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Laboratory evaluation of production efficiency for removable partial denture frameworks using in-house casting versus outsourced additive manufacturing techniques.

Abstract

Selective laser sintering (SLS) is an alternative workflow for fabricating metal prosthodontic frameworks. Production efficiency of this workflow was compared to traditional casting (CAST) in a prospective pilot evaluation in a hospital prosthodontic laboratory setting. Time taken to complete each of the identified stages in the production of fifty removable partial denture frameworks made using either SLS (n=25) or CAST (n=25) workflows was measured. Mean time for production was calculated for each workflow and the difference was tested for statistical significance. Results indicate that an SLS workflow may be more time efficient and further cost-effectiveness research is indicated.

Introduction

Production of cast metal denture frameworks requires a great deal of technical skill and precision to avoid the introduction of inaccuracies at each stage of the fabrication process to achieve an accurate, well-fitting framework.(1) Concerns over the potential for occupational exposure to materials involved in this process have also been considered.(2) Strict adherence to health and safety protocols are therefore required by production laboratories to reduce the risk of staff exposure to these materials.(2)

Selective Laser Sintering (SLS) is a development in computer aided additive manufacturing, which avoids the need for wax pattern laying, investment and casting in the fabrication of metal frameworks such as cobalt-chrome (CoCr) for removable partial dentures (RPD).(3) A further advantage over other computer aided alternatives such as milling is that the SLS process is an additive one which reduces waste.(3)

The accuracy of SLS frameworks has been evaluated against that of casting in laboratory and clinical studies, and parameters such as mechanical properties, biocompatibility and fitting accuracy have been reported in the literature, however one pertinent question relates to the efficiency of fabrication.(4, 5)

This aim of the service evaluation reported here is to compare the production efficiency of the manufacturing process of SLS versus traditional wax pattern casting for CoCr RPD frameworks in a busy NHS production laboratory.

Material and Methods

A convenience sample of fifty patients requiring fabrication of RPDs for the replacement of missing teeth were selected. Treatment was provided in both service and teaching clinics at the Charles Clifford Dental Hospital (CCDH), Sheffield, UK. Patients provided with frameworks made with either traditional wax pattern and casting or a digital design and SLS fabrication workflow. Allocation was provided in an un-randomized manner with the patients allocated to a workflow on the basis of the time that their dentures were made and availability of technicians. The steps in each production workflow were identified as seen in Table 1. Each of these steps were timed by the same technician (PK) who produced all frameworks. Examples of frameworks made with the different production workflows are shown in Figures 1 and 2.

Outsourced stages of manufacture for the SLS framework occurred at step 6 for the SLS frameworks. These were not included in the evaluation time as they occurred outside of the dental laboratory and are included in the cost of SLS framework production. These steps include:

- Data download
- Development of 'build file'
- Selective Laser Melting production process
- Post-fabrication processing including
    - removal of framework from the build plate,
    - removal of excess metal support required for manufacture e.g. sprues and support struts
- Packaging and delivery to the dental laboratory

To allow any improvement in efficiency of the workflow to be considered against potential cost a standard non-pay cost was calculated for each workstream. Pay costs were not included as laboratory staff costs will vary between sites and production time was considered a more appropriate measure of production efficiency.

Mean and standard deviation for production time and was calculated for each group. The difference between groups was assessed using an independent samples t-test. Number of frameworks made in the production laboratory per year was calculated using historic activity data. This data was used to calculate the time saving per year for the most efficient workflow. The increase in capacity was calculated using the time saving per year divided by the time taken to make a framework using the most time efficient framework.

Results

Twenty-five traditional cast frameworks were evaluated. Fabrication for cast framework took a mean time of 273.3 mins (SD: 107.9mins, range: 130 to 569 mins). Twenty-five SLS workflow frameworks were evaluated. The mean time for fabrication of SLS frameworks was 154.4mins (SD: 37.9mins, range: 100 to 225 mins).

The SLS workflow therefore resulted in a mean time saving of 118.9 minutes [$t=5.2$, $p<0.001$, 95% CI: 72.9-164.9] per framework.

Activity data identified that the number of frameworks made per year in the CCDH Prosthetic Dental Laboratory was 241. The time saving per year therefore for this production laboratory would be 28,438 minutes per year. Given the mean production time for the most time efficient workflow (SLS) this would mean an increase in capacity of 184 frameworks per year for this production laboratory.

Discussion

This evaluation identifies significant savings in technician time when a part-digital workflow for the fabrication of CoCr RPD frameworks is adopted. Digital workflows may be totally digital, requiring the use of intra-oral scanning to produce a .stl file for digital denture design, or part-digital whereby the dentist acquires a traditional impression of the denture bearing surfaces and a model is cast. This model is then scanned to create an .stl file or digital denture design. In this evaluation the clinical steps for the SLS framework were exactly the same as those for the cast frameworks. This evaluation therefore did not evaluate any clinical time savings but was focused on changes within the dental laboratory.

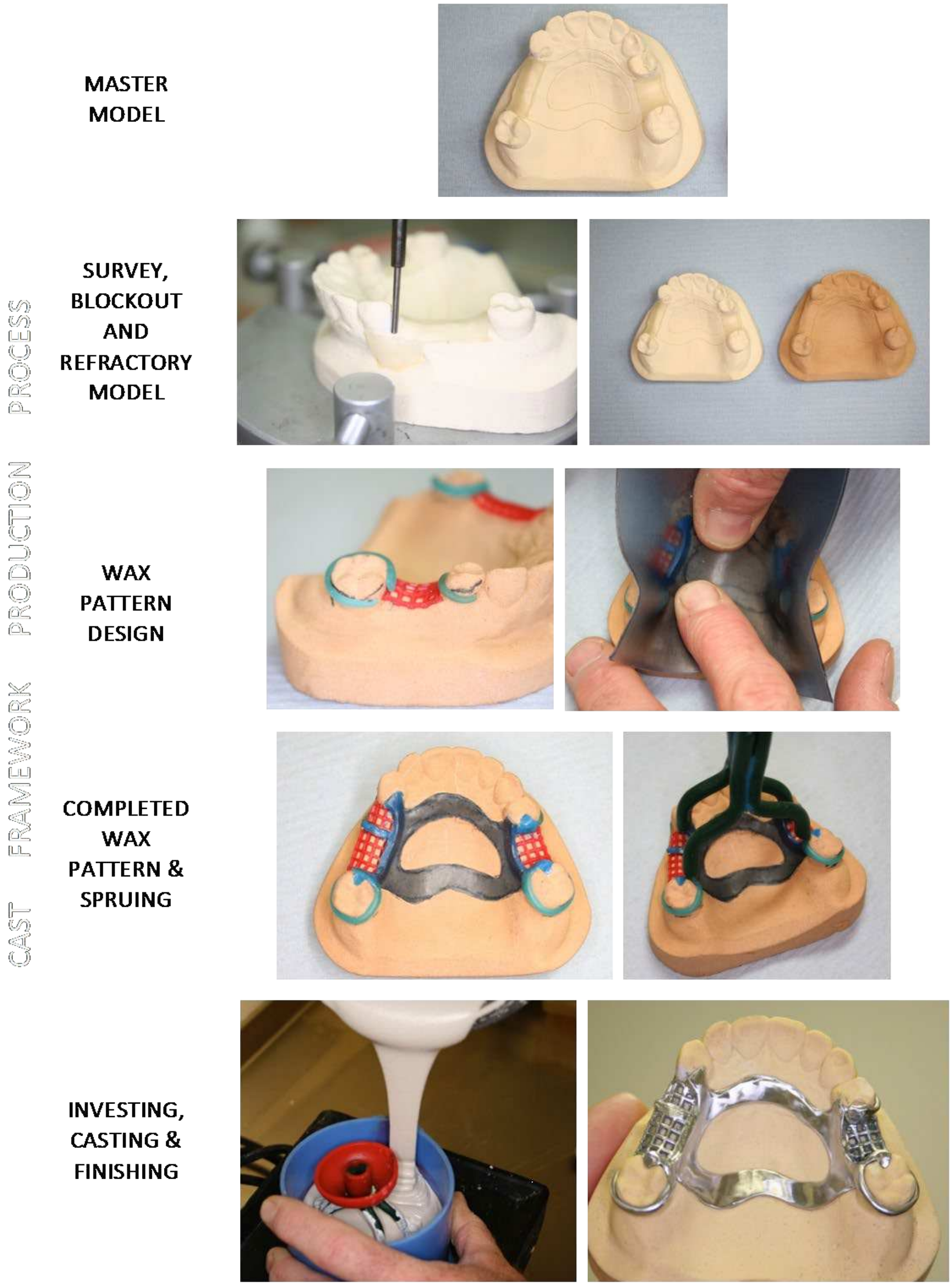
Clearly many issues will influence decisions by production laboratories in regards to the introduction of digital designing and SLS workflows to their practice including digital expertise of staff, cost of scanning equipment, IT hardware and digital design software, costs of outsourcing the SLS fabrication and acceptability of the finished product for clinicians. In this evaluation all frameworks made using the SLS workflow were eventually fitted for patients though some modifications were required for three out of the 25 frameworks provided. In a clinical evaluation of SLS versus cast frameworks, SLS had fewer inaccuracies, though this study only evaluated 9 frameworks.(5)

A full cost-effectiveness analysis would be a useful addition to the research literature, taking account of both laboratory and clinical costs including the cost of return visits by patients for further adjustments after the fit of prosthesis and effectiveness in the context of accuracy of fit and patient centered outcomes of effectiveness.

Table 1 – Production stages for CAST and SLS workflows

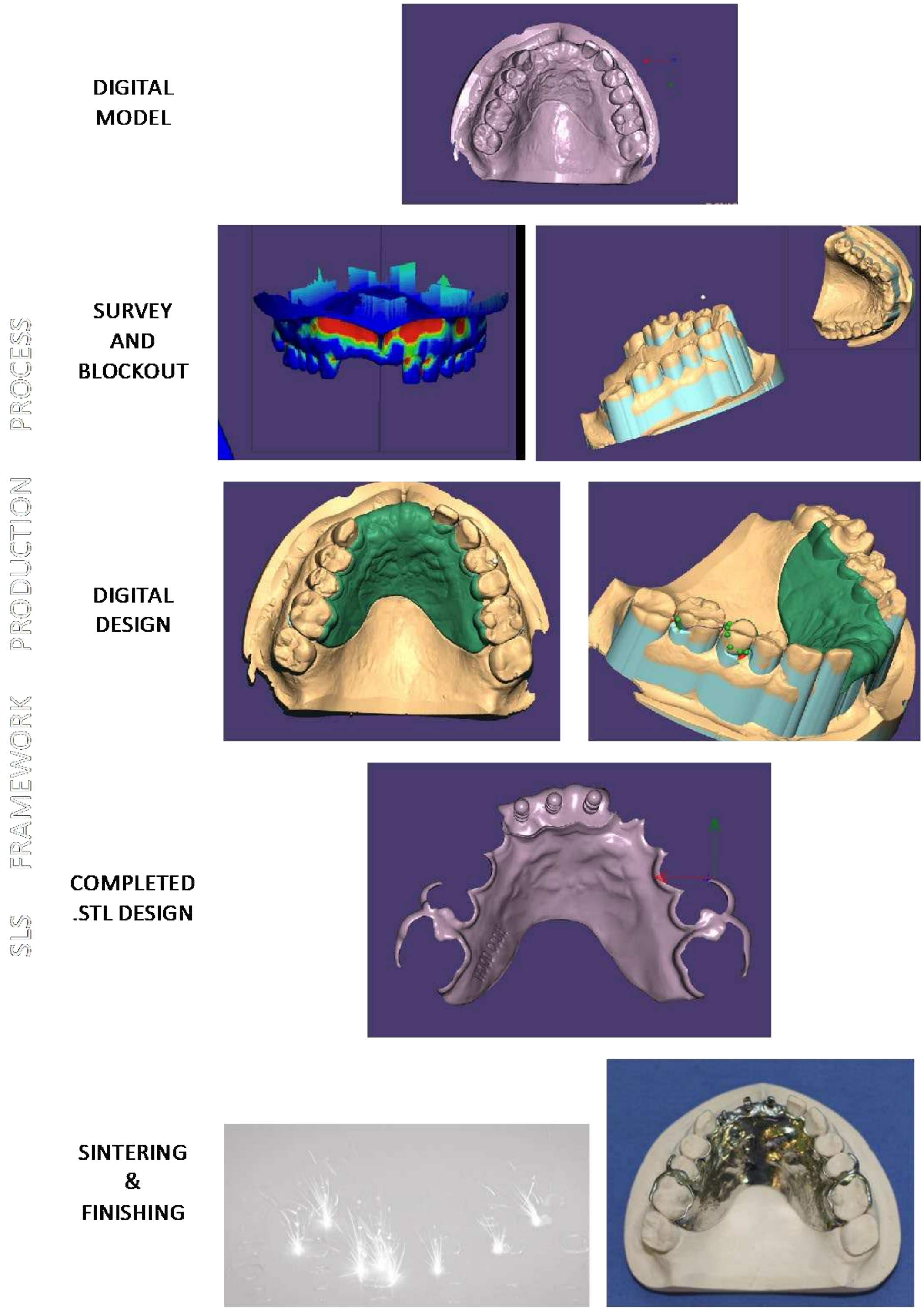
Traditional Casting (CAST)	Selective Laser Sintered (SLS)
1. Casting of master model 2. Trimming master model 3. Surveying 4. Blocking out undercuts 5. Duplication for working model 6. Pouring Refractory Stone for working model 7. Dipping 8. Wax Pattern Laying 9. Attaching Sprues 10. Investing 11. Removal of Former 12. Placement in furnace 13. Casting 14. De-vesting 15. Blasting 16. Sprue removal 17. Trimming framework 18. Polishing 19. Electrolyte brightening	1. Casting master model 2. Trimming master model 3. Scanning master model 4. Digital framework design 5. Email and correspondence with manufacturing laboratory 6. Outsourced SLS production steps (time not included) 7. Checking framework on receipt 8. Polishing 9. Electrolyte brightening

Figure 1 –Key steps in casting production workflow



Images courtesy of Dr D Wood

Figure 2 – Key steps in SLS production workflow



Images courtesy of Dr D Wood and Renishaw plc

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