removed by suction. In contrast, this experimental system forms porcelain with a constant water-to-porcelain powder ratio, and no condensing measure has yet been devised. Considering evaporation, determination of the optimum quantity of water for forming is complex. Consequently, water supply during automatic forming should be controlled by feedback based on the water content of the porcelain slurry. It is clear that water supply and condensation are interdependent. The experimental system needs further improvement before complex shape forming will be possible.

CONCLUSION

An experimental system composed of a porcelain feeder, water jet unit, XY stage, and computer was developed. Test pieces were made by forming porcelain powder into square plates under different forming conditions. Water quantity turned out to be an influential factor affecting surface characteristics and shapes of porcelain formed by the system. The proper quantity of water for automatic forming was related to evaporation. It was concluded that investigation is required on feedback-driven control of a variable water supply capable of responding to varying conditions during forming.

REFERENCES


バルビツル酸/塩化第二鉄を開始剤とするレジンによる象牙質の接着

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バルビツル酸/塩化第二鉄を重合開始剤とするレジンの象牙質への接着において，バルビツル酸の構造ならびに前処理剤の効果を検討した，4種類のバルビツル酸/塩化第二鉄を開始剤とするMMA–PMMAレジンを用いて，硬化工時間とウシ象牙質への接着強さを測定した，象牙質面を3％の塩化第二鉄または塩化第二鉄を添加あるいは添加していない10％クエン酸またはリン酸水溶液6種類で前処理した，4種類のバルビツル酸で硬化工時間は有意差が認められたが，3％塩化第二鉄を含む10％クエン酸水溶液処理した象牙質への接着強さには有意差はなかった，前処理剤は接着強さに有意に影響し，リン酸系処理剤の方がクエン酸系処理剤よりも有意に接着強さが大きかった，バルビツル酸/塩化第二鉄系レジンを用いて最適条件下で接着すると，MMA–TBBレジンに匹敵する大きな接着強さが得られた。

試作デンティンプライマー1,6−ヘキサデキサール水溶液の
至適濃度および至適作用時間の検討

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1,6-hexanediol水溶液からなる試作デンティンプライマーの至適濃度および，至適作用時間を決定する目的で，ヒト抜去大臼歯に形成された円柱窩洞にEDTAによるクリーニング，試作プライマーによる前処理，および市販デンティンセメントを併用して塗施した市販可視光線重合コンポジットレジンのコントラクションギャップを計測した，その結果，コントラクションギャップの形成は45wt％の1,6-hexanediol水溶液を60秒間作用させた場合にのみ完全に抑制され，この条件が最適と評価された，また引張り接着性試験においては20.0wt％から57.5wt％濃度の1,6-hexanediol水溶液を用いた場合で統計学的に有意差は認められなかった，

コンピュータによる陶材の自動築盛の試み

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従来的陶材技工システムを発展させた新しい補綴物の自動製作システムの開発を目的とし，コンピュータで用いた陶材の自動築盛に関する基礎的研究を行うとともに築盛作業を自動化する上での問題点について検討した，実験は陶材吐出装置，蒸留水噴射装置，XY軸ステージ，制御用コンピュータから構成される装置を試作し，陶材を平板状に自動築盛することを試みた，水量，面積，厚みの各築盛条件を変えて自動築盛を行った結果，試作装置のように水と陶材粉末を築盛対象の局所に交互に供給し，泥化させて盛り上げていく方法では水量が築盛体の
熱湯浸漬処理が硬質石こう模型の表面粗さおよび表面微細構造に及ぼす影響

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熱湯浸漬が硬質石こう模型表面に及ぼす影響を調べるため、熱湯浸漬前後の石こう試料表面について、表面粗さ・ヌーブ硬さの測定，および走査型電子顕微鏡観察を行い比較検討を行った。その結果、アクリル板に接して硬化した石こう試料表面は、アクリル板の表面に比べ表面粗さの増加が認められた。またSEM像では石こう結晶の凝集形状に多数の空隙が生じていた。これに対して熱湯浸漬後、試料は、明らかに面荒れが生じ、SEM像の観察では結晶自体が細くなり、お互いの絡み合いも弱まっており、ヌーブ硬さは、熱湯浸漬により著しい硬度の低下を示した。また、熱湯処理後の超硬質石こうと未処理の硬質石こうと同程度か、あるいはそれ以下の値に低下した。以上の結果から、短時間の熱湯浸漬が石こう模型に大きく影響を及ぼすことがわかった。

チタン鍛造床作製モデルと臨床要因：鍛型温度とスプルース条件

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前回報告したチタン鍛造床作製技法を評価するための実験モデルに、二種の臨床要因を加えてさらに検討を加えた。鍛造を試みに推奨されている埋没材の組み合わせを鍛造システムと呼ぶことにし、実験1では二室構造鍛造機を用いる鍛造システムによる鍛型温度の影響，実験2では一室構造鍛造機を用いる鍛造システムによるスプルースの影響を検討した。既製の鍛造システムに第三の埋没材を導入することの影響も検討した。完全に鍛造されたモデルパターンの保持孔の数により鍛造の成功率を算出した。メーカー指定の高温鍛型（620°C）では完全な成功率を得たが，任意に選出した中温（350°C）と低温（100°C以下）では成功率は低下した。中温と低温では有意な差がなく，これは第三の埋没材で同様であった。コバルトクロム床で一般的な4 mm直径のスプルースよりも大きなものが有利であろうという仮定が一室構造鍛造機システムで証明されたが，臨床で使用するような長いスプルース（26 mm）と短いスプルース（5 mm）との間には有意な差がみられなかった。第三の埋没材では4 mmの直径でも高い成功率が得られ，鍛造機の作動原理と埋没材の組み合わせを考慮することの必要性が示唆された。